

UNIVERSITÀ POLITECNICA DELLE MARCHE

FACOLTÀ DI INGEGNERIA

Corso di Laurea Triennale in Ingegneria Elettronica

Studio e sviluppo di piattaforme educative per l'introduzione della robotica in età scolare

Design and implementation of edutainment platforms for robotics and environment awareness literature

Relatore: Chiar.mo

Prof. **David Scaradozzi**

Correlatori:

Daniele Costa

Laura Screpanti

Tesi di Laurea di:

Giacomo Fiara
Matricola 1093962

A.A. **2022** / **2023**

Abstract

A remarkable opportunity emerges in the ever-changing education landscape – Educational Robotics (ER). ER, uniting Robotics, Pedagogy, and Psychology, ignites students' curiosity, fostering authentic learning through hardware and software tools. However, integrating ER into traditional education faces significant challenges [1, 2].

This thesis embarks on a voyage of discovery, seeking to unearth the profound influence of software in every facet of Educational Robotics activities. The thesis aims to analyze how software profoundly impacts every stage of Educational Robotics activities and employs a comprehensive method approach, including a literature review to establish a theoretical foundation and structured surveys for quantitative insights into educators', students', and stakeholders' experiences. In-depth case studies complement the survey data, offering a holistic view of Educational Robotics' impact.

This research yields a comprehensive understanding of software's profound impact on Educational Robotics, encompassing theoretical foundations and practical applications. The subsequent chapters delve into crucial insights, covering areas from exploring the latest developments in ER and designing edutainment platforms to scrutinizing hardware technology. The concluding case study exemplifies the practical implementation of curriculum and ER activities, anchoring insights in data and providing valuable guidance for future research.

In conclusion, this study underscores the multifaceted impact of software on Educational Robotics, improving accessibility and flexibility in e-learning, empowering educators to personalize their teaching methods, and emphasizing collaboration and the democratization of ER across diverse educational settings. Placing software at the forefront of this transformation promises more effective and inclusive educational strategies, benefiting students, institutions, and educators worldwide.

Summary (in Italian)

In un'epoca caratterizzata da repentini e rapidi progressi tecnologici, il campo dell'istruzione ricopre un ruolo cruciale. La Robotica Educativa (ER) rappresenta un'innovativa convergenza tra Robotica, Pedagogia e Psicologia che può risvegliare la curiosità innata degli studenti, guidandoli in un viaggio di apprendimento autentico. L'ER, supportata da un mix di strumenti hardware e software, consente agli studenti di esplorare concetti profondi, sviluppare abilità di risoluzione dei problemi e coltivare la consapevolezza ambientale in un contesto di apprendimento aperto e creativo.

Nonostante il suo innegabile potenziale, l'integrazione dell'ER nei curricula scolastici tradizionali è segnata da sfide e ostacoli. In un contesto in cui il mercato della robotica educativa cresce e la ricerca scientifica ne esalta i benefici in molteplici pubblicazioni, questa nuovo approccio tecnologico ed educativo non ha ancora trovato il suo posto all'interno delle istituzioni scolastiche e programmi scolastici.

Questa tesi si propone di analizzare come il software possa avere un impatto profondo su ogni fase delle attività e lezioni di Robotica Educativa (ER). Per far ciò, è stato utilizzato un approccio misto di collezione e analisi dei dati che combina le seguenti metodologie:

- Revisione della Letteratura: la letteratura esistente è stata analizzata per costruire una solida base teorica alla trattazione, per valutare criticamente la ricerca nel campo della Robotica Educativa e per identificare possibili tendenze e lacune.
- Indagini: Sono state condotte indagini strutturate tramite questionari per catturare dati quantitativi e comprendere le prospettive e le esperienze di educatori, studenti e altre figure interessate, fornendo una prospettiva quantitativa sull'impatto dell'ER.
- Analisi di Casi Studio: Un importante componente di questa ricerca è l'analisi approfondita di casi di studio, che fornisce dati qualitativi. Attraverso l'analisi di implementazioni reali, lo studio valuta l'impatto pratico dell'ER negli ambienti educativi.

Questi metodi di ricerca combinati garantiscono una comprensione completa dell'impatto del software nell'ER, esplorando sia gli aspetti teorici che le implicazioni pratiche di questa metodologia educativa.

Nelle conclusioni, viene sottolineato dalla ricerca l'impatto profondo e poliedrico del software nelle attività di Educazione Robotica (ER). Infatti, oltre a fornire innovative esperienze di apprendimento agli studenti, il software è uno strumento che può beneficiare sia le istituzioni d'istruzione, che gli insegnanti. Le istituzioni possono sfruttare strumenti software, quali Moodle o altri strumenti a supporto della realizzazione di Massive Open Online Courses (MOOC), per gestire ed erogare efficacemente i propri corsi in modalità online, espandendo le potenzialità dei propri corsi, la loro portata e garantendo una maggiore flessibilità nell'istruzione. La capacità del software di misurare e valutare le attività di ER, sia prima, durante che dopo la loro implementazione, consente invece agli educatori di adattare il loro approccio all'insegnamento ed arricchire il percorso di apprendimento in base alle necessità degli studenti.

Il software, quando attentamente integrato nelle attività di ER, promuove una didattica più inclusiva, aprendo le porte agli studenti di ambo i generi e preferenze e necessità di apprendimento. Questa inclusività è cruciale per affrontare un panorama dell'istruzione in costante evoluzione, dove esperienze di apprendimento personalizzate ed adattabili sono fondamentali. In questo contesto, il valore del software permette di promuovere concetti sempre più importanti quali la consapevolezza ambientale e la sostenibilità,

supportando il processo di apprendimento e preparando la prossima generazione ad affrontare con successo le sfide e le opportunità del mondo moderno. Questa ricerca enfatizza l'importanza fondamentale delle iniziative e delle collaborazioni nel campo dell'Educazione Robotica (ER) al fine di promuovere uno sviluppo più integrato di queste nuove metodologie didattiche. L'implementazione e la validazione di tali approcci innovativi richiedono un'efficace collaborazione tra docenti, istituti d'istruzione, pubbliche amministrazioni, enti di ricerca e aziende provenienti da contesti e paesi diversi.

I fondamenti di questo lavoro di tesi attingono anche dalla mia esperienza personale, avendo collaborato con ANcybernetics s.r.l., uno spin-off accademico dell'Università Politecnica delle Marche. ANcybernetics ha giocato un ruolo pionieristico nel campo della robotica educativa e marina ed è stato un partner stretto del Laboratorio di Modellazione, Analisi e Controllo dei Sistemi Dinamici (LabMACS), guidato dal Professor D. Scaradozzi.

Content

Abstract 2

Summary (in italiano) 3

Content 5

Introduction 8

1. State of the art 11

1.1. Definition of ER 11

1.2. ER for environmental education 11

1.3. The relevance of bio-inspired robotics 12

1.4. Barriers to Integrating Educational Robotics in School Curricula 13

1.5. Classifying Educational Robotics Activities and Assessment Methods 14

1.5.1. Learning Environment: Formal or Non-Formal Projects 14

1.5.2. School Curriculum Impact: Curricular or Non-Curricular Projects 14

1.5.3. Evaluation: Qualitative, Quantitative, or Mixed Methods 14

1.5.4. A Classification of the Assessment of ER Activities 14

2. MOOCs, Robotics Technology, and Software for Modern Education 17

2.1. Moodle for Creating a MOOC 17

2.1.1. The Synergy of Moodle and MOOCs 18

2.1.2. Why is it Worth the Effort? 18

2.1.3. Moodle During the Pandemic: a mentionable case study 19

2.1.4. Moodle's Rich Functionality 19

2.1.5. Demand for Commercial Education 19

2.1.6. Personalisation of the Learning Process 20

2.1.7. Improving Evaluation and Assessment 20

2.2. E-Tech Project 21

2.2.1. E-Tech eBook: A Comprehensive Resource for Advancing Online STEM Education 22

2.3. RoboPisces Project 23

2.3.1. Overview of the RoboPisces European Project 23
2.3.2. Project Outputs 24
2.4. Commercial Tools and Robots for ER 25
2.4.1. RiE 25
2.4.2. Integration of robotic tool 25
2.4.3. A classification of ER tools 25
2.4.4. Some examples of commercial tools and robots for ER 26
2.5. Unveiling a Leading ER Tool: M5Stack's Impactful Journey 27
2.5.1. M5StickC Plus: Compact Powerhouse Unleashed 27
2.5.2. Harnessing M5Stack Technology for Educational Robotics Kits 28
2.5.3. Guizzo: A Unique ER Tool for Exploring the Underwater World 29
2.6. Blockly 30
2.7. UIFlow by M5Stack: Bridging Hardware and Software in Educational Robotics 31
2.7.1. General overview 32
2.7.2. GUI 32
2.7.3. Programming with blocks 36
2.7.4. Custom blocks 36
3. Implementation and Validation of Educational Robotics Curricula 41
3.1. First stage: mapping of educational curricula in ER 41
3.2. Second stage: Lesson Plans 41
3.2.1. Basic Topics 42
3.2.2. Advanced Topics 43
3.3. Third stage: Assessment tools 43
3.4. Fourth stage: Evaluation 44
3.5. Fifth stage: The RoboPisces educational curriculum 44
4. Case study and results 46
4.1. Healthy Life One 46

4.2. Assessment 48
4.3. Results 49
4.4. Future Developments: RoboAquaria 52
Conclusions 54
List of Images 57
List of Tables 59
Bibliography 60
Acknowledgements 63

Introduction

In an era of rapid technological advancement, education has been presented with a remarkable opportunity: Educational Robotics (ER). ER represents a dynamic convergence of Robotics, Pedagogy, and Psychology at its core, designed to ignite students' curiosity and facilitate their authentic learning journey. Using hardware and software tools, ER empowers students to explore profound concepts, nurture problem-solving skills, and cultivate environmental awareness in open-ended, creative learning environments [1].

While the potential of ER is unmistakable, integrating it into traditional school curricula has been marked by challenges and barriers. Despite an ever-growing market of ER products and a substantial body of scientific research extolling its benefits, this transformative technology has not yet found its rightful place within the structured confines of educational institutions [2].

This thesis embarks on a voyage of discovery, seeking to unearth the profound influence of software in every facet of ER activities. From the meticulous design of ER courses and curricula the crafting of coding tools for ER toolkits, to the formulation of rigorous evaluation methods that measure the outcomes of individual activities and entire courses, this research aims to cast light upon the transformative power of software in ER.

The thesis aims to analyse how software profoundly impacts every stage of ER (ER) activities and employs a mixed-method approach, integrating the following methodologies:

- Literature Review: The study comprehensively reviews existing literature to build a solid theoretical foundation, critically evaluate prior research in ER, and identify key trends and gaps.
- Surveys: To capture quantitative data and understand the perspectives and experiences of educators, students, and other stakeholders, structured surveys are conducted. These surveys serve as valuable instruments for collecting quantitative insights and gauging the impact of ER activities.
- Case Study Analysis: A significant component of this research is the in-depth analysis of case studies, providing qualitative data. Through the analysis of real-world implementations, the study assesses the practical impact of ER in educational environments. These case studies offer valuable qualitative insights, complementing the quantitative survey data.

By combining these research methods, this study ensures a holistic understanding of the impact of software in ER, exploring both the theoretical underpinnings and practical implications of this transformative educational technology.

Through the following pages, the thesis unfolds in a series of distinct chapters, each addressing a crucial aspect of ER. The exploration begins by delving into the compelling reasons behind the fundamental challenges and barriers ER faces. This pivot leads to an examination of the intricate design and implementation of edutainment platforms, meticulously engineered to harness the full potential of ER in cultivating environmental awareness and literacy.

The journey also involves thoroughly examining hardware technology and seeking the most efficient tools for implementing ER in educational settings. However, the world of software takes centre stage in this landscape. Primary software tools designed to empower ER activities are the focus of our exploration, ultimately demonstrating their pivotal role in shaping the future of education.

Finally, attention will be dedicated to validating and implementing ER courses intended for integration into school curricula. It includes meticulously examining the challenges and solutions devised during the implementation process. Within this context, a detailed case study will be outlined, providing insights into the practical realization of ER within a structured educational framework. Subsequently, the data collected during this case study will be subjected to comprehensive analysis to measure the discernible impact of these ER courses on the degree of student interest and their overall learning process. This examination will provide a valuable empirical perspective on the effectiveness and practicality of ER within educational settings.

The foundation of this research is rooted in personal experience, with ANcybernetics s.r.l., an academic spin-off of Università Politecnica delle Marche, leading the way. ANcybernetics has been a steadfast advocate for educational and marine robotics, collaborating closely with the Laboratory of Modeling, Analysis, and Control of Dynamical Systems (LabMACS) under the guidance of Professor D. Scaradozzi. Additionally, the journey is enriched by the invaluable insights drawn from the RoboPisces and E-Tech projects, which serve as prominent case studies within this thesis.

The chapters that follow in this thesis present a rich tapestry of insights and discoveries.

In Chapter 1, a comprehensive exploration of the state of the art commences. The concept of ER is defined, elaborating on its framework and underscoring its pertinence in primary school education. The focus delves into the intrinsic role of ER in environmental education, confronting the critical challenges associated with its adoption in educational institutions. Moreover, a systematic classification of ER activities is presented, paired with their assessment and evaluation methodologies.

Chapter 2 highlights the essential tools required to construct a Massive Open Online Course (MOOC) and presents exemplary projects meticulously tailored to integrate ER into K-12 education. The journey then transitions into the realm of hardware and software technologies. Emphasis is placed on the latter due to its influential role at every stage of ER implementation. Commercial robots and technologies that lead the way in this transformative space are dissected, offering valuable insights for educators.

Chapter 3 unfolds an in-depth exploration of methodologies for implementing and validating environmental ER courses, spotlighting the FISH curriculum within the context of the RoboPisces Project. The practical realization of ER within a structured educational framework is the central focus.

In Chapter 4, the concluding section of this thesis, a compelling case study is presented where the curriculum and ER activities are rigorously applied. The groundwork for future developments is laid through meticulous outcomes analysis and informed by pre- and post-questionnaire data. By grounding insights in concrete data, the course is set for upcoming horizons, extending a hand toward the uncharted territories of ER. In this spirit, valuable recommendations are offered to guide forthcoming research and development endeavours in ER.

In the final pages of this thesis, the task of synthesizing the collective journey is embarked upon, weaving together the threads of knowledge and experience gained throughout the preceding chapters. Here, the essence of the findings is distilled, bringing them into focus and providing a comprehensive overview of the insights gathered. These insights serve as the cornerstone upon which the concluding chapter is built, offering a panoramic view of the intricate tapestry of ER and its implications.

As the intricate tapestry of ER is navigated, one thing remains unequivocal: the transformational power of this technology has the potential to redefine education and inspire generations to come.

1. State of the art

This chapter provides an overview of the current state of ER. It explores the foundational work of scholars such as Seymour Papert and Jean Piaget in shaping ER. The chapter touches on the multidisciplinary nature of ER, its role in environmental education, the emergence of bio-inspired robotics, challenges in integrating ER into curricula, and the classification of ER activities and assessment methods. This overview sets the stage for a deeper exploration of these topics in the subsequent sections.

1.1. Definition of ER

The foundation of ER is deeply rooted in the pioneering work of prominent scholars, including Seymour Papert and Jean Piaget. Seymour Papert, renowned for his perspective on computers as learning aids rather than the central focus of education, emphasized that technology can facilitate knowledge construction. His approach aligns with Piaget's insight, which recognized that children's play serves as a valuable vehicle for learning and not only provides enjoyable moments [2].

ER represents a pivotal intersection of Robotics, Pedagogy, and Psychology, driven by the vision of empowering students to explore profound concepts and foster authentic learning within open-ended environments [1].

This multidisciplinary approach seeks not merely integrating robotics and technology into educational curricula. The core idea of ER lies in its ability to leverage robotics (composed of hardware and software) and STEAM (Science, Technology, Engineering, Arts, and Mathematics) subjects as instruments for creating enriching, hands-on educational experiences and developing transversal skills, enabling students to engage in creative problem-solving while crafting solutions to defined challenges [1]. Therefore, ER is an intricate ecosystem comprising versatile robots designed for construction, deconstruction, and programming and supported by educators and experts facilitating these activities. Simultaneously, it integrates pedagogical methodologies that empower students to explore diverse subjects, environments, and content while enhancing their skills and knowledge [1].

Practically speaking, ER projects often introduce students to unassembled robot kits and challenges to accomplish by cooperating in teams, fostering interdisciplinary creativity and critical thinking. Through the meticulous assembly and programming of robots, students master the fundamental principles of Robotics, facilitating their subsequent application in various contexts [1].

Students are encouraged to infuse their creations with unique creative insights and solutions as they construct and program these robots. Consequently, ER catalyses the development of transversal skills such as rational thinking, creativity, innovativeness, teamwork, problem-solving, and motivation, and it can help children develop computational thinking or the ability to design products and solutions [2]. It also supports inclusive education [3] by involving students in a technological environment from early education to fight gender stereotypes [4].

1.2. ER for environmental education

Fostering automation literacy from an early age, particularly in Primary School, becomes pivotal as it promotes essential skills for comprehending and analysing real-world phenomena [5]. This priority aligns with

the evolving landscape of education, transcending mere innovation to equip students with critical competencies necessary for addressing global challenges. These challenges comprehend sustainability and inclusivity, enclosing fields like clean air, sustainable energy, quality education, access to clean water, and preserving life below water, as articulated in the UN Sustainable Goals [6]. In this context, technology (and therefore ER) is crucial for shaping a sustainable and inclusive future [7].

Integrating technology, science, engineering, and environmental education creates a powerful synergy with the potential to foster a sustainability mindset, a vital asset for addressing future challenges. This fusion, enabled by robotics as a learning facilitator, prepares the upcoming generation to confront the urgent imperatives of sustainability and environmental awareness [7].

Using ER in education has brought about a significant change in environmental education. The "OpenFISH.science" project exemplifies this shift, a remarkable initiative by D. Scaradozzi et al. [2]. OpenFISH.science is an illustrative case study in the intersection of Robotics, STEM (Science, Technology, Engineering, and Mathematics), and the Internet of Things (IoT). It uniquely engages students in marine environment themes, raising awareness and imparting knowledge in fields like RoboEthics [8], blue careers, and ocean literacy.

OpenFISH.science introduces an innovative curriculum and novel technological devices to teach eSTrEM (environment Science Technology robotics Engineering Math) at the primary school level. This educational initiative seeks to cultivate essential skills such as creativity, problem-solving, teamwork, and innovation capacity. By integrating robotics into the curriculum, OpenFISH.science embodies a comprehensive approach to STEM education, effectively engaging students in constructing knowledge. This connection between the STEM acronym and the concept of RoboEthics holds profound significance for the scientific community and society, addressing critical areas of study and societal concerns [2].

The OpenFISH.science project represents a compelling exemplar of how ER can catalyse environmental education. By intertwining technology, science, and robotics, it not only equips students with knowledge and skills but also nurtures a sustainability mindset, thus preparing them to address the pressing challenges of environmental awareness and sustainability [7].

1.3. The relevance of bio-inspired robotics

Bio-inspired ER in the educational landscape offers a paradigm shift that departs from traditional robotics, profoundly enhancing the learning journey in multiple ways. Bio-inspired robotics draws inspiration from natural organisms' intricate designs and behaviours and fosters a profound connection between students and the machines they interact with, resulting in heightened empathy and engagement. Unlike conventional programming activities, this approach enables students to receive constant feedback from the physical robot during the programming process, encouraging them to iteratively observe and test the robot's behaviour, promoting a recursive learning process [9].

Furthermore, ER, especially in the bio-inspired realm, allows students to manipulate the robot's structure and observe its physical behaviour. These interactive experiences engage students in relevant cognitive activities linked to lateralization, spatial awareness, and embodiment, enriching their understanding of the subject matter [5]

A distinctive advantage of bio-inspired robotics lies in its capacity to provide tangible, relatable means for exploring ecological concepts. By emulating natural processes, students gain a deeper understanding of environmental issues, empowering them to effectively comprehend and address these challenges. Additionally, bio-inspired robotics opens doors to introducing intricate biology and physics problems, compelling students to deal with the particulars of replicating natural phenomena in their robotic creations, like emulating the underwater physics and dynamics of an oceanic fish.

Noteworthy examples of bio-inspired ER, particularly within the marine domain, have been presented by Daniele Costa et al. [7]. However, it is worth noting that the limited availability of suitable commercial toolkits has hindered the broader adoption of marine robotics in educational settings. Such toolkits should encompass critical features, including assembly, programmability, and submersion capabilities while being cost-effective and accompanied by comprehensive lesson plans [2].

Moreover, bio-inspired educational robots, often designed to mimic animal behaviours, have demonstrated their potential to promote inclusive education by piquing interest across diverse student groups [10]. Therefore, introducing bio-inspired robotics represents an exciting frontier in educational technology, offering a dynamic and immersive approach that enhances understanding, instils empathy, and prepares students to address complex environmental challenges.

1.4. Barriers to Integrating ER in School Curricula

Despite the growing relevance of ER and its tools as promising methodologies for introducing automation and STEM education in early education [5], notable obstacles prevent widespread integration into school curricula. While the market offers an increasing array of ER products, and substantial scientific research underscores their benefits and potential [11], robotics has yet to secure a consistent place within educational systems [2].

One significant challenge lies in the lack of teacher training and readily available educational resources, hindering the effective implementation of ER in classrooms [1]. Additionally, there is a pressing need for valid and reliable assessment instruments to gauge students' learning gains in ER programs, a factor pivotal for their acceptance within formal education systems [1]. Establishing ER as an integral part of education requires longitudinal studies to validate ER curricula, motivated educators, and the active engagement of teachers and stakeholders to usher ER methodologies and tools into the education system and prepare future citizens for the digital age [1].

Traditional educational structures often lack the flexibility and openness required to accommodate the novelty and creativity inherent in ER [2]. In many instances, ER activities focus solely on building robots with step-by-step instructions, missing the opportunity to engage students in more comprehensive construction activities that foster essential 21st-century skills. Additionally, the absence of well-designed educational activities and a means for their proper assessment further contributes to the scarcity of robust robotics curricula in schools [2].

In navigating these challenges and breaking down barriers, educators and policymakers must collaborate to promote the adoption of ER as an innovative and effective tool for enhancing learning outcomes and preparing students for the dynamic challenges of the modern world.

1.5. Classifying ER Activities and Assessment Methods

In this section, we draw upon the comprehensive work of Scaradozzi, Screpanti, and Cesaretti as presented in their publication titled "Towards a definition of ER: a classification of tools, experiences, and assessments" [1]. Their research provides valuable insights into classifying ER tools, experiences, and assessment methods, contributing to our understanding of this field.

1.5.1. Learning Environment: Formal or Non-Formal Projects

ER activities can occur in diverse settings, including schools, homes, and outdoor environments, each characterized by specific rules and learning contexts. It is essential to distinguish between formal and non-formal learning environments in ER activities. Formal education typically occurs in recognized organizations with structured activities and evaluations, often by trained teachers. In contrast, non-formal education can complement formal education but is separate from the national education system, often shorter in duration and leading to competencies without formal qualifications. Formal environments include schools, while non-formal environments encompass locations like private houses, company headquarters, and museums [1].

1.5.2. School Curriculum Impact: Curricular or Non-Curricular Projects

The impact of ER activities on school curricula plays a crucial role in their design and outcomes. Curricular activities are designed to align with curriculum needs, regularly occurring in classrooms to support students' learning of specific concepts. The evaluation of curricular activities is recognized in the final assessment of students. In contrast, non-curricular activities may occur inside or outside the classroom, often focusing on specific concepts but not leading to formal recognition. Despite occurring in a formal learning environment, some school-based activities may not contribute to a student's final evaluation, making them non-curricular activities [1].

1.5.3. Evaluation: Qualitative, Quantitative, or Mixed Methods

Evaluating ER activities can employ various methods, including qualitative, quantitative, or mixed-methods approaches [1].

- Qualitative methods encompass analysing essays, focus groups, scenarios, projects, case studies, personal experiences, portfolios, role play, and simulations, providing rich insights into students' learning experiences. However, these methods may be impractical in crowded classrooms and are susceptible to personal biases and external influences.
- Quantitative methods aim to summarize outcomes numerically, often using questionnaires, tests, and rubrics. While they are easier to replicate, they may be considered reductive.
- Recently, researchers have been exploring mixed-methods approaches, combining qualitative and quantitative data collection to address complex educational issues. From this perspective, it is important to note how technology and artificial intelligence could offer real-time monitoring tools that seamlessly integrate qualitative and quantitative assessment methods into the classroom.

1.5.4. A Classification of the Assessment of ER Activities

Another classification of assessment methods considers the target of evaluation: performance, attitude, and behaviour [1].

- Performance measurement involves assessing knowledge acquisition and the ability to apply it through tests or neuropsychological measures.
- Attitudes and skills are often measured using surveys and questionnaires, which are easy to administer.
- Assessing students' behaviours during ER activities helps improve the learning environment and gain insights into their learning processes.

Evaluation of ER activities should also encompass another crucial aspect: timing. Measuring progress and understanding can significantly impact the effectiveness of ER in education. Scaradozzi et al. [1] identify two critical phases for evaluation:

- Before/During the Activity (Pre-Activity Assessment): This formative assessment stage occurs before students engage in ER activities but can also be iterative, occurring periodically throughout the ER activity. It serves to gauge their existing knowledge, skills, and readiness. Pre-activity assessment allows educators to tailor their teaching approaches and set appropriate student expectations. In this phase, teachers can identify potential gaps in students' understanding and adapt their instructional strategies accordingly.
- After the Activity (Post-Activity Assessment): Summative assessment, or evaluation after the ER activity, measures the overall impact and outcomes. It assesses how well students have grasped the intended concepts and skills. Traditional written tests may reflect theoretical knowledge, while practical exercises or tests demonstrate applied skills. Post-activity evaluation can also extend beyond knowledge and skills assessment. It can encompass measuring attitudes, behaviours, and changes in students' problem-solving approaches. Additionally, it can help identify the lasting impact of ER experiences on students' overall learning and development.

Understanding how students learn within ER activities is paramount for educators and researchers. Scaradozzi et al. [1] highlight various aspects of this process:

- Exploring Problem-Solving Strategies: ER activities often involve students experimenting with and modifying instructions or robotic hardware sequences. This iterative process allows them to explore different problem-solving strategies and approaches. Observing how students navigate these challenges can provide valuable insights into their cognitive development and problem-solving abilities.
- Team Collaboration and Iterative Improvement: Collaboration is a common feature of ER projects. Students typically work in teams, continuously refining their robotic creations. This collaborative approach fosters teamwork, communication skills, and the ability to adapt to changing circumstances. It also enables educators to assess how effectively students collaborate and contribute to the group dynamic.
- The Role of Educational Data Mining and Learning Analytics: Evaluation during the ER activity is dynamic and ongoing. As students experiment, modify instructions, and work collaboratively, their learning processes continually unfold. However, it is unrealistic for a single teacher to closely monitor every student's development in a crowded classroom. That is why technology, such as Educational Data Mining (EDM) and Learning Analytics (LA), plays a vital role. These technologies provide real-time insights into students' interactions with ER tools, capturing their learning trajectories as they explore, tinker, and refine their solutions. Automated data collection and analysis can offer a nuanced understanding of how students engage with the material, allowing for timely interventions and personalized feedback.

- Tailoring Feedback and Support: The ability to assess students' learning processes in real-time offers tailored feedback and support opportunities. Educators can identify students needing additional assistance or challenge those ready for more advanced tasks. Teachers can provide timely guidance by understanding how students learn, fostering a more effective and personalized learning experience.

Incorporating these insights into the evaluation of ER activities can lead to more informed instructional decisions and a deeper understanding of how robotics can enhance the learning journey for students.

2. MOOCs, Robotics Technology, and Software for Modern Education

In ER, software is of paramount importance, complementing hardware components like robots and sensors. This chapter emphasizes the significance of software in facilitating effective interaction, programming, and control of these devices.

The journey begins with examining Moodle, a linchpin in developing Massive Open Online Courses (MOOCs). This platform's versatile features highlight the pivotal role of software tools in the continually evolving landscape of digital education. The E-Tech Project exemplifies the growing importance of these tools in digital education, shedding light on the critical role of software tools in delivering engaging and comprehensive learning experiences to meet the evolving needs of educators.

Mentioning another relevant initiative in ER, RoboPisces is a compelling case study illustrating how software is instrumental in enhancing STEAM and digital skills education. By empowering primary school teachers and embracing a constructionist educational approach, this project underscores the fundamental role of software.

An overview of the world of commercial ER tools will be done. M5Stack, a noteworthy technology company, significantly contributes to the ER domain. It exemplifies how software and hardware synergize to enhance the ER experience and keep it accessible for multiple reasons. This technology empowers various ER solutions, including Guizzo, an underwater bio-inspired robot designed for primary school workshops, which further accentuates the capability of software to create engaging learning experiences, especially in environmental education.

The chapter culminates by discussing Blockly, a versatile visual programming tool, and UIFlow by M5Stack, an integrated development environment that seamlessly bridges hardware and software in the ER landscape. It will be highlighted how these components create a cohesive and dynamic ER experience when intertwined.

2.1. Moodle for Creating a MOOC

Moodle, an abbreviation for "Modular Object-Oriented Dynamic Learning Environment", is a prominent and versatile open-source Learning Management System (LMS) extensively employed by educational institutions and organisations worldwide [12]. With its comprehensive features, Moodle empowers educators and instructional designers to construct engaging and interactive e-learning experiences [12]. It facilitates content management, assessment tools, communication tools, and learner tracking, offering an invaluable resource for efficiently delivering course content and assessments in traditional and online learning settings.

On the other hand, a Massive Open Online Course (MOOC) represents a revolutionary form of online education designed for unlimited participation and open access via the internet [13]. MOOCs transcend traditional boundaries, offering diverse course materials, including video lectures, readings, quizzes, and interactive elements like forums and social media discussions. This format promotes community interactions among students, instructors, and teaching assistants (TAs), allowing immediate feedback through quick quizzes and assignments. MOOCs, which gained immense popularity in 2012, are a well-researched development in distance education [13] and for their ability to democratise education, allowing individuals worldwide to access high-quality courses on various subjects from leading institutions and educators [14].

2.1.1. The Synergy of Moodle and MOOCs

Utilising Moodle for the creation of MOOCs yields several advantages, as outlined on the Moodle website [12]:

- Cost-effectiveness: Moodle is open source, eliminating licensing costs, which is especially advantageous for organisations with limited budgets.
- Scalability: Moodle efficiently scales to accommodate large enrolments, a crucial feature for MOOCs, which frequently attract substantial participation.
- Flexibility: Moodle's high customizability and extensibility enable instructors to tailor MOOCs to meet specific needs. Plugins and integrations expand course features and functionality.
- Supportability: With an extensive and active community of users and developers, Moodle offers robust support, which is vital for educators new to Moodle or those requiring assistance in MOOC creation and management.

Moodle's versatility is showcased in various aspects of MOOC creation [12]:

- Delivering Learning Materials: Moodle facilitates the creation and delivery of diverse learning materials, including video lectures, readings, and interactive activities.
- Creating and Administering Assessments: Instructors can employ Moodle to design and administer assignments, quizzes, and assessments, providing valuable feedback to students.
- Facilitating Discussion and Collaboration: Moodle features discussion forums and interactive activities that foster student engagement, interaction, and collaborative learning.
- Tracking Student Progress: Instructors can monitor student progress through Moodle, identifying and supporting struggling learners.

2.1.2. Why is it Worth the Effort?

The adoption of Moodle for creating a Massive Open Online Course (MOOC) is a strategic choice underscored by its potent capabilities [15]. Moodle, an acronym for "Modular Object-Oriented Dynamic Learning Environment," serves as a robust Learning Content Management System (LCMS) that empowers the establishment of virtual classrooms equipped with two essential user roles: the teacher and the learner [15]. As illustrated in [15], this LCMS offers an array of pivotal features that enhance the educational experience:

- Customised Learning Pages: Moodle furnishes each learner with a personalised page, enabling them to access and manage their enrolled courses quickly.
- Empowered Instructors: Educators control their instructional domains, as they possess dedicated pages to oversee and administer all the courses they instruct. Here, they can effortlessly upload didactic materials and share information vital for students' success.
- Storage Capacity: Moodle boasts ample storage capacity, accommodating the diverse needs of educational content, assignments, and assessments.
- Official Course Pages: Instructors can establish official course pages, serving as hubs for essential information such as teacher contact details, course syllabi, prerequisites, task descriptions, examples of past student achievements, and timely notifications regarding schedules or modifications.
- Assignment Submission: Students can easily upload assignments within specified timeframes and designated sections, streamlining the submission process.

However, while Moodle offers many advantages, it also presents challenges. This open-source application, designed for seamless integration with various other applications, offers assignment and grading services while maintaining user-friendliness. Nevertheless, the challenge lies in harnessing the full potential of this powerful tool, necessitating time for educators to explore its functionalities and harmoniously organise resources and activities within their courses [15]. For these reasons, Moodle offers solutions to mitigate these challenges, providing valuable insights, tips, and tricks, guiding educators on crafting effective e-courses successfully, and ensuring a productive and efficient educational experience [15].

2.1.3. Moodle During the Pandemic: a mentionable case study

The COVID-19 pandemic underscored the importance of platforms like Moodle in ensuring continuity in education and democratizing access. Even during the pandemic, institutions and educators successfully maintained the continuity of education by employing Moodle for reference lessons available for asynchronous consultation [15]. This adaptability and reliability proved invaluable in ensuring students could continue learning despite the challenging circumstances.

The E-Tech Project eBook [15] highlights notable case studies, such as Professor D. Scaradozzi's work in the LabMACS (Laboratory of Modeling, Analysis and Control of dynamical Systems) and Professor L. Screpanti in Manufacturing Models and Optimization. Professors like Scaradozzi and Screpanti have experimented with Moodle and its add-ons to personalise feedback and automate assessments, contributing to the platform's practical use in various educational contexts.

2.1.4. Moodle's Rich Functionality

Moodle offers a plethora of plugins, tools, and functions that make it an ideal choice for flexible learning experiences [15].

- For instance, the 'Lesson' activity enables teachers to deliver content and practice activities engagingly. This tool allows instructors to create linear sets of content pages or instructional activities, offering various paths and options for learners.
- Additionally, Moodle supports coding assignments for teaching programming languages like Matlab and Python, which can be submitted individually or in groups.
- The 'Workshop' activity enables the collection, review, and peer assessment of student work.
- Furthermore, Moodle quizzes are a versatile tool for formative and summative e-assessment.
- The platform's forum feature fosters interactive discussions, enabling students and teachers to share ideas and rate each other's contributions.
- Moreover, Moodle allows the upload of podcasts, further diversifying the learning experience.
- Integrating Kaltura with Moodle enables easy recording, uploading, and publishing high-quality videos and audio.

2.1.5. Demand for Commercial Education

The burgeoning demand for commercial education alternatives underscores the decision to invest effort in Moodle and MOOCs. Online education, in the form of e-learning courses, is experiencing a remarkable surge in popularity, with Class Central reporting that the number of MOOC participants exceeded 180 million students in 2020 [15]. This trend is further validated by students' opinions, with up to 70% of them asserting that online education is either as good as or superior to face-to-face learning [15]. Moreover, educators

exhibit unwavering confidence in the evolution of e-learning in schools, with three-quarters of teachers anticipating the replacement of traditional textbooks with digital educational content within the next decade [15]. This compelling shift toward digital education is not limited to primary and secondary education, as evidenced by the proliferation of online university courses, with as many as 857 online courses in Poland alone [15]. The growing demand for digital education makes Moodle an essential tool for effectively meeting these educational needs.

2.1.6. Personalisation of the Learning Process

One of the paramount advantages of utilising Moodle in the context of Massive Open Online Courses (MOOCs) is the potential for personalising the learning process. Each student embarks on a unique educational journey with strengths, weaknesses, and individual learning paces. When integrated with AI-based software, Moodle unlocks the capability to cater to this diversity by offering personalised learning paths [15]. These learning paths are tailored to the specific needs of learners, ensuring that they receive tasks and content that align with their current proficiency levels and aptitudes. This personalisation is not static but dynamic, adapting in real-time to provide students with tasks of the right level of difficulty, precisely when they need them, and in the most contextually relevant manner [15]. While renowned companies like Coursera, Udemy, and EDX have been at the forefront of incorporating intelligent systems into MOOCs, the potential for personalisation within Moodle-based e-learning systems is still evolving, with plans for such solutions actively in development. However, this does not preclude educators from integrating external solutions that allow for the seamless personalisation of e-courses, making them an accessible and powerful tool for meeting the diverse needs of learners in MOOCs [15].

2.1.7. Improving Evaluation and Assessment

Integrating Moodle into MOOCs also brings remarkable enhancements to evaluation and assessment processes. Artificial intelligence (AI) advancements have paved the way for innovative assessment methods that streamline the evaluation process and enhance its accuracy and efficiency [15]. AI algorithms emerge in automatically testing students' knowledge, revolutionising traditional assessment approaches. These AI-powered assessments require a multifaceted approach, harnessing image recognition, textual analysis, and deep learning-based models, including contextual text analysis and Natural Language Processing (NLP) language models [15]. Such comprehensive evaluation methodologies enable the system to capture nuanced test information, comprehend it, and assign an appropriate grade, all with unprecedented precision.

For instance, a notable development within the GUT's e-learning platform [15] is the introduction of offline test functionality, a testament to the evolution of assessment techniques. Educators can now construct tests based on a database of questions, administer them in the classroom, and subsequently scan students' answers. What sets this innovation apart is the system's ability to autonomously recognise, analyse, and grade the tests, streamlining the assessment process and significantly reducing the burden on instructors.

Moreover, AI extends its reach to open-ended questions, such as essays, where it can comprehend student responses and assign appropriate grades. While these functionalities are in the developmental phase, they are already on the cusp of mass deployment across various MOOC platforms. Beyond evaluation, AI solutions are also making strides in plagiarism detection, leveraging text analysis techniques that are continually evolving and growing in sophistication [15]. These aspects underscore the transformative potential of AI in reshaping assessment practices within the realm of MOOCs, promoting efficiency and accuracy while reducing the time and effort required from educators.

In summary, incorporating AI-powered personalisation and assessment mechanisms within Moodle-driven MOOCs enhances the learning experience significantly. These innovations cater to individual learners' unique needs while streamlining and elevating the evaluation process, reflecting modern education's dynamic and adaptive nature.

Moodle's role in MOOC creation and the broader e-learning landscape is paramount. Its adaptability, rich feature set, and versatility make it an ideal choice for educators and institutions seeking to offer accessible, high-quality education to learners worldwide. The choice to leverage Moodle in creating MOOCs is underpinned by the platform's rich features and the burgeoning demand for digital education. The versatility and adaptability of Moodle make it an essential tool for modern education, whether in a traditional or remote learning environment.

2.2. E-Tech Project

The global digital education market is experiencing a remarkable surge, penetrating not only homes, businesses, and corporations but also the realm of academia [16]. Educational institutions, including universities, must adapt swiftly to a changing educational landscape. The global pandemic and the ensuing need for social distancing measures have significantly accelerated the rapid adoption of online learning. Moreover, today's students, particularly those in technical universities, exhibit increasing expectations for teaching materials—they demand dynamism, a digital approach, and exceptional visual quality.

In response to these evolving demands and challenges, higher education teachers, especially those in STEM fields, find themselves in a pressing need to acquire new skills quickly. Key among these competencies are methodical, design, and technical skills that enable educators to deliver high-quality online education and create engaging e-learning courses. Recognising this imperative, researchers at the Gdansk University of Technology embarked on a collaborative endeavour. They joined forces with the Austrian University of Applied Science FH Joanneum Gesellschaft MBH in Graz and the Italian Università Politecnica delle Marche in Ancona. This ambitious project received invaluable support from the Polish Association for Academic E-learning (SEA). Together, they embarked on a mission to develop practical materials and multimedia resources to empower European teachers to design compelling online education experiences for their students [16].

One notable aspect of this project is the involvement of Professor D. Scaradozzi's research group, the Laboratory of Mechatronics and Modeling and Identification of Dynamic Processes (LabMACS). This involvement underscores the significance of interdisciplinary collaboration and the integration of cutting-edge technologies into education. Professor Scaradozzi and his team have contributed their expertise to the project, further enhancing its credibility and potential impact on modern education.

The E-Tech Project, officially titled "Comprehensive Project for Distance Teaching Skills and Multimedia Resources for Technical Universities in Europe (2020-1-PL01-KA226-HE-096375)," is funded through the Erasmus+ Strategic Partnership programme. It represents a shining example of collaborative research to enhance e-learning tools, particularly in integrating STEM (Science, Technology, Engineering, and Mathematics) subjects into school curricula.

The E-Tech Project, driven by a shared vision among its partner institutions, has yielded significant outcomes that hold great promise for the future of education. These outcomes include [16]:

- A Comprehensive eBook: At the heart of this project is a comprehensive ebook with practical advice and tips for online teaching at the academic level. This resource serves as a guidepost for educators navigating the intricacies of online education, particularly in STEM fields. It equips teachers with the necessary skills and insights to create engaging and effective e-learning experiences for their students.
- E-Learning Courses: The project has also led to the developing of e-learning courses tailored to teachers and students. These courses provide structured learning experiences that empower educators to master the art of online teaching while offering students valuable tools and techniques for successful online learning.
- Interactive Resources: The project has assembled a bank of interactive resources to enrich the teaching and learning process further. These resources are valuable assets in the educational toolkit, enhancing engagement and interactivity within online courses.

The E-Tech Project exemplifies academia's commitment to meet students' evolving needs and the demands of the digital age. It represents a collaborative effort that bridges research, technology, and education to create tangible solutions for modern teaching and learning challenges. The impact of this project extends beyond its immediate goals, as its outcomes have been cited and integrated into the broader discussion of e-learning, as previously explored in the chapter.

2.2.1. E-Tech eBook: A Comprehensive Resource for Advancing Online STEM Education

This section will delve into the E-Tech eBook [15], a comprehensive academic resource developed as part of the E-Tech European Project. This scholarly document is a valuable tool for educators seeking to enhance their capabilities in delivering effective and engaging online STEM (Science, Technology, Engineering, and Mathematics) courses. The E-Tech eBook is a testament to collaborative research efforts involving multiple European universities and significantly contributes to online education. The structure comprehends four main sections, each offering valuable insights and guidance for educators navigating the evolving landscape of online STEM education.

Exploring the content and objectives of this scholarly work in more detail:

- The first section introduces fundamental concepts of online education, including definitions, benefits, challenges, and critical terminology. In this section, we elucidate what online education entails, its primary characteristics, advantages and disadvantages compared to traditional education, and its prevalent concepts and terminology.
- The second section focuses on online teaching in STEM courses, presenting examples, tools, and strategies to enhance the effectiveness and engagement of lessons. Here, we illustrate how to design and conduct online classes in scientific and technological subjects, address the specific challenges of these disciplines, and identify suitable tools and platforms for simulating experiments, labs, and collaborative projects.
- The third section provides suggestions and advice for crafting compelling online content, such as online lessons, webinars, videos, quizzes, presentations, ebooks, and other multimedia formats. This section demonstrates how to create and organise online educational materials that are intriguing, interactive, and personalised for students, utilising various techniques and digital resources.
- The fourth section explores emerging technologies that can enrich the online learning experience, including Extended Reality (XR) technologies, cyber-physical laboratories, assessments based on digital twins, and artificial intelligence. This section overviews technological innovations reshaping

online education's landscape, opening new opportunities for immersive, collaborative, and adaptive learning experiences.

This eBook represents a comprehensive resource tailored to educators seeking to navigate the dynamic landscape of online education, particularly in STEM fields, and harness the power of emerging technologies to enhance the learning journey for their students.

2.3. RoboPisces Project

2.3.1. Overview of the RoboPisces European Project

The RoboPisces project ("Innovative Educational Robotics strategies for Primary School Experiences," 2019-1-IT02-KA201- 92 063073) is a collaborative European initiative that aims to revolutionise primary school education by introducing the realms of ER and STEAM (Science, Technology, Engineering, Arts, and Mathematics) skills [17]. Spanning six countries, namely Croatia, Greece, Latvia, Ireland, Italy, and Malta, this project involves academic institutions and primary schools in a transnational effort to bring innovation and engaging learning experiences to young students.

Within the constellation of project partners, Italy plays a crucial role. Notably, the research group led by Professor D. Scaradozzi is actively involved in driving the RoboPisces project forward. Their expertise and contributions have been instrumental in shaping the project's direction and outcomes.

Furthermore, the RoboPisces project has been a pivotal occasion for the emergence of innovative ER solutions from ANcybernetics s.r.l. This Italian partner has embarked on its journey in ER, with the RoboPisces initiative serving as a foundational stepping stone. The project has provided a platform for ANcybernetics to develop and showcase its initial ER solutions, marking the beginning of a promising venture in this educational domain.

RoboPisces fosters a robust transnational collaboration among high-level academic institutions and primary schools, pooling their expertise to advance STEAM and digital skills education. Incorporating ER is central to this initiative, enhancing learning outcomes through hands-on, enjoyable activities that captivate young learners [17].

An essential component of the RoboPisces project is empowering primary school teachers. They participated in training courses [17], equipping them with the knowledge and skills to effectively integrate RoboPisces' technological and methodological resources into their teaching practices. This initiative aims to cultivate a new digital attitude among educators, enabling them to incorporate technological laboratories into the regular Curriculum seamlessly.

RoboPisces employs a constructionist educational approach to create a teaching and learning curriculum based on ER. This project centres around developing the RoboFISH toolkit [18], a dynamic tool designed to engage primary school students effectively, focusing on enhancing STEAM learning outcomes. The toolkit encourages students to construct, program, and work with robots, fostering creativity, innovation, and transversal skills such as rational thinking.

The RoboPisces project sets forth a range of ambitious objectives [17]:

- Enhance students' achievement and engagement in STEAM subjects through innovative teaching methods, including Robotics kits and inventive assessment strategies.
- Develop transversal skills in pupils through ER, enriching their problem-solving abilities.
- Introduce the theme of the marine environment through the RoboFish toolkit, promoting sustainability concepts.
- Promote digital competence across curricula tailored to different age groups.
- Improve student interest, participation, and motivation to reduce early school leaving (ESL).
- Enhance primary school teachers' competencies in robotics, enabling them to implement a robotics-based curriculum effectively.
- Create specific assessment tools, including lesson plans, to evaluate learning outcomes and attitudes toward learning.

2.3.2. Project Outputs

The RoboPisces project yielded three main outputs: the RoboFISH toolkit, the RoboPisces curriculum, and the Teacher Training Manual. These resources are available under a CC BY-NC-SA 4.0 license and are accessible on the Erasmus+ Project Results platform and the RoboPisces MOOC platform [19], developed on Moodle.

- RoboFISH Toolkit: This intellectual output, represented by IO2, offers a set of kits for teaching educational and marine robotics at primary schools. It includes both Basic and Advanced Toolkits [18, 20], with the second which resembles a robotic fish (RoboFish). The toolkit's modularity allows for compatibility with various educational systems, enhancing students' technological backgrounds. This innovative toolkit combines elements of marine and ER and introduces concepts of IoT (Internet of Things) while providing opportunities for 3D printing projects.
- RoboPisces Curriculum: IO3 comprises an innovative educational curriculum designed to teach ER and the marine environment at the primary school level. The Curriculum, divided into basic and advanced sections, introduces students to the principles of robotics and then delves into the study of the marine environment and IoT concepts. It empowers educators with lesson plans, learning objectives, training materials, practical activities, and assessment methods, emphasising the synergy between robotics and environmental education [21].
  The RoboFISH curriculum, a central component of the RoboPisces project, will be comprehensively elucidated in the third chapter of this thesis. In this section, we will delve into the meticulous implementation and rigorous validation of the activities and methodologies meticulously proposed by the project. This in-depth exploration will shed light on the real-world impact and efficacy of the RoboFISH curriculum, providing invaluable insights into its application within primary school education.
- Teacher Training Manual [22]: IO4, the "RoboPisces Teachers Training Manual," equips primary school teachers with the necessary knowledge and skills to effectively incorporate ER into their classrooms. This manual encompasses pedagogical approaches, guidelines for open educational resources, policy recommendations, innovative teaching methods, 3D printing guidelines, and a glossary of technical terms, facilitating teachers' professional development in robotics education.

The RoboPisces project advances STEAM education and introduces innovative pedagogical approaches, fostering creativity, digital competence, and sustainability awareness among the next generation of learners.

2.4. Commercial Tools and Robots for ER

This section explores the various commercial tools and robots available for ER. ER enhances students' understanding of STEM (Science, Technology, Engineering, and Math) concepts and nurtures their problem-solving skills. It will begin by distinguishing between Robotics in Education (RiE) and ER, as proposed by authors in [1].

2.4.1. RiE

While RiE and ER are often used interchangeably, [1] suggests a distinction. RiE encompasses a broader spectrum of how robotics can contribute to education. It goes beyond classroom activities and includes assisting students with disabilities, capturing students' attention, or aiding teachers in content delivery.

2.4.2. Integration of robotic tool

Within the realm of RiE, [1] categorises robotic tools based on their intended purpose, identifying four types:

- Assistive Robots: These medical devices assist individuals with physical disabilities in performing daily tasks. While not initially designed for education, they can facilitate learning for impaired students.
- Socially Assistive Robots: These robots aid users through social interaction, which is particularly beneficial for individuals with social impairments like autism, fostering social and emotional skills.
- Social Robots: These robots engage with users naturally and interpersonally, serving as companions to students and teachers, offering feedback, motivation, or guidance.
- Educational Robots: Designed explicitly for students, these robots enable construction, programming, and experimentation with robotics concepts and skills, emphasising meaningful and interdisciplinary learning experiences.

The last category, Educational Robots, aligns closely with the tools suitable for ER activities, forming a subset of RiE robots.

2.4.3. A classification of ER tools

ER encompasses various tools and kits to engage students in hands-on learning experiences. To understand the diversity of ER tools available, we categorise them based on several critical criteria [1]:

- Age: Educational robots are often tailored to specific age groups, ensuring that the content and complexity align with students' developmental stages. For instance, some kits are designed for Kindergarten students, while others are suitable for primary or secondary school levels. The versatility of these tools allows educators to adapt them to different age groups, making them valuable across various educational settings.
- Programming Language: Programming is a fundamental aspect of ER, and the choice of programming language can significantly impact students' learning experiences. ER tools offer three main types of programming languages:
- Text-based: These tools introduce students to text-based programming languages, providing a more advanced coding experience. Teachers frequently adopt this approach when preparing secondary school students to explore more intricate programming concepts.

    - Block-Based: Block-based programming environments, such as Scratch, Blockly, or similar platforms, are popular in ER. These environments use visual blocks that students can drag and snap together to create sequences of commands. They are ideal for younger students and beginners, offering a visually intuitive way to learn programming without the complexities of syntax.
    - Unplugged: ER tools may employ an "unplugged" approach for the youngest learners. In this method, students do not require screens or digital devices. Instead, they use physical blocks or buttons to program the robot. This hands-on approach is especially suitable for Kindergarten students and emphasises physical engagement and tactile learning.
- Assembly Feature: ER tools vary in terms of assembly requirements. Some kits allow students to build the robot from scratch, providing valuable insights into mechanical and electronic components. These are often called "To Build" kits and are favoured for their educational value as students gain a deeper understanding of the robot's structure. In contrast, "Ready to Use" robots come pre-assembled, focusing solely on programming the robot's behaviour without the option to modify its physical components. This distinction caters to different learning objectives and preferences.
- Robot's Environment: Educational robots can operate in diverse environments, including land (Earth), water (Water), and air (Air). The choice of environment impacts the types of accessible activities and experiments. For example, Earth-based robots are suitable for terrestrial exploration and navigation, while Water-based robots may involve aquatic environments and marine studies. Air-based robots, such as drones, open up opportunities for aerial exploration and data collection. These distinctions enable educators to select tools that align with their curriculum objectives and educational contexts.

2.4.4. Some examples of commercial tools and robots for ER

In [1], the authors introduced a table that compiles the primary tools and robots available for ER activities. These tools are categorised based on their features and characteristics, aligning with the four parameters outlined in the preceding section.

Furthermore, [2] offers additional notable examples of tools for STEM, STrEM, and eSTrEM curricula in K12 education, with a specific focus on the marine environment. In this case, the classification predominantly relies on the age groups of students who will engage with the tools and the technological themes they aim to convey.

Tools for Early Stage Learning (1st/2nd Classes - 1st/2nd Years):

LEGO WeDo System: Designed for students in their first and second years of primary school, the LEGO WeDo system prioritises simplicity and playfulness. It sparks curiosity and encourages communication, creativity, collaboration, and critical thinking. Students have the opportunity to create original robotic artefacts, enhancing their understanding of how STEM concepts affect their daily lives. Collaboration thrives as students take on roles like the designer, warehouse worker, technical assembler, and validator to work in teams.

Tools for Secondary Level Learning (3rd/4th Classes - 3rd/4th Years):

LEGO NXT/EV3 Systems: Targeting students in their third and fourth years of primary school, LEGO NXT and EV3 systems introduce more complex robotics concepts. These kits allow students to build autonomous robots capable of communication and reaction through structured programming. They also offer the potential for rapid prototyping of new software blocks, enabling educators to create personalised educational kits.

Tools for IoT and Control Strategies (4th/5th Classes - 4th/5th Years):

SAM Labs Systems: Tailored for fourth and fifth-grade students, SAM Labs provides wireless electronic blocks programmable for various actions. Students learn to code behaviours, apply sequencing, selection, and iteration, and control and simulate physical systems. SAM Labs fosters an understanding of sensory networks, distributed actuation, and centralised and distributed control systems.

Tools for eSTrEM, Marine Robotics, and RoboEthics (4th/5th Classes - 4th/5th Years):

OpenFISH.science Kit: This modular kit resembles the anatomy of a fish and is suitable for introducing advanced topics like eSTrEM, Marine Robotics, and RoboEthics to fourth and fifth-grade students. It incorporates hardware and software components for real-time data collection. Students have the opportunity to assemble the fish themselves, gaining hands-on experience with mechatronics. The flexible kit allows for structural, sensor, and actuator adaptations, making it ideal for marine environments.

These examples showcase how ER tools progress with students' age and development, gradually introducing them to more complex concepts in robotics, coding, IoT, and environmental awareness. Additionally, they emphasise the importance of fostering creativity, teamwork, and critical thinking skills in the learning process.

2.5. Unveiling a Leading ER Tool: M5Stack's Impactful Journey

In ER, M5Stack's solutions shine as a beacon of innovation. The M5Stack ecosystem offers many features and advantages, making it a standout choice. This example is particularly noteworthy in its extensive testing and validation by LabMACS and ANcybernetics, underscoring its effectiveness in fostering ER activities.

Founded in 2016, M5Stack is a Chinese company renowned for producing an array of microcontrollers based on the ESP32 module [23]. Within their ecosystem lies a diverse range of products encompassing development boards, modules, accessories, and components. Their products are designed to be user-friendly and accessible to a broad audience, making them a versatile choice for IoT, robotics, artificial intelligence, and prototyping applications.

2.5.1. M5StickC Plus: Compact Powerhouse Unleashed

At the forefront of M5Stack's offerings, the M5StickC Plus [24] emerges as a compact and highly adaptable development board. With a suite of features, including a 0.96-inch OLED display, integrated Wi-Fi and Bluetooth capabilities, ambient light and temperature sensors, and even a built-in speaker, the M5StickC Plus is a potent tool for diverse applications. Key attributes include:

- Comprehensive Hardware Ecosystem: M5Stack's hardware ecosystem provides a rich assortment of complementary products that can enhance the capabilities of the M5StickC Plus.
- Leveraging ESP32 Technology: This remarkable device is built upon the ESP32 module, affording a broad spectrum of functionalities, encompassing Wi-Fi, Bluetooth, BLE, GPS, and IMU.
- IoT Applications: The M5StickC Plus is particularly suited for IoT applications, facilitating data collection, device control, and interaction with the physical world.
- Modularity: Its modular design lets users easily customise it with various modules and accessories.
- Versatility: The M5StickC Plus proves its mettle across a plethora of applications.

The advantages of M5Stack products are manifold:

- Affordable Excellence: M5Stack products, including the M5StickC Plus, are celebrated for their exceptional value, ensuring accessibility for educational initiatives.
- Championing Open-Source Hardware: M5Stack embraces open-source principles, making its hardware freely available for customisation and utilisation.
- User-Friendly Design: The M5Stack product line is thoughtfully designed to cater to users of all levels, offering extensive resources such as tutorials, code examples, and comprehensive documentation.
- Customization Galore: These products are incredibly customisable, allowing the integration of various modules and accessories for tailoring projects.

M5Stack products find their footing across a multitude of domains, including:

- IoT Exploration: The M5StickC Plus effectively gathers sensor data, wields control over devices, and interfaces with the tangible world.
- Robotics Endeavors: It can be the foundation for crafting autonomous robots or remotely controlled robotic systems.
- Educational Empowerment: M5StickC Plus is an exceptional tool for imparting IoT, robotics, and programming concepts to students.

An exceptional feature of the M5StickC Plus is its versatility in programming. It accommodates Blockly (via UIFlow IDE), MicroPython, and C++ (via Arduino IDE) programming languages. This adaptability ensures a broad user base, ranging from novices to experts, with the capability to transition from visual, block-based programming to text-based coding. Blockly offers a visual programming language that's easy to learn, MicroPython optimises Python for microcontrollers, and C++ proves robust for complex applications.

In line with the ER tool classification elucidated in Section 2.4.3, the M5StickC Plus fits into the following categories:

- Age Group: Versatile for a wide age range.
- Programming Language: Supports both text-based and block-based programming.
- Assembly Feature: Requires assembly, promoting hands-on learning.
- Robot's Environment: Primarily designed for Earth-based applications.

M5StickC Plus is a versatile and potent ER tool, making it an excellent choice for DIY projects and educational endeavours.

2.5.2. Harnessing M5Stack Technology for ER Kits

Thanks to the highlighted features and strengths of this technology platform, it is easy to create customised kits for teaching ER by selecting a microcontroller and some specific add-on modules (sensors and actuators) and integrating these components into a precise curriculum of lessons, guides and activities offered to support educators and teachers to explore the potential of each part and possibility to create a more complex system by connecting the different parts each other. An example is demonstrated by the Basic Kit, one of the results of the RoboPisces project [20].

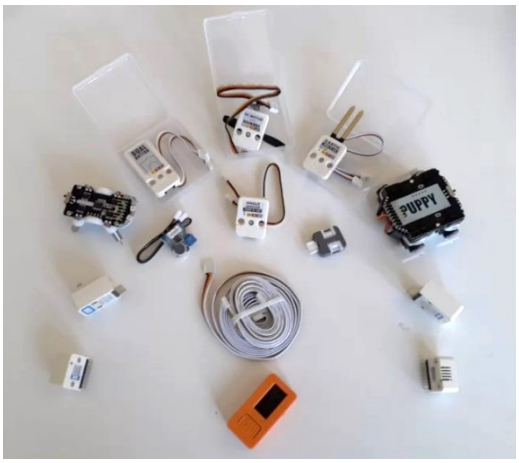


Figure 1 - RoboPisces Basic Toolkit

Alternatively, M5Stack technology can also be integrated into brand-new products and devices, which can exploit the technological advantages of the M5StickC Plus and extend them, taking different forms and integrating new functionalities such as adaptability to extreme environments. Take, for example, the RoboFISH Advanced Toolkit developed as part of the RoboPisces project. The RoboFISH Advanced Toolkit, also called RoboFISH, is an innovative educational tool: a pisciform robot born to introduce marine and submarine robotics experiences with ER and STEAM learning purposes [18].



Figure 2 - RoboPisces Advanced Toolkit (RoboFISH)

2.5.3. Guizzo: A Unique ER Tool for Exploring the Underwater World

From the evolution of the RoboFISH Advanced Toolkit, ANcybernetics has introduced Guizzo, an educational fish robot tailored for teaching STEAM concepts within ER experiences. Guizzo exhibits remarkable features that enable it to navigate underwater while boasting wireless charging and programming capabilities. This bio-inspired robot, built upon the M5StickC Plus, mimics the appearance of a fish and showcases the following characteristics [7]:

- Wireless Control and Programming: Guizzo can be programmed and operated remotely using a wireless controller and a visual programming editor.
- Wireless Recharging: It offers the convenience of wireless recharging without opening the sealed compartment housing its electronics and battery.

- Propulsion and Steering: Guizzo is equipped with a waterproof servomotor that propels the tail, generating thrust and steering.
- IMU Sensor: An integrated IMU sensor measures the robot's attitude and acceleration.
- User-Friendly Interface: It features a display and buttons accessible from the outside using magnets.
- Buoyancy Control: Guizzo's hollowed head and tail can be filled with weights to adjust its buoyancy and balance.
- Safety and Environmental Compliance: The robot's materials meet high standards, adhering to the Machine Directive and the Toys Safety Directive, ensuring safety and environmental friendliness.



Figure 3 - Guizzo (Bio-inspired Educational Robot)

While the robot's propulsive performance could have been enhanced through a more complex design, such as a multi-joint tail mechanism, the authors opted for a simple ostraciiform locomotion to create a robust and cost-effective robot. This design choice aligns with the intention to craft a bio-inspired toolkit for primary school workshops. The project prioritises delivering a reliable, fully functional product that can be produced in large quantities and distributed to numerous public schools [7].

Notably, Guizzo stands as one of the few examples of ER tools designed for water use, exploring topics related to the marine environment, as referenced in [2] and [7]. While some ER activities have been centred on environmental education at schools, only a handful of examples in K12 education focus on the marine environment [7].

2.6. Blockly

In previous sections, we delved into the world of ER tools and the impactful M5Stack technology. Now, the focus shifts towards the essential software components that enable hands-on coding experiences in ER. This section delves into Blockly, a versatile visual programming environment that facilitates coding for learners of all ages. In the following one, the document will explore UIFlow, an integrated development environment (IDE) based on Blockly and tailored to the M5Stack ecosystem, offering a seamless bridge between hardware and software for ER. These IDEs, Blockly and UIFlow, empower educators and students to embark on engaging coding journeys, fostering creativity and computational thinking.

Blockly is a versatile JavaScript library that empowers users to construct visual programming languages and editors using drag-and-drop blocks [25, 26]. Initially developed by Google, Blockly operates as open-source software under the Apache License 2.0 and draws inspiration from Scratch, a renowned visual programming language primarily designed for young learners.

One of Blockly's standout features is its ability to generate code in various textual programming languages, including JavaScript, Lua, Dart, Python, and PHP [26]. Moreover, Blockly's extensibility shines through its capacity to facilitate custom code generation in virtually any programming language by defining new blocks and generators. These blocks serve as graphical components representing programming commands, variables, expressions, and other language elements, while generators act as functions responsible for translating blocks into executable code.

Blockly provides a user-friendly graphical interface (GUI) consisting of a toolbox and a workspace. The toolbox houses an array of available blocks that users can select and effortlessly drag into the [26]. Users can seamlessly arrange, connect, and modify blocks within the workspace to craft their programs. To enhance usability, the GUI offers zoom icons and a trashcan for block deletion. Blockly's flexibility extends to GUI customisation, allowing adjustments tailored to diverse needs and preferences.

Blockly offers predefined blocks for joint programming operations, such as arithmetic, logic, loops, text, lists, colour, variables, and functions, as well as the Block Factory. The Block Factory is a visual tool enabling users to create new blocks by employing existing ones [25]. Creating a new block involves providing a definition, describing its appearance and behaviour, and crafting a generator elucidating how the block translates into code.

Blockly has found extensive application across diverse educational and creative domains. Through Blockly, users across diverse backgrounds and age groups can harness the power of visual programming to explore, create, and learn. It is fundamental for teaching programming concepts and cultivating computational thinking skills [26]. Furthermore, Blockly extends its utility to crafting games, animations, interactive stories, and simulations. Blockly Games, App Inventor, Code.org, and Scratch are prominent educational projects that harness Blockly's capabilities [26].

Blockly is an accessible web-based solution that utilises Scalable Vector Graphics (SVG) and client-side JavaScript. This flexibility allows Blockly to be compatible with major web browsers. Blockly's support extends to various programmatic constructs, such as variables, functions, and arrays, making it an adaptable choice for dynamically typed languages. Customisation is further facilitated by integrating plugins, code labs, samples, and a developer forum [26]. In fact, Blockly thrives as an open-source project initially developed by Google and maintained by a robust community of contributors. Its code and comprehensive documentation are openly accessible on GitHub, and its licensing allows unrestricted use, modification, and distribution.

2.7. UIFlow by M5Stack: Bridging Hardware and Software in ER

UIFlow is a user-friendly integrated development environment (IDE) designed by M5Stack to facilitate programming and project development for its hardware ecosystem [27]. It is a vital bridge between hardware and software, making it an ideal platform for ER activities. UIFlow offers a range of visual programming options, including Blockly, MicroPython, and custom code, accommodating learners at different levels of expertise. By combining the capabilities of M5Stack's hardware with the versatility of UIFlow, educators and

students can seamlessly transition from building physical robots to programming them, creating a holistic ER experience.

2.7.1. General overview

UIFlow's visual programming interface, powered by Blockly, empowers even novice learners to write code through drag-and-drop blocks, enabling them to experiment with robotics concepts without the complexities of traditional text-based programming languages. Moreover, UIFlow supports MicroPython, a simplified Python variant optimised for microcontrollers [28]. This feature allows more advanced users to transition to text-based coding while maintaining compatibility with M5Stack hardware.

UIFlow potentially simplifies the integration of M5Stack hardware into ER curricula, offering a rich set of resources, tutorials, and sample projects. These resources can help educators harness the potential of UIFlow to nurture students' coding skills and foster a deeper understanding of robotics concepts in a hands-on and engaging manner.

As Blockly, UIFlow offers blocks for joint programming operations, such as arithmetic, logic, loops, text, lists, colour, variables, and functions. Additionally, for interacting with the hardware components, specific blocks for interacting with the hardware embedded and module or sensors/actuators add-ons are available in the IDE.

Moreover, UIFlow provides professional and practical network development components for developing IoT solutions. It provides standard network communication methods such as MQTT(s), HTTP, and Socket UDP and integrates efficient solutions to quickly establish connections with various cloud platforms (e.g. Azure, AWS, Tencent, Aliyun) [27].

UIFlow by M5Stack is a robust platform that unifies hardware and software, making it accessible for learners of all levels and enhancing the ER experience.

2.7.2. GUI

UIFlow inherits some of the main aspects of its GUI (Graphical User Interface) from Blockly, notably the foundational elements of the toolbox and the workspace. However, UIFlow goes beyond these basics, enriching the available features to provide a comprehensive platform for programming M5Stack devices.

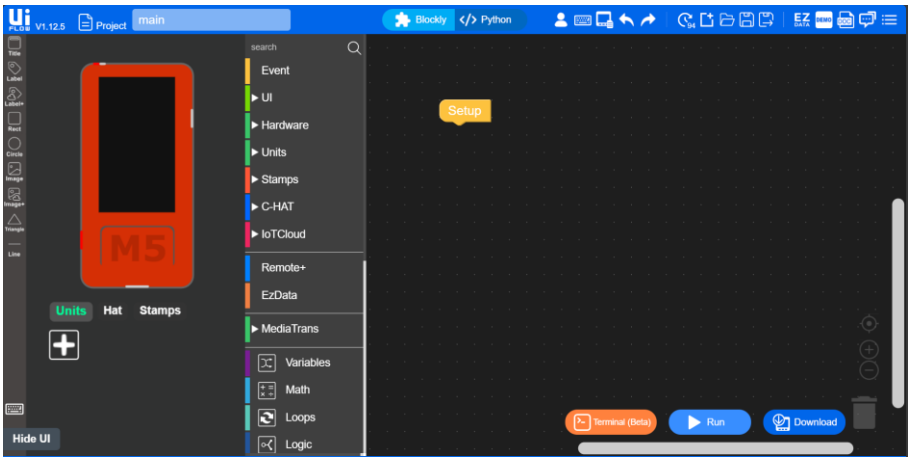


Figure 4 - UIFlow IDE

In UIFlow, the graphical user interface (GUI) consists of several critical components designed to facilitate both beginners and experienced users in creating, customising, and executing programs [https://m5stack.oss-cn-shenzhen.aliyuncs.com/resource/docs/UIFlow-StickC-Book-English.pdf]:

Project Title

In every coding activity, it is vastly recommended to enter the project name. The IDE offers a field for inserting the project name on which the user is working. The project will retain this name Whenever the program is downloaded to the user's computer or M5Stack module.



Figure 5 - Project name field

Blockly</>Python switch

UIFlow empowers users to seamlessly transition between visual block-based programming and text-based coding in Python. The interface includes a button that allows users to view the Python code generated by their blocks. This functionality promotes a gradual transition from visual coding to text-based programming, allowing learners to explore more complex coding concepts.



Figure 6 - Blockly</>Python switch

Units/Hat

An essential aspect of ER involves configuring the hardware components. UIFlow facilitates this by offering a dedicated interface for selecting the module's add-ons (sensors/actuators). Users can also specify the ports

to which these units will be connected. This intuitive feature ensures the hardware setup aligns seamlessly with the project's objectives.

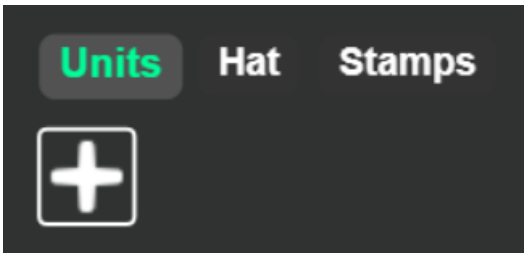


Figure 7 - Units and Hats manager

UI Preview

UIFlow extends its capabilities beyond traditional coding. Users can design graphical user interfaces (UI) by dragging and dropping text and visual elements onto the M5StickC (or any other M5Stack module used) screen. A corresponding set of blocks appears in the UI panel, enabling users to manipulate these elements effortlessly. This feature opens the door to projects that require user interaction and data visualisation.



Figure 8 - UI Manager and Preview

Coding Area

The coding area is the workspace where blocks are dragged and assembled to construct the program.

In the Coding Area, there are also two crucial functions:

- The "Run" button allows the user to quickly test the code on the device without saving it permanently. It is helpful for immediate testing.
- The "Download" button permits the user to save the program to the device for future use or sharing. After downloading, accessing the program from the app list upon boot is possible.

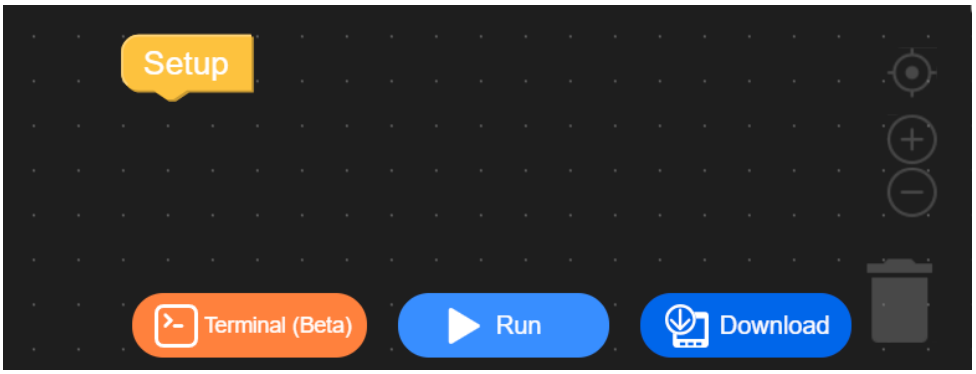


Figure 9 - Coding area

Code blocks menu

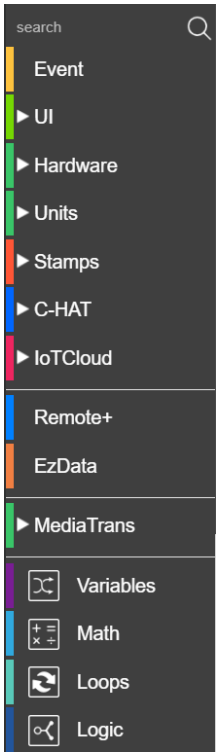


Figure 10 - Code blocks menu

The code block menu encompasses a comprehensive collection of blocks required to create a wide range of programs. It includes hardware blocks for direct hardware interfacing with the M5StickC, mathematical blocks for calculations, and logic blocks to facilitate the integration of different program components.

Below is a list of the most essential and used categories:

Event: In this section, users can access Loop and button press event blocks.
Hardware: This section allows users to program the internal peripherals of the M5StickC, such as the LED, IMU, and Power management.
Units/C-Hat: Whenever a Unit/Hat is added, it will appear here, along with all the related code blocks.
Math: Mathematics plays a crucial role in programming, and this section provides all the necessary blocks for simple and complex calculations.

Logic: Every program requires logic to determine the appropriate actions for specific events.

Advanced: Advanced blocks are available for experienced coders, including blocks for networking, digital/analogue pin control, and more.

Menu tab

The Main navigation bar is a gateway to key functions within the UIFlow interface. Users can easily access the official forum to share code or seek assistance or the Documentation pages for extensive information about each add/on and UIFlow's functions. Additionally, users can explore example programs for adaptation and learning purposes. The Undo/Redo functions allow error correction by retracing steps. Furthermore, the Settings section permits users to configure device connections, modify language preferences, select devices, and tailor colour schemes.

Please note that these are among the most relevant functions available in the Main navigation bar, providing essential tools and resources for users of UIFlow.



Figure 11 - Menu tab

2.7.3. Programming with blocks

UIFlow relies on Blockly, a block-based programming language, to provide users with a user-friendly coding experience. Blockly's primary goal is to simplify programming, especially for beginners, by eliminating the common challenges associated with typed programming languages. These challenges often involve dealing with syntax errors, whitespace issues, and other complexities that can discourage newcomers from pursuing programming. Blockly's ingenious design allows its blocks to encapsulate the core functionalities found in traditional typed languages, covering vital elements like variables, arrays, and functionshttps://flow.m5stack.com/download/M5GO_User_Manual_en.pdf [27].

To understand how these blocks operate, picture them as jigsaw puzzle pieces [27]. As users manipulate the blocks, they automatically snap together and change colour when they come into proximity. This change indicates a successful connection, effectively constructing a segment of code. Conversely, if the blocks do not change colour when brought near each other, they remain unconnected and will not be executed as part of the program. This intuitive approach to block-based coding streamlines the process and empowers users to focus on their creative and problem-solving aspects of programming without being hindered by syntactical complexities.

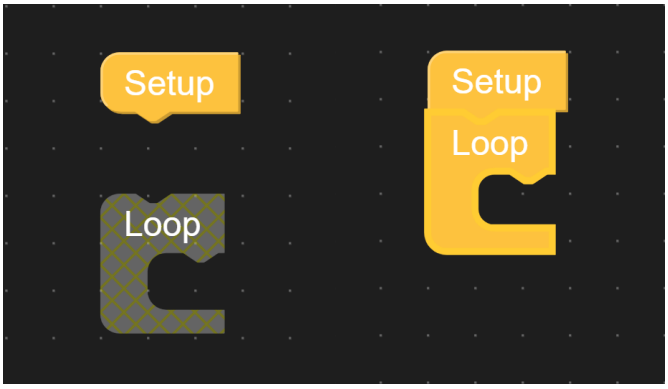


Figure 12 - An example of unconnected blocks (left) and correctly connected blocks (right) on UIFlow.

2.7.4. Custom blocks

This section will delve into Custom Blocks within UIFlow, a feature analogous to Blockly's "Block Factory". Just as Blockly empowers users to construct custom blocks for their programming needs, UIFlow extends a similar capability through its dedicated tool. This tool enables users to create personalised blocks tailored to their unique requirements, ultimately enhancing the functionality and flexibility of the IDE.

To access the UIFlow Block Maker, users can follow these steps:

1. Click on the "Custom" section, the last option in the "code blocks menu".
2. Within the block list, select "Create *.m5b file".

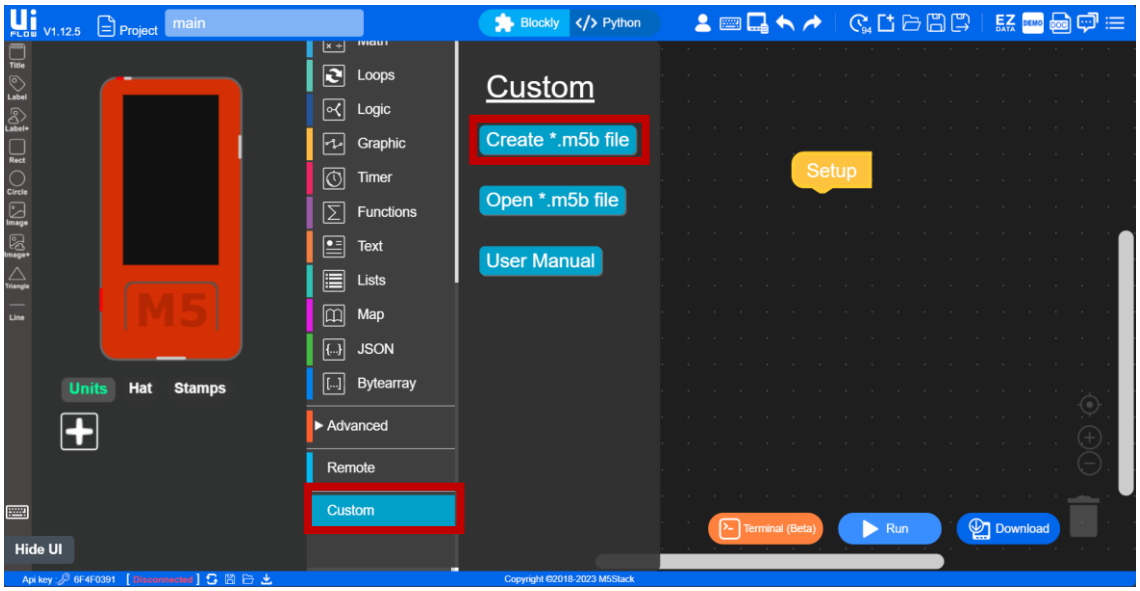


Figure 13 - Block Maker in UIFlow IDE

Running the Block Maker allows users to create new custom blocks by providing the following information:

1. Group Name (Namespace): This is the group name where the custom block will be contained.
2. Block Color: Choose the appearance color of the block.
3. Block Label (Name): Here, only letters, numbers, and underscores are allowed for the block's name.
4. Block Type: Define whether the block should be categorised as a "Value" or "Execute" type.



Figure 14 - An example of a block of type "Value" (left) and "Execute" (right)

5. Number of Blocks: Users can simultaneously add multiple blocks within the same group and save them to a .m5b file.

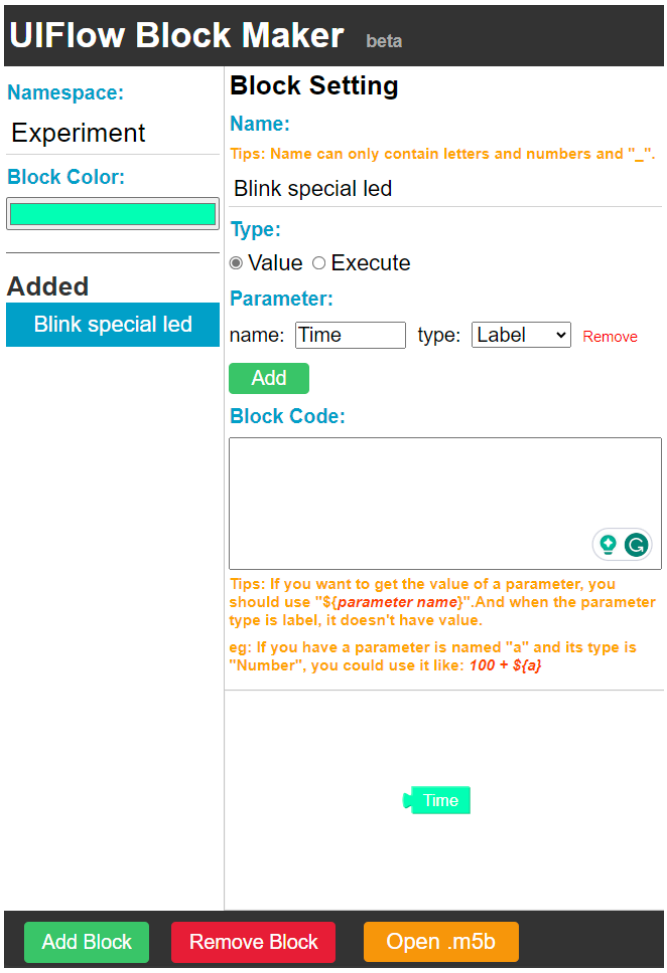


Figure 15 - Block Maker's U

These steps enable users to create and customise their blocks to suit their specific programming needs.

1. Adding Parameters:
   - Click the "Add" option under "Parameter."
   - Add a program property to define the name displayed in the block.
   - Select the property type that corresponds to the specific needs.
2. Adding Code to the Block:
   - Enter the desired code in the custom block in the "Block Code" option box.
3. Working with Input Values:
   - When the attribute type of a custom block involves constant or variable input, the user can access these values within the code for further processing and operations.
   - Utilise ${Parameter name} in the code to retrieve and work with the input values defined by the parameters.

These steps allow the user to create custom blocks with parameters and associated code, enabling them to tailor programming to specific requirements.

Ultimately, it is possible to save the changes by clicking "Download" or open the saved custom program for modification by the "Open" button.

Once back on UIFlow, it will be possible to use the new custom blocks made:

1. Click on the "Custom" section, the last option in the "code blocks menu".
2. Within the block list, select "Open *.m5b file".

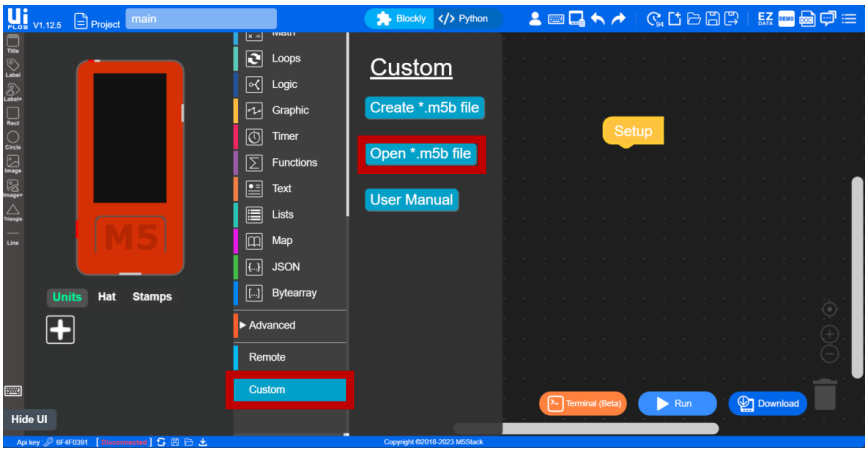


Figure 16 - Custom blocks in UIFlow IDE

Integrating Third-Party Solutions with Custom Blocks

In the ever-evolving landscape of ER and programming, custom blocks bridge the M5Stack technology platform and innovative solutions provided by third-party companies. These custom blocks empower end-users to seamlessly control and interact with complex hardware and software. This section explores how these custom blocks are employed to make advanced concepts more accessible, engaging, and educational.

Example 1: ANcybernetics- Empowering the Motion of Guizzo

ANcybernetics, an ER and marine exploration company, exemplifies the utility of custom blocks in facilitating user-friendly interactions with intricate hardware systems. Guizzo, their pisciform robot, captivates users by emulating the delicate movement of a fish's caudal fin in water. To achieve this, ANcybernetics has designed a set of custom blocks tailored to control Guizzo's actions.

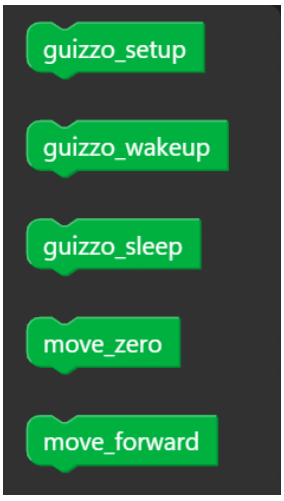


Figure 17 - Guizzo's custom blocks

Among the notable custom blocks developed by ANcybernetics are:

- "guizzo_setup": This block configures Guizzo's features, allowing users to fine-tune the behaviour of this aquatic robot.
- "guizzo_wakeup": Used to prepare Guizzo for movement, this block makes the initialisation process intuitive and engaging.
- "guizzo_sleep": With this block, Guizzo's movements can be seamlessly disabled, contributing to energy efficiency and safety.
- "move_zero": This block repositions Guizzo's fin to the mid-position, simplifying its control.
- "move_forward": Designed to make Guizzo glide forward effortlessly with a single fin flick, enhancing the user's experience.

ANcybernetics uses terms reminiscent of natural actions, such as "waking up" and "sleeping," to describe complex hardware operations. This approach demystifies intricate robotics concepts and fosters an empathetic connection between users, especially K12 students, and their aquatic companion, Guizzo. Through this example, ANcybernetics showcases the transformative power of custom blocks in merging cutting-edge technology with user-friendly educational experiences.

Talking Blocks: A Proof of Concept Project

Taking inspiration from the SMART BLOCKS patent, a real-time learning assessment system based on ER kits and artificial intelligence, the Proof of Concept project "TALKING BLOCKS" aims to finalise the necessary technological and artificial intelligence developments to validate a prototype at TRL6 [29].

"TALKING BLOCKS" exploits the tremendous advantages of M5Stack technology and the flexibility of custom blocks. As highlighted in [30], M5Stack's custom blocks empower users with unparalleled freedom. This distinctive feature sets M5Stack apart from competitors like the Lego Mindstorms EV3, where various constraints and limitations can hamper custom block creation. With "TALKING BLOCKS," the possibilities for developing custom blocks are boundless, allowing maximum flexibility and adaptability in educational settings [5].

3. Implementation and Validation of ER Curricula

This chapter comprehensively explores the 'FISH curriculum,' a central educational component fundamental to the RoboPisces project. The curriculum is foundational for fostering Environmental ER in primary schools, mainly focusing on marine and underwater themes. It delves into the practical aspects of environmental ER, emphasising the implementation and validation of the innovative curriculum. Drawing from sources such as [7], the [21], [19], and personal involvement in the curriculum's development, this chapter offers a meticulous examination of the FISH curriculum's objectives, content, and its significant role in fostering environmental awareness while discovering ER among students.

3.1. First stage: mapping of educational curricula in ER

In the project's initial phase, the partners undertook a comprehensive mapping of educational curricula in robotics applied to STEAM subjects within primary schools across the participating countries, including Italy, Greece, Latvia, Croatia, Malta, and Ireland. While robotics in education is not new, it predominantly exists within non-formal educational activities. This phase uncovered significant questions regarding effectively employing robotics to cultivate specific competencies and the pedagogical principles necessary to enhance student motivation and ensure inclusivity [21].

The results of this mapping phase offer a comprehensive overview of the existing ER curricula in primary schools. The key findings highlighted several critical issues [21]:

1. The challenges of incorporating robotics activities within the constraints of compulsory educational settings necessitate dedicated lesson planning.
2. Misalignment of ER activities with compulsory curricula, often provided as extracurricular options.
3. Variation in teachers' readiness to integrate robotics into compulsory education indicates the need for further training and support.
4. Potential barriers for students, including a lack of foundational knowledge, can lead to reduced participation.
5. Practical challenges include damage to robotic kits, connectivity issues, charging problems, and equipment theft.
6. The imperative need to identify and mitigate risks associated with robotics activities within the classroom for a safe and productive learning environment is needed.

3.2. Second stage: Lesson Plans

The project's second phase was to create detailed lesson plans that are the foundation of the RoboFISH curriculum (IO3) (Figure 18). This curriculum follows a two-year educational path, encompassing various educational modules. In the initial two quarters, students are introduced to fundamental robotics concepts, while the subsequent two quarters delve into an advanced curriculum, exploring topics like IoT, 3D printing, the marine environment, and marine robotics. Each lesson in this curriculum includes comprehensive lesson plans, clearly defined learning objectives, essential training materials, engaging practical activities, and appropriate assessment methods and content [21].

These lessons were designed as an open-source training resource for primary school teachers. Since primary school teachers often have limited practical knowledge of programming and mechatronics, these lessons aim to enhance their skills and understanding of robotics [7].

In order to approach the course in the best possible way, the RoboPisces partners developed the Basic Toolkit and the Advanced Toolkit. While the former is nothing more than a collection of sensors and actuators configurable with a central unit (M5Stick C Plus), the latter, called RoboFISH [18], integrates these components into a fish-shaped shell that allows it to withstand water and swim.

However, the bio-inspired ER tool, Guizzo, discussed in a previous chapter, embodies all the features presented in these lessons, making it the optimal hardware and software tool for the training course [7].

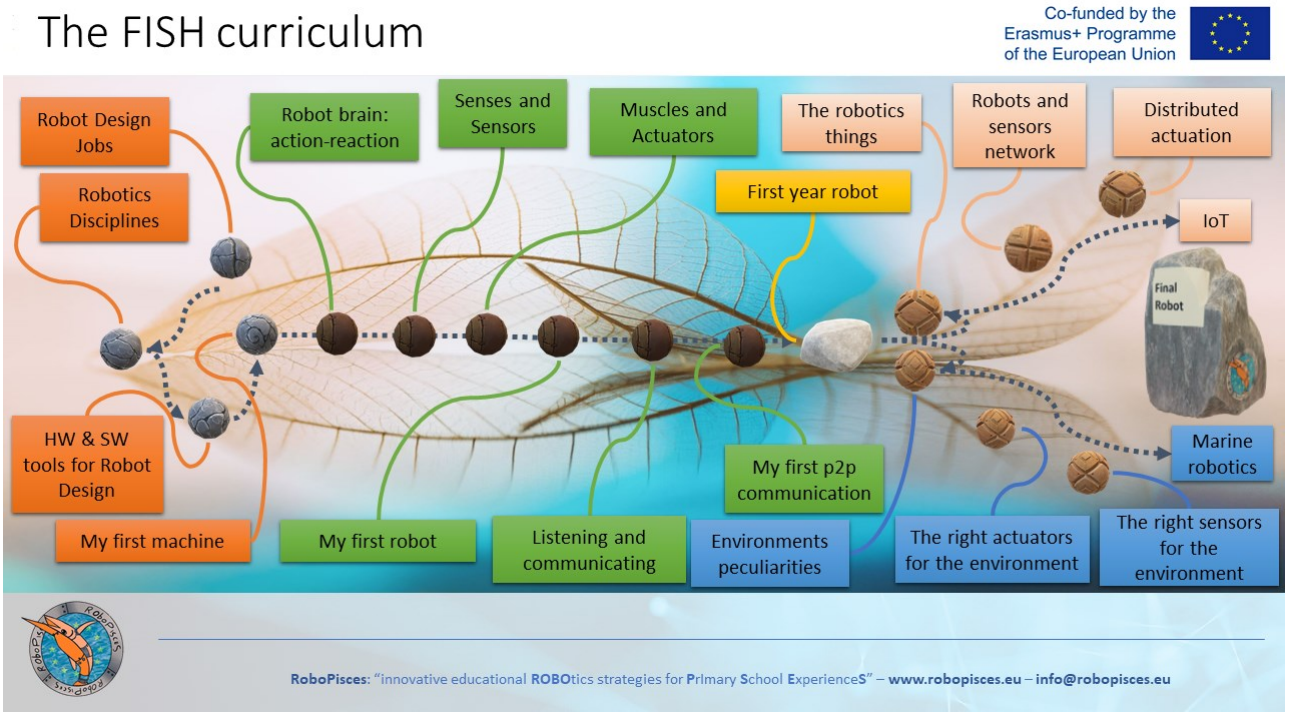


Figure 18 - The FISH curriculum

3.2.1. Basic Topics

The basic course initiates with a theoretical lesson highlighting the distinctions between robots and machines, emphasising autonomy and the capability of robots to sense their surroundings, process information, and autonomously perform various tasks. In contrast, machines lack such capabilities, typically limited to a single function. This concept forms the backbone of the curriculum and is thoroughly explored throughout the lessons and workshops. The practical part of this lesson encourages teachers to organise a contest where students provide examples of machines and robots from their daily experiences [7].

The second lesson delves into the role of a roboticist, introducing teachers to the various engineering skills required for designing, fabricating, programming, repairing, and retiring robotic systems while minimising their environmental impact. This practical session employs role-playing games that teachers can subsequently introduce to primary students to demonstrate how engineering skills interact when designing a new robot [7].

The third class involves a three-module session dedicated to the functional blocks introduced in the first lesson [7]: sensors, actuators, and controllers. The teachers gain hands-on experience with coding by using

UIFlow, which allows them to create projects by dragging and dropping code blocks. In the practical session, teachers are assigned several tasks and exercises to practice standard coding features.

The second lesson of the three-module session is dedicated to sensors, focusing on exteroceptive and proprioceptive sensors and their similarities to human perceptions. In the practical session, teachers are tasked with implementing code to measure a specific device's attitude through its Inertial Measurement Unit.

The final lesson of this module focuses on actuators, explaining their roles and similarities with human being muscles and introducing teachers to the concept of motor drives. In the practical session, teachers learn how to connect boards with the servo drive, developing a code to generate servo oscillations which mimic the movement of a caudal fin of a fish.

3.2.2. Advanced Topics

The advanced course begins with a critical lesson on ocean literacy, emphasising the importance of preserving the aquatic environment, the role of water for life sustainability, and its impact on modern society [7]. This session introduces teachers to the seven principles of Ocean literacy and highlights the significance of cultural heritage preservation, drawing attention to the hidden treasures and mysteries of the ocean.

The second advanced class marks the commencement of physics-dedicated sessions, focusing on fluid statics and static equilibrium in the aquatic environment. Teachers will have an introduction to Archimedes' principle and stable conditions of equilibrium during immersion in a liquid. In the practical session, teachers conduct experiments to help students practice buoyancy [7].

The second physics-dedicated lesson explores fluid mechanics further by introducing the concept of dynamic equilibrium, emphasising the need for thrust to balance or overcome the drag force exerted by a fluid. The practical activity involves driving a servo embodied in a fishtail to push the robot along a planned path, allowing teachers to experience the Principle of Action and Reaction [7].

The last of the physics-dedicated lessons is a workshop that teaches teachers how to organise a speed race [7], challenging students to program the toolkit to cross the finish line quickly and providing an engaging application of their knowledge.

Lessons on IoT concepts build on the communication lessons from the Basic course. The first lesson introduces the concept of smart things, how they can connect to other smart things, and the real-world applications of these devices. It aims to raise curiosity about the technology devices that support various aspects of modern human life [7]. The second lesson on IoT explains how to send messages between more than two smart things, with hands-on activities gradually leading to the creating of a sensor network. For the final hands-on activity, teachers explore the basics of Control System Theory, covering dynamic systems, open-loop control, and closed-loop control.

3.3. Third stage: Assessment tools

The project's third stage centred around developing assessment tools within the RoboPisces Educational Curriculum (IO3). The design of these tools helps evaluate students who have actively engaged with the curriculum or the KIT after the project's conclusion [21].

The Basic Toolkit includes a variety of evaluation tools. Online questionnaires, implemented through Kahoot!, a game-based learning platform that allows students to learn engagingly and interactively [31], facilitate interactive assessment and are available in four languages: Italian, English, Croatian, and Greek. These questionnaires are supplemented by a list of correct answers, which aids teachers in conducting effective evaluations.

In contrast, the Advanced Toolkit features an immersive online escape game constructed using Genially, an interactive content creation platform that allows users to create engaging presentations, infographics, and other types of content [32]. This assessment tool, available in the same four languages, offers an innovative approach to student evaluation. It is accompanied by a list of correct answers to facilitate the assessment process.

3.4. Fourth stage: Evaluation

The evaluation of project modules and resources played a pivotal role in gauging the effectiveness of the implemented strategies in educational institutions. A comprehensive validation plan was formulated, encompassing assessments from both teachers and students.

Teachers' feedback was collected through two distinct questionnaires: "BEFORE" and "AFTER." The "BEFORE" questionnaire was administered before commencing school activities, while the "AFTER" questionnaire was distributed upon concluding the implementation phase. Students' assessments occurred during the implementation phase, following the completion of each module. These evaluations took the form of Kahoot! Quizzes for the Basic Toolkit and Genially escape room challenges for the Advanced Toolkit [21].

A mixed-method approach was adopted to ascertain the alignment of instructional strategies with project objectives. Data collection and triangulation were employed to validate activities and assess learning outcomes. The research model and evaluation tools developed during this project can be readily applied in diverse contexts to evaluate outcomes, including increased student motivation, enhanced attitudes toward learning, and improved behavioural and problem-solving skills [21].

The outcomes of this evaluation underscore the achievement of initial project goals, as indicated by several critical indicators:

- Improvement of students' interest, participation, and motivation in STEAM subjects.
- Development of digital competence, rational thinking, creativity, and innovativeness through a simple approach to robotics.
- Promotion of technology and robotics in the partner schools as transversal components of the school curricula.
- Enhancement of primary school teachers' skills and comprehension in the field of robotics.
- Creation of a transnational learning and sharing environment for teachers.

3.5. Fifth stage: The RoboPisces educational curriculum

Following the validation of the curriculum, a comprehensive inventory of educational activities was compiled, aimed at providing teachers with essential materials for the curriculum's implementation within schools. This

inventory consists of two distinct sections: the Basic Curriculum Manual and the Advanced Curriculum Manual.

The Basic and Advanced Curriculum Manual encompasses educational materials tailored explicitly for implementing fundamental activities associated with the basic and advanced curriculum. These materials include lesson plans and assessment resources to support teachers' teaching endeavours and offer teachers a structured instruction framework [21]. While the basic curriculum follows an ideal sequence of fundamental activities, the advanced curriculum is instead organised following sequential learning scenarios.

4. Case study and results

In this chapter, attention turns to Istituto Comprensivo Giannuario Solari in Loreto, Italy, where (in 2021) a non-formal implementation of environmental ER took the form of a summer camp catering to 25 students aged 10 to 13, as outlined in [7]. The forthcoming discussion will centre on the results and implications emerging from this validation process, presenting tangible evidence of the practical utility of the FISH curriculum and its potential to revolutionise educational methodologies within environmental education.

The results will be commented on by thoroughly analysing pre- and post-camp assessments. These assessments are instrumental in gauging the effectiveness of the FISH curriculum and its potential to reshape traditional environmental education approaches.

The ensuing account will provide a nuanced examination of the experiential journey, shedding light on how these curricula play a pivotal role in moulding the forthcoming generation of environmentally conscious individuals.

Finally, the chapter will introduce future developments, shedding light on the innovative RoboAquaria project. This project aims to further expand the potential of ER in school curricula, particularly in environmental education, building upon the achievements of RoboPisces.

4.1. Healthy Life One

In August 2021, a pilot project was conducted at Istituto Comprensivo Giannuario Solari in Loreto, Italy, to assess the effectiveness of the Toolkits and activities. With the collaboration of the school's staff, 25 students aged 10 to 13 participated in this unique summer camp experience, where they had the opportunity to engage in non-formal activities focusing on robotics and sustainability [7]. Over six days, for 5 hours a day, the students benefited from the school's facilities (Table 1).

This educational program was designed to integrate various components of the FISH curriculum (Figure 18), utilising both the "Basic Toolkit" and the "Advanced Toolkit" developed as part of the RoboPisces Course (discussed in chapter 2.5.7).

Table 1 - Healthy Life One educational program

Day	Topics	Tool
1	The robotic disciplines The robotics jobs The Hardware and Software tools for robot design	Basic Toolkit
2	My first machine The robot brain	Basic Toolkit

Day	Topics	Tool
3	Senses and Sensors Muscles and actuators Environments peculiarities	Basic Toolkit
4	Marine robotics	Advanced Toolkit
5	Sustainability	Advanced Toolkit
6	Sharing the lesson learnt	Basic Toolkit and Advanced Toolkit

During the initial three days, the students delved into the fundamentals of robotics, leveraging the Basic Toolkit to create an intelligent system capable of measuring the humidity of different foods. This exploration aimed to emphasise the critical role of water in plant growth and food production (Figure 19).

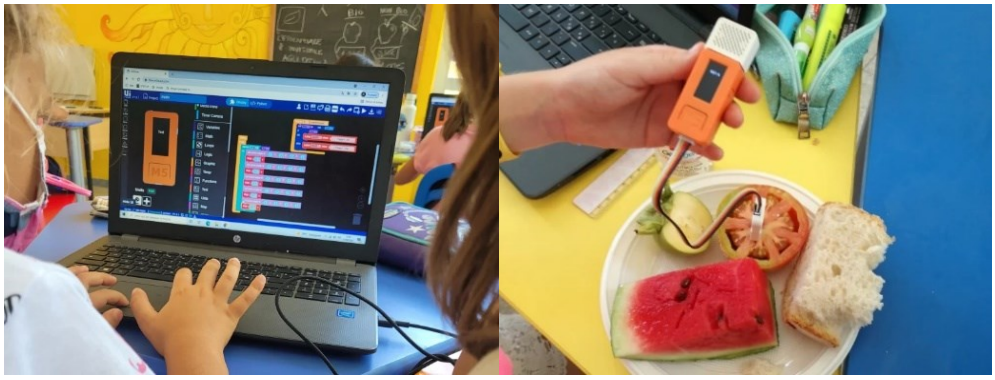


Figure 19 - Coding activity (left) and measurement of humidity food (right)

In the second part of the camp, the students ventured into the world of marine robotics and environmental education, guided by the Advanced Toolkit (the RoboFISH). They engaged in hands-on activities to grasp the concept of "buoyancy" and understand fundamental principles (Figure 20). These tinkering exercises introduced key concepts and allowed for personalisation and enhancement of the toolkit [7]. In a visually engaging session, students actively participated in a swim activity, utilising the Advanced Toolkit within a water tank (Figure 21).



Figure 20 - Workshop activity on "buoyancy" with custom aluminium vessels



Figure 21 - Marine robotics activity with the Advanced Toolkit

An integral component of the camp's conclusion involved students sharing stories they had created using the fish robot and various materials. This storytelling activity consolidated their knowledge and skills, applying the principles of social constructivism [33] while fostering connections between robotics and sustainability. These hands-on experiences underscore the potential of the FISH curriculum and its real-world impact on students' environmental awareness and knowledge (Figure 22).



Figure 22 - Story telling activity

Indeed, a carefully structured schedule was followed each day during the summer camp to ensure a well-rounded educational experience for the students. The activities were thoughtfully alternated, including theoretical lessons, games, workshops, and coding activities. This approach aimed to keep the students engaged and foster cross-curricular learning on each topic. It enhanced their understanding and promoted a dynamic and interactive learning environment.

4.2. Assessment

As previously highlighted in this thesis, a two-phase assessment was undertaken, emphasizing the paramount significance of evaluating ER activities. Before commencing the activities, students participated in a baseline assessment (BL), and after the activities concluded, a post-test assessment (PT) was administered. During both phases, the students were asked to complete a brief questionnaire to gauge their interest, self-efficacy in robotics [34], and engagement with sustainability themes. This thorough evaluation process was pivotal in discerning the enjoyment derived from the activities and the effectiveness of integrating the new educational marine robot in heightening their awareness of environmental issues and sustainability [7]. A comprehensive breakdown of the questionnaire items and the dimensions they explored is presented in Table 2.

Table 2 - Baseline (BL) and post-test (PT) assessment questionnaire with the possible response options and the dimensions analysed with each question.

BL	PT	Response option/s	Dimension
What do you expect from this experience? (BL1)	Now the experience is over, you think you did… (**PT1**)	carry out fun activities; study; learn by doing	Motivation
You think that this experience will be engaging and fun. (BL4)	This experience was engaging and fun. (**PT4**)	Disagree; Somehow Agree; Agree; Strongly Agree	Overall satisfaction
It will be easy to use the robotic devices. (BL6)	It was easy to work with the toolkit. (**PT5**)	Disagree; Somehow Agree; Agree; Strongly Agree	Self-efficacy
You chose to participate in this lab because… (BL3)		Out of curiosity; I like Robotics; I will improve the way I deal with Robotics	Motivation
What would you like to do with the things you will learn at the course? (BL10)	What would you like to do with the things you learnt at the course? (**PT7**)	Free text (recorded after the main themes of the responses)	Interest in sustainability
	What did you like the most during the activities? (**PT3**)	work with the toolkit; having fun while working; programming using code blocks	Overall satisfaction

4.3. Results

The answers and, thus, the results of the questions in Table 2 are analysed below.

Figure 23 illustrates the distribution of student responses concerning their perceptions before and after the course. Comparing the results of BL1 and PT1, it is evident that students initially displayed a higher inclination towards the fun factor (70%) rather than prioritizing the acquisition of new knowledge (3%) or learning through practical engagement (27%). However, by the end of the course, this trend had shifted, with more students expressing an appreciation for the course's value and the knowledge they had gained (38 compared to the initial 30). This tendency is complemented by a significant increase in students who reported acquiring

new knowledge during the course (60%, up from the initial 3%). These findings underscore how such experiences, which incorporate enjoyable and engaging activities, can have a profound cross-disciplinary impact on students' competencies and knowledge.

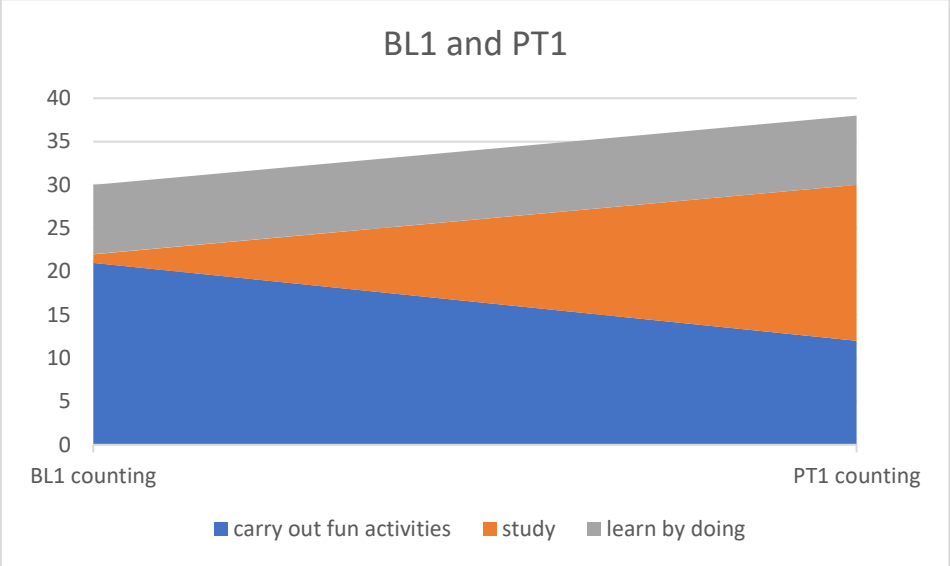


Figure 23 - Counting and distribution of BL1 and PT1 preferences

Furthermore, most students found the activities fun and engaging before and after the summer camp (88%). The questionnaire results for PT4 and BL4 affirm that robotics activities were already perceived as enjoyable and engaging even before the camp began, with the same percentage of students agreeing or strongly agreeing about their fun and engaging nature after completing the program, as depicted in Figure 24.

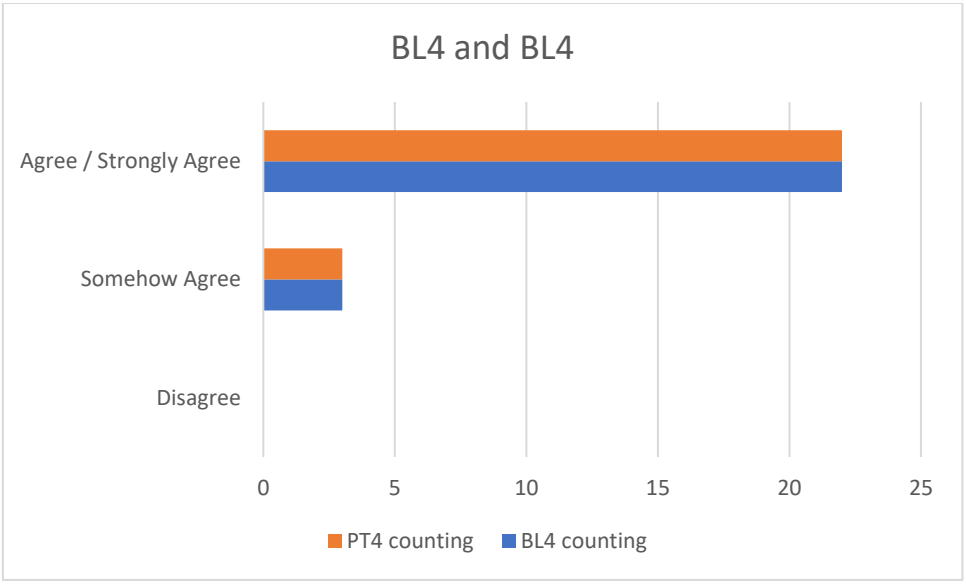


Figure 24 - Comparison of responses to BL4 and PT4

The students' perception of the ease of robotics increased from the beginning to the end of the camp (from 40% to 68%). As indicated by the comparison between BL6 and PT5, this percentage increase reflects students' growing self-efficacy and the successful transfer of knowledge from educators to students, as visually represented in the graph shown in Figure 25.

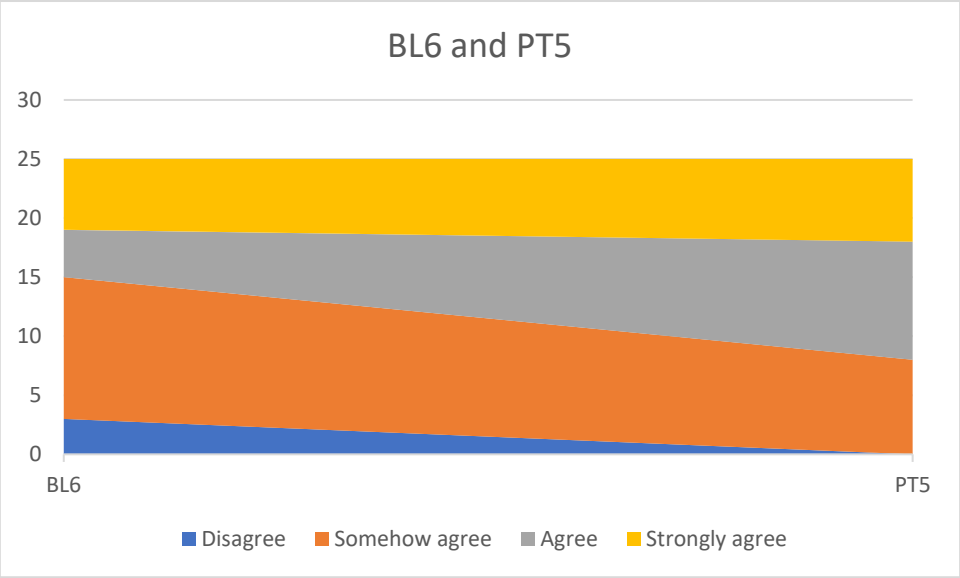


Figure 25 - Variation in the distribution of perceived ease of use of robotics before (BL6) and after (PT5) the course

Initially, students displayed a strong interest in technology (80%). However, by the end of the course, their focus had evolved towards the practical applications of robotics, with a prominent emphasis on environmental themes (60%), often referencing the RoboFISH (28%). This transformation is vividly illustrated by comparing responses to questions BL10 and PT7, which can be observed in Figure 26. Moreover, students' written feedback revealed their pre-existing experience with diverse media and devices, encompassing activities such as enhancing YouTube videos, inventing apps, creating videos, and utilizing 3D printers. Following their participation in the summer camp activities, students distinctly redirected their attention from the intrinsic aspects of technology to its potential real-world applications and impacts.

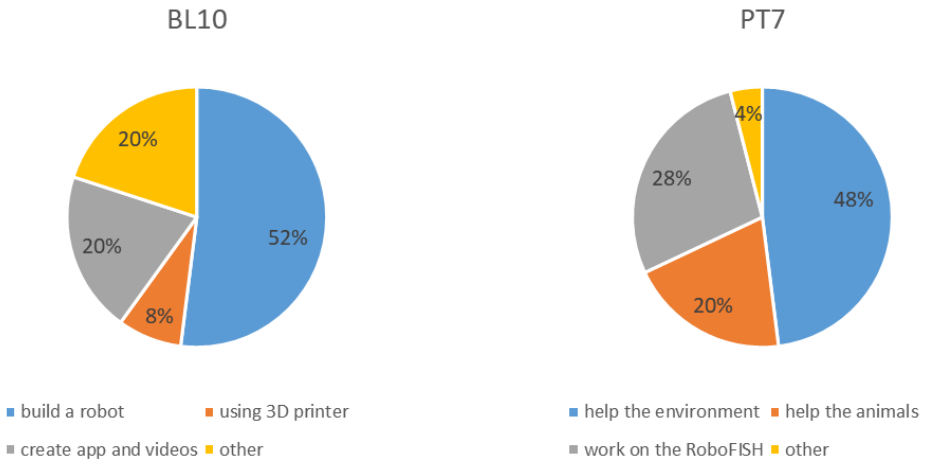


Figure 26 - Comparison of filtered open-ended responses of BL10 and PT7

In conclusion, by the end of the course, students expressed particular fascination with using the toolkits (51%). This result suggests that robotics activities conducted in groups involving role division, assembly, and validation of solutions created by the students were perceived as the most stimulating and inclusive phases, defined as active participation in resolving the challenges presented during the course. The pie chart of responses to question PT3 is displayed in Figure 27.

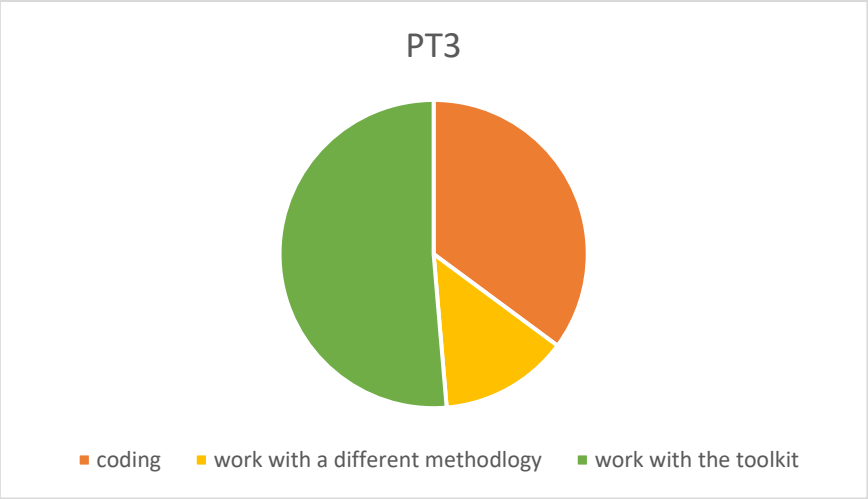


Figure 27 - Pie chart of PT3 responses

The fish robot, in particular, seemed to capture students' curiosity. When asked what they liked most about the camp, students cited working with the toolkit (51%), programming (35%), and experiencing a different methodology compared to what they were accustomed to at school (14%), as shown in Figure 27. These findings collectively highlight the positive impact of the educational summer camp on the students' perception, skills, and engagement in the realm of robotics and sustainability.

4.4. Future Developments: RoboAquaria

The RoboAquaria project builds upon the successes of RoboPisces, refining the experimental approach and seamlessly integrating environmental education into school curricula. It aims to democratize access to ER tools, supported by digital technologies, to address the climate crisis and promote sustainable behaviours within school communities using educational aquatic robots.

Aligned with the priorities of "Environment and the Fight Against Climate Change" and "Addressing Digital Transformation Through the Development of Digital Readiness, Resilience, and Capacity," the project consortium includes universities (Università Politecnica delle Marche - Coordinator, University of Aegean, University of Zagreb), educational and research centres (CARDET, Future in Perspective, INNOVADE, ANcybernetics), and schools (IC Solari, Primary School Osnovna škola Tituša Brezovačkog, ICS Largo Cocconi) [35].

The project will produce:

- A Methodological Framework for the Pilots, Guidelines for Teachers, and Validation: A report outlining pedagogical approaches for sustainability competencies.
- Toolkits and Lesson Topics: Guidelines for constructing the Roboaquarium and implementing a curriculum.
- E-Learning Platform and Open Educational Resources (OERs): A digital space with free pedagogical resources and augmented reality tools.
- Policy Recommendations: Lessons learned, best practices, challenges, and policy suggestions.

Additionally, both physical and digital toolkits will be provided to teachers, making the course experience more accessible and democratic, enabling classes to perform the same activities without physical toolkits. In summary, RoboAquaria is a proactive step towards nurturing environmentally conscious and technologically adept individuals, emphasizing the intersection of environmental education, robotics, and digital literacy, all vital in today's ever-changing world.

Conclusions

This research delves into a comprehensive exploration of the multifaceted impact of software in ER activities. ER represents an exciting intersection of pedagogy, psychology, and robotics. Integrating software in ER can revolutionize education by empowering students with innovative learning experiences and cultivating a broad range of skills. A mixed-method approach that combines various research methodologies is employed to investigate the transformative power of software in ER. These methodologies include literature reviews, surveys, case studies, and assessments.

The journey commences with an in-depth literature review, which serves as the foundational pillar of this research. The literature review demonstrates that ER is a multidisciplinary approach that combines robotics, pedagogy, and psychology. Designed to empower students with diverse skills and foster authentic learning experiences, ER incorporates robotics, hardware and software and integrates STEM (Science, Technology, Engineering, and Mathematics) subjects. This integration offers a unique opportunity for students to engage in hands-on educational activities that develop their problem-solving abilities, creativity, and teamwork. Furthermore, ER plays a pivotal role in cultivating rational thinking, creativity, and computational thinking, essential skills for success in the modern world.

One of the remarkable aspects of ER is its potential to promote inclusive education. It plays a critical role in breaking down gender stereotypes by involving students in technology-related activities from a young age. As a result, ER contributes to nurturing an environment where all students can explore technology and science, regardless of gender. This fusion of technology, science, engineering, and environmental education creates a potent synergy. This synergy has the potential to imbue students with a strong sense of environmental awareness, an indispensable asset in confronting the sustainability challenges that lie ahead.

Moving beyond the theoretical foundation, integrating ER into formal education encounters various challenges. These obstacles include a lack of teacher training, limited resources, and the need for reliable assessment methods. ER's innovative and creative nature can sometimes clash with traditional educational structures, necessitating collaboration between educators, policymakers, and other stakeholders. The successful integration of ER into education hinges on finding innovative ways to harmonize these innovative approaches with existing educational frameworks.

To holistically assess the impact of software in ER, amalgamating Massive Open Online Courses (MOOCs) and Learning Management Systems like Moodle is crucial. MOOCs provide a platform where diverse course materials are accessible, fostering global interactions among students and instructors. Simultaneously, Moodle offers educators a versatile platform for creating and managing interactive e-learning experiences. This combination enhances personalization in education and improves evaluation and assessment methods, thanks to integrating AI-powered tools.

The E-Tech eBook, emerging as an essential resource in this exploration, equips educators with knowledge and strategies, particularly in STEM fields. This resource guides teachers in creating practical online courses, offering insights into online teaching, content creation, and technological innovations. By leveraging the expertise embedded within the E-Tech eBook, educators can enhance their online teaching skills and craft engaging e-learning experiences, enriching the overall educational experience for students.

International collaboration is paramount in exploring innovative technologies and methodologies within education. The RoboPisces project illustrates the potential of collaborative initiatives in reshaping primary education. This project offers a standardized curriculum introducing ER and STEM skills to primary education. RoboPisces promotes a more uniform, widespread dissemination of innovative methodologies and teacher resources by fostering transnational collaboration among academic institutions and primary schools. This approach empowers educators to effectively integrate ER and Marine Robotics curricula into the K-12 education pathway. Furthermore, it addresses student engagement, digital competence, teacher skills, and assessment tools. The RoboPisces project exemplifies how collaborative efforts can transform primary education by providing comprehensive solutions to modernize and enrich the learning experience for young students.

Delving deeper into the hardware domain, an extensive array of commercial tools and robots has emerged to support the field of ER. These tools cater to students of different age groups and learning environments, enhancing STEM education and problem-solving skills. They offer a range of programming languages and assembly options, allowing educators to select the most suitable tools for ER activities based on curriculum objectives and educational contexts. This diversity in available tools makes it possible for ER to be adaptable to various learning environments and infrastructural capabilities.

In hardware and software, technologies like M5Stack and UIFlow simplify access to ER. They streamline hardware setup and coding processes, making ER more inclusive and engaging. M5Stack's user-friendly ecosystem eliminates cost barriers, while UIFlow's Blockly-based interface simplifies coding. Custom blocks further enhance the user-friendliness and possibilities of use of these technologies, democratizing ER by simplifying both hardware and software components. This simplification is a significant step toward making ER accessible to a broader audience.

Throughout the research journey, various facets of ER have been explored. As part of the exploration, implementation and validation of the FISH curriculum, an integral component of the RoboPisces project aimed at promoting Marine ER in primary schools, progressed through various phases. These phases encompassed an analysis of existing curricula, the creation of comprehensive lesson plans, innovative assessment tools, and a mixed-method evaluation. The outcomes observed are noteworthy, including a remarkable increase in student interest in STEAM subjects and the simultaneous enhancement of teacher skills. These findings underscore the systematic implementation and validation of the FISH curriculum, emphasizing its pivotal role in primary school education and its broader implications in ER.

The case study at Istituto Comprensivo Giannuario Solari in Loreto, Italy, validates the FISH curriculum and its potential to transform traditional ER. Through pre- and post-camp assessments, tangible evidence of the curriculum's effectiveness is obtained. The assessments shed light on students' motivation, self-efficacy in robotics, and engagement with sustainability themes. This case study vividly illustrates how the FISH curriculum significantly influenced students' perspectives and learning experiences. Initially inclined toward the fun factor, students began to prioritize knowledge acquisition and practical engagement by the end of the camp. This shift in perspective demonstrates the power of integrating ER within the educational framework.

The research also looks toward the future with the RoboAquaria project. The project aims to build upon the successes of RoboPisces, focusing on addressing the climate crisis and promoting sustainable behaviours using educational aquatic robots. The project emphasizes developing physical and digital ER toolkits to make ER experiences more accessible and inclusive across diverse educational settings. This commitment to

innovation and accessibility underscores the continued evolution of ER and its potential to have a transformative impact on education.

In conclusion, this research underscores software's profound and multifaceted impact on ER. Beyond its role in providing innovative student learning experiences, software is a transformative force that benefits educational institutions and teachers alike. Educational institutions can harness software to manage and deliver e-learning courses effectively, thus broadening their reach and ensuring flexibility in education. Furthermore, the software's capacity for assessing and evaluating ER activities, both before, during, and after their implementation, empowers educators to tailor their approach and enhance the learning journey for students. Software, when thoughtfully integrated into ER activities, fosters inclusivity, as it opens doors for students of diverse backgrounds and learning preferences. This inclusivity is pivotal in addressing the evolving landscape of education, where tailored and adaptable learning experiences are paramount. In this regard, the value of software extends to nurturing environmental awareness and promoting sustainability, preparing the next generation to tackle the challenges and opportunities of the modern world effectively. This research journey serves as an advocate for collaborative efforts and innovative initiatives in the field of ER. Moreover, it strongly advocates for the democratization of ER, making it more accessible and engaging across diverse educational settings. Placing software at the forefront of this transformation contributes to realising more effective and inclusive educational strategies for students, educational institutions, and educators worldwide.

List of Images

Figure 1 - RoboPisces Basic Toolkit ____ 29

Figure 2 - RoboPisces Advanced Toolkit (RoboFISH) ____ 29

Figure 3 - Guizzo (Bio-inspired Educational Robot) ____ 30

Figure 4 - UIFlow IDE ____ 33

Figure 5 - Project name field ____ 33

Figure 6 - Blockly</>Python switch ____ 33

Figure 7 - Units and Hats manager ____ 34

Figure 8 - UI Manager and Preview ____ 34

Figure 9 - Coding area ____ 35

Figure 10 - Code blocks menu ____ 35

Figure 11 - Menu tab ____ 36

Figure 12 - An example of unconnected blocks (left) and correctly connected blocks (right) on UIFlow. ____ 36

Figure 13 - Block Maker in UIFlow IDE ____ 37

Figure 14 - An example of a block of type "Value" (left) and "Execute" (right) ____ 37

Figure 15 - Block Maker's U ____ 38

Figure 16 - Custom blocks in UIFlow IDE ____ 39

Figure 17 - Guizzo's custom blocks ____ 39

Figure 18 - The FISH curriculum ____ 42

Figure 19 - Coding activity (left) and measurement of humidity food (right) ____ 47

Figure 20 - Workshop activity on "buoyancy" with custom aluminium vessels ____ 47

Figure 21 - Marine robotics activity with the Advanced Toolkit ____ 48

Figure 22 - Story telling activity ____ 48

Figure 23 - Counting and distribution of BL1 and PT1 preferences ____ 50

Figure 24 - Comparison of responses to BL4 and PT4 ____ 50

Figure 25 - Variation in the distribution of perceived ease of use of robotics before (BL6) and after (PT5) the course ____ 51

Figure 26 - Comparison of filtered open-ended responses of BL10 and PT7 _____ 51

Figure 27 - Pie chart of PT3 responses _____ 52

List of Tables

Table 1 - Healthy Life One educational program _____ 46

Table 2 - Baseline (BL) and post-test (PT) assessment questionnaire with the possible response options and the dimensions analysed with each question. _____ 49

Bibliography

[1] D. Scaradozzi, L. Screpanti and L. Cesaretti, "Towards a Definition of Educational Robotics: A Classification of Tools, Experiences and Assessments,", Jun 29, pp. 63-92.

[2] D. Scaradozzi, L. Cesaretti, L. Screpanti, D. Costa, S. Zingaretti and M. Valzano, "Innovative Tools for Teaching Marine Robotics, IoT and Control Strategies Since the Primary School,", Jun 29, pp. 199-227.

[3] L. Daniela and M.D. Lytras, "Educational Robotics for Inclusive Education," *Tech Know Learn*, vol. 24, no. 2, Jun 1, pp. 219-225.

[4] S. Kucuk and B. Sisman, "Students' attitudes towards robotics and STEM: Differences based on gender and robotics experience," *International Journal of Child-Computer Interaction*, vol. 23-24, Jun, pp. 100167.

[5] L. Screpanti, D. Scaradozzi, R.N. Gulesin and N. Ciuccoli, "Control Engineering and Robotics since Primary School: an Infrastructure for creating the Digital Twin model of the Learning Class," *IFAC-PapersOnLine*, vol. 55, no. 17, pp. 267-272.

[6] United Nations, "The 17 goals | sustainable development," https://sdgs.un.org/goals (accessed Oct. 16, 2023).

[7] D. Costa, L. Screpanti and D. Scaradozzi, "Disseminating STEM Subjects and Ocean Literacy through a Bioinspired Toolkit," *Biomimetics (Basel, Switzerland)*, vol. 8, no. 2, Apr 17, pp. 161.

[8] Wikipedia contributors, "Robot ethics," Wikipedia, https://en.wikipedia.org/wiki/Robot_ethics (accessed Oct. 16, 2023).

[9] D. Scaradozzi, L. Cesaretti, L. Screpanti and E. Mangina, "Identification and Assessment of Educational Experiences: Utilizing Data Mining With Robotics," *MRA*, vol. 28, no. 4, Dec, pp. 103-113.

[10] B.K. Maigaard Kjar Pedersen, B. Charlotte Weigelin, J.C. Larsen and J. Nielsen, "Using educational robotics to foster girls' interest in STEM: A systematic review," *RO-MAN*, pp. 865-872.

[11] E. Mangina, G. Psyrra, L. Screpanti and D. Scaradozzi, "Robotics in the Context of Primary and Pre-School Education: A Scoping Review," *IEEE transactions on learning technologies*, pp. 1-10.

[12] Moodle.org, "Moodle - open-source learning platform," https://moodle.org/ (accessed Oct. 16, 2023).

[13] Wikipedia contributors, "Massive open online course," Wikipedia, https://en.wikipedia.org/w/index.php?title=Massive_open_online_course&oldid=1171690342.+Accessed+October+9%2C+2023 (accessed Oct. 16, 2023).

[14] Mooc.org, "Learn about moocs - massive open online courses: An EDX site," https://www.mooc.org/about-moocs (accessed Oct. 16, 2023).

[15] E-Tech Project, "The Big Book of Online Education", https://www.etechproject.com/wp-content/uploads/2023/09/E-tech-ebook_26.09.23.pdf, (accessed Oct. 16, 2023).

[16] E-Tech Poject, "E-Tech: About the project", https://www.etechproject.com/about-the-project/ (accessed Oct. 16, 2023).

[17] RoboPisces, “RoboPisces project,” https://www.robopisces.eu/ (accessed Oct. 16, 2023).

[18] RoboPisces, “RP Advanced Toolkit,” https://www.robopisces.eu/robofish-advanced-toolkit/ (accessed Oct. 16, 2023).

[19] RoboPisces, “RoboPisces MOOC,” https://www.robopisces.eu/robopisces-mooc/ (accessed Oct. 16, 2023).

[20] RoboPisces, “RP Basic Toolkit,” https://www.robopisces.eu/robofish-basic-toolkit/ (accessed Oct. 16, 2023).

[21] RoboPisces, “RoboPisces Intellectual Output 3 (IO3),” https://www.robopisces.eu/io3/ (accessed Oct. 16, 2023).

[22] RoboPisces, “RoboPisces Intellectual Output 4 (IO4),” https://www.robopisces.eu/io4/ (accessed Oct. 16, 2023).

[23] M5Stack Technology Co., Ltd., “Modular Rapid ESP32 IOT Development Board - ESP32 dev kits,” m5stack, https://m5stack.com/about-us (accessed Oct. 16, 2023).

[24] M5Stack Technology Co., Ltd., “M5StickC plus ESP32-Pico Mini IOT Development Kit,” m5stack, https://shop.m5stack.com/products/m5stickc-plus-esp32-pico-mini-iot-development-kit (accessed Oct. 16, 2023).

[25] Google, “Blockly | google for developers,” https://developers.google.com/blockly (accessed Oct. 16, 2023).

[26] Wikipedia contributors, “Blockly,” Wikipedia, https://en.wikipedia.org/w/index.php?title=Blockly&oldid=1158892179 (accessed Oct. 16, 2023).

[27] M5Stack Technology Co., Ltd., “Modular Rapid ESP32 IOT Development Board - ESP32 dev kits,” https://m5stack.com/uiflow (accessed Oct. 16, 2023).

[28] George Robotics Limited, “MicroPython,” Python for microcontrollers, https://micropython.org/ (accessed Oct. 16, 2023).

[29] UNIVPM, “Programma proof of concept (POC) faster,” https://www.univpm.it/Entra/Ricerca/Universita_e_Impresa/PoC_FASTER/Programma_FASTER/Progetto_TALKING_BLOCKS_-_FASTER (accessed Oct. 16, 2023).

[30] R. N. Gulesin, “Strumenti di Robotica Educativa per l’Identificazione e la Modellazione dell’Apprendimento", B.S.E. thesis, Università Politecnica delle Marche, Italy, 2021.

[31] Kahoot!, https://kahoot.it/ (accessed Oct. 16, 2023).

[32] Genial.ly, “Genially, the platform for interactive animated content”, https://genial.ly/ (accessed Oct. 16, 2023).

[33] M. Cole, "Mind in society: the development of higher psychological processes," 1978.

[34] A. Bandura, "Self-efficacy: Toward a unifying theory of behavioral change," *Psychological review*, vol. 84, no. 2, Mar, pp. 191-215.

[35] Roboaquaria, https://roboaquaria-project.eu/ (accessed Oct. 16, 2023).

Acknowledgements

I begin these acknowledgements by reflecting on what this thesis represents. It not only marks the conclusion of a course of study that will culminate in the attainment of a degree but also symbolizes the end of a significant chapter in my life. These years have been filled with discoveries, learning, and growth, often overlapping with the extraordinary challenge of the pandemic. In this journey, I have faced numerous difficulties, alternating between demanding periods and frenetic phases, often punctuated by first-time experiences. Despite being marked by exceptional circumstances, I could have never imagined that this academic path would contribute so profoundly to my personal growth, as well as provide a solid foundation for my future academic and professional career.

I often contemplate the concept of opportunity, considering how it frequently arises from the intersection of my personal research desires and the presentation of specific possibilities. While the former element of this duo falls within my will and ambition, the latter often remains beyond my control. Therefore, as this journey and the results achieved over the years represent an extraordinary opportunity for growth, it is only fitting that I express my gratitude to those who have made these opportunities accessible.

My first and most heartfelt thanks go to my thesis advisor, Professor Scaradozzi, for his trust from the very beginning, his invaluable guidance, and the sharing of a wide range of advice, experiences, and knowledge over the years. It has been an honour to collaborate with a professor of his calibre and to contribute, even in part, to the research conducted by the laboratory.

I express my gratitude to my co-advisors, Dr Screpanti and Dr Costa, for supporting me from the outset, inspiring me with their deep knowledge and expertise, and passionately sharing the cause of their work.

I also thank Professor Gatti for the collaboration within ANcybernetics. His generous sharing of knowledge has significantly enriched the skills I have developed during my course of study.

I extend my appreciation to LabMACS, from the colleagues with whom I shared my first day to all the students and researchers with whom I had the opportunity to collaborate over the years. Your invaluable contributions have greatly enriched my knowledge and experiences. You have been a constant source of support and joy in all the days we spent together.

In my pursuit of opportunities and the associated goals, I have learned that willpower alone is not sufficient. It is essential to maintain a delicate balance between my search and the offering of opportunities. In this journey, I have been fortunate to be surrounded by many people who have always believed in me without ever judging me or making me feel out of place, even in the most challenging moments.

Among my colleagues, to whom I am deeply grateful, I would like to express my sincere thanks to Dr. Bartolucci. She has been an invaluable support in these long years of collaboration, offering not only her academic support but also her human warmth. Her kindness, tireless altruism, and high professionalism have always illuminated our daily work.

I was genuinely surprised to discover a person with so much enthusiasm and determination. Over the past demanding months, I have had the privilege of sharing moments of my life and my academic journey with Dr. Castagna, and this experience has changed my perspective. I would like to thank her for her remarkable

sensitivity, for always being ready to offer her support when needed, and for the positive and never-harmful ambition she shares.

Special thanks go to my mother, my father, Costanza, and Andrea, who have supported me consistently. Although they had to postpone an important goal and investment in my education, they have never made me feel left behind. Thank you for the unconditional trust you have placed in me, for believing in my abilities, and for supporting all the choices I have made over time, even when they were difficult and went beyond everyday conventions. Thank you for understanding my highs and lows, periods of exhaustion, and moments of isolation that I have faced in the most challenging times. You have consistently been an example of commitment, dedication, and seriousness, both in your public and private lives. I hope that this achievement can be a source of personal pride for all of us.

I extend these warm wishes to all my loved ones, including my relatives and my dear grandparents. Over the years, you have consistently shown deep trust in me, supporting my choices and goals. Thank you from the bottom of my heart for the affection you have always shown me and for your understanding, even in times when I may not have been as present as I would have liked.

Special thanks to all my friends and the dearest people with whom I have shared, even if only for a brief moment, this long journey. Thank you for always showing me genuine affection and for accepting and appreciating me unconditionally. I deeply appreciate the fact that you have never negatively judged the unconventional choices I have made in life. On the contrary, you have always shown a deep appreciation and support for the bold decisions I have made over the years. I thank you for your patience in enduring my moments of difficulty when, unfortunately, my mood was affected, and above all, I am grateful for all the moments of joy, sharing, music, and love that you have brought into my life.

However, I would like to dedicate special thanks to Manuele, the person who has been closest to me in recent years. His value is immeasurable, and I have had the privilege of having his presence with me throughout this journey. I thank him for the countless days spent together, for the shared adventures, and for those we will face in the future. Manuele has always been by my side with unwavering calm, sensitivity, and patience, teaching me to be a better person. Thank you for holding my hand constantly, for the support offered even when I deserved reproach, and for accepting my occasionally insensitive and selfish nature. I thank Manuele for always believing in me, even when I had doubts about myself. Thank you for being a source of pride every time you achieve results that sometimes seem unattainable to me. Our countless discussions, debates, and conversations, often stemming from opposing perspectives, have been invaluable for personal growth. I wish him all the best for his future, and I hope to be as positive and supportive in his life as he has been in mine. I dedicate this moment in my life to Manuele, recognizing that with him, I have found the balance and support that I so greatly need.

Acknowledgements (in Italian)

Inizio questi ringraziamenti riflettendo su quanto questa tesi rappresenti. Non solo segna la conclusione di un percorso di studi che culminerà con il conseguimento di un titolo, ma simboleggia anche il termine di un importante capitolo della mia vita. Questi anni sono stati ricchi di scoperte, apprendimento e crescita, e hanno coinciso con periodi di sfide uniche, spesso sovrapposti alla straordinaria sfida della pandemia. In questo cammino, ho dovuto affrontare numerose difficoltà, alternando periodi impegnativi a fasi frenetiche, costellate di prime esperienze. Mai avrei immaginato che questo percorso accademico, seppur caratterizzato da circostanze eccezionali, avrebbe contribuito così profondamente alla mia crescita personale, oltre a fornire una solida base per la mia futura carriera accademica e professionale.

Mi soffermo frequentemente sulla nozione di opportunità, considerando come essa spesso derivi dall'intersezione tra il mio desiderio di ricerca personale e l'offerta di una specifica possibilità. Se il primo elemento di questo duo è sotto la mia volontà e ambizione, il secondo spesso sfugge al mio controllo. Pertanto, poiché questo percorso e i risultati raggiunti nel corso degli anni rappresentano un'opportunità straordinaria di crescita, ritengo doveroso esprimere la mia gratitudine a coloro che hanno reso queste possibilità accessibili.

Il mio primo e più sentito ringraziamento va al mio relatore, il Prof. Scaradozzi, per la sua fiducia fin da subito, per la sua preziosa guida, e per la condivisione di una vasta gamma di consigli, esperienze e conoscenze nel corso degli anni. È stato un onore collaborare con un professore del suo calibro e contribuire, anche se in parte, alla ricerca del laboratorio.

Ringrazio i correlatori, la Dott.ssa Screpanti e il Dott. Costa, per avermi sostenuto dall'inizio, per avermi ispirato con la loro profonda conoscenza e competenza, e per aver condiviso con passione la causa del loro lavoro.

Ringrazio il Prof. Gatti per la collaborazione all'interno di ANcybernetics. La sua generosa condivisione di conoscenze ha notevolmente arricchito le competenze che ho sviluppato durante il mio percorso di studi.

Ringrazio il LabMACS, da quei colleghi con cui ho condiviso il mio primo giorno, a tutti gli studenti e ricercatori con cui ho avuto l'opportunità di collaborare nel corso degli anni. La vostra preziosa contribuzione ha notevolmente arricchito il mio bagaglio di conoscenze ed esperienze. Siete stati un costante sostegno e fonte di gioia in tutte le giornate che abbiamo trascorso insieme.

Nella mia ricerca di opportunità e nel perseguimento degli obiettivi che ne derivano, ho imparato che la volontà da sola non è sufficiente. È essenziale mantenere un delicato equilibrio tra la mia ricerca e l'offerta di opportunità. In questo percorso, ho avuto la fortuna di essere circondato da molte persone che hanno sempre creduto in me, senza mai giudicarmi, senza mai farmi sentire fuori posto, nemmeno nei momenti più difficili.

Tra i miei colleghi di cui sono profondamente grato, vorrei esprimere la mia sincera gratitudine alla Dott.ssa Bartolucci. Lei è stata un sostegno inestimabile in questi lunghi anni di collaborazione, offrendo non solo il suo supporto accademico ma anche il suo calore umano. La sua gentilezza, il suo altruismo instancabile e la sua elevata professionalità hanno sempre illuminato il nostro lavoro quotidiano.

Sono rimasto sinceramente sorpreso nel scoprire una persona con tanto entusiasmo e determinazione. Nel corso degli ultimi impegnativi mesi, ho avuto il privilegio di condividere momenti della mia vita e il mio percorso accademico con la Dott.ssa Castagna, e questa esperienza mi ha fatto cambiare idea. Desidero ringraziarla per la sua straordinaria sensibilità, per essere stata sempre pronta ad offrire il suo sostegno quando ne avevo bisogno e per l'ambizione che condivide in modo così positivo, mai dannoso, e mai irrealistico.

Un ringraziamento speciale va a mia madre, mio padre, Costanza e Andrea, che mi hanno sostenuto costantemente. Nonostante abbiano dovuto rinviare il raggiungimento di un importante obiettivo e investimento nella mia istruzione, non mi hanno mai fatto sentire indietro. Grazie per la fiducia incondizionata che avete riposto in me e per aver creduto nelle mie capacità, supportando tutte le scelte che ho fatto nel corso del tempo, anche quando erano difficili e andavano al di là delle convenzioni quotidiane. Grazie per aver compreso i miei momenti d'alti e bassi, le fasi di stanchezza e i periodi di isolamento che ho affrontato nei momenti più difficili. Siete stati costantemente un esempio di impegno, dedizione e serietà, sia nelle vostre vite pubbliche che private. Spero che questo risultato possa essere motivo di orgoglio personale per tutti noi.

Estendo questi affettuosi auguri a tutti i miei cari, inclusi i miei parenti e i miei amati nonni. Nel corso degli anni, avete costantemente dimostrato una profonda fiducia in me, sostenendo le mie scelte e i miei obiettivi. Grazie di cuore per l'affetto che mi avete sempre dimostrato e per la vostra comprensione, anche nei momenti in cui potrei non essere stato così presente come avrei voluto.

Un ringraziamento speciale va a tutti i miei amici e alle persone più care con cui ho condiviso, anche solo per un breve istante, questo lungo percorso. Grazie per avermi sempre dimostrato affetto sincero, per avermi accettato e stimato incondizionatamente. Apprezzo profondamente il fatto che non abbiate mai giudicato negativamente le scelte poco convenzionali che ho fatto nella vita. Al contrario, avete sempre mostrato un profondo apprezzamento e sostegno per le audaci decisioni che ho intrapreso nel corso degli anni. Ringrazio per la vostra pazienza nel sopportare i miei momenti di difficoltà, quando purtroppo il mio umore ne risentiva, e soprattutto vi sono grato per tutti i momenti di allegria, condivisione, musica e amore che avete portato nella mia vita.

Tuttavia, desidero dedicare un ringraziamento speciale a Manuele, la persona che è stata più vicina a me in questi ultimi anni. Il suo valore è inestimabile, e ho avuto la fortuna di avere sempre la sua presenza accanto a me in questo percorso. Ringrazio per le innumerevoli giornate trascorse insieme, per le avventure condivise e per quelle che affronteremo in futuro. Manuele mi ha sempre affiancato con una calma instancabile, sensibilità e pazienza, insegnandomi a essere una persona migliore. Grazie per avermi tenuto per mano costantemente, per il sostegno offerto anche quando avrei meritato un rimprovero e per accettare la mia occasionalmente insensibile e egoista natura. Ringrazio Manuele per aver sempre creduto in me, persino quando io stesso avevo dubbi. Grazie per essere una fonte di orgoglio ogni volta che raggiungi risultati che a volte sembrano irraggiungibili per me. I nostri innumerevoli discorsi, confronti e dibattiti, spesso provenienti da prospettive opposte, sono stati preziosi per la crescita personale. Mi auguro tutto il meglio per il suo futuro e spero di essere altrettanto positivo e di sostegno nella sua vita come lui lo è stato per me. Dedico questo momento della mia vita a Manuele, riconoscendo che con lui ho trovato il punto di equilibrio e il supporto di cui ho tanto bisogno.