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T1.1 Literature review on the current trends in educational robotics

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CONTENTS

EXECUTIVE SUMMARY

Recently, several countries' governments have focused their attention on educational robotics (ER), promoting legislation incorporating robotics in their curriculum. However, the plurality of robotics technologies and the methodologies available for their application constitutes a quite bewildering background for ER.

In line with the FERTILE project's aim to develop a methodology integrating ER with Arts in a blended learning context, the FERTILE consortium conducted a literature review on the current trends in ER. We explored the Robotics technologies available in the market and the methodologies for applying Robotics described in educational research.

This document contains this exploration. In the first section, we present contemporary robotics technologies, i.e., programming languages used to program robots, physical robots, and robotics simulators currently available. The second section offers examples of using educational robotics to create artful projects. In the third section, we approach how educational robotics holds the potential to promote computational thinking skills. The fourth section includes an overview of robotics and arts in current educational legislation across the different consortium members' countries. Lastly, the fifth section draws the main conclusions of the review included in previous sections and elaborates on possible implications of the FERTILE methodology.

ACRONYMS

List of abbreviations

Abbreviation	Definition
CCPS	Creative Computational Problem Solving
CSTA	Computer Science Teachers Association
CT	Computational Thinking
EDP	Engineering Design Process
ER	Educational Robotics
ERS	Educational Robotics System
ICT	Information and Communication Technologies
IDE	Integrated Development Environment
ISTE	International Society for Technology Education
LfU	Learning-for-Use
LOMCE	Ley Orgánica para la Mejora de la Calidad Educativa
SDK	Software Development Kit
STEAM	Science, Technology, Engineering, Arts and Mathematics

INTRODUCTION

The integration of Educational Robotics (ER) in the educational practice, usually in Informatics/Information and Communication Technologies (ICT) courses, was associated with the development of digital skills and Computational Thinking (CT), positively affecting students' personal development (Angeli et al., 2019). Considering that CT skills are fundamental for everyday problem solving, influencing nearly all disciplines, the FERTILE project introduced the term "Artful ER projects". This cross-disciplinary learning was a challenging goal towards cultivating CT and going beyond the traditional approach of using Arts as a stimulus for developing robotic constructions that either draw designs or produce sounds/music.

The project's main goal[1] was to propose a design methodology for Artful ER projects cultivating computational thinking that may apply in a blended learning context exploiting ER simulators and a community platform for remote collaboration. Developing such a methodology was the first intended project result[2]. However, before proposing, it was necessary to review the associated literature (task T1.1) and the current situation regarding (i) available ER tools, (ii) previous related teaching experiences, (iii) previous methodologies for applying Artful ER projects, and (iv) current education organization contexts (laws, levels, official curricula contents), at least in the countries of the consortium partners. We note that the FERTILE consortium gathered more relevant information from the educator's profiling task (T1.2) before proposing the FERTILE methodology.

The primary purpose of this document was to recap and summarize the current state-of-the-art in ER and Arts. Consequently, it is mainly a descriptive document aiming to lay the foundations on which the following tasks of the FERTILE project were based. The FERTILE project plan included utilizing in task T1.2 the analysis done in task T1.1. To compile the technologies used by teachers, the methodologies they followed, and how the legislation affected them when including ER in their sessions. The methodologies detailed in this document were planned to be used in task T1.3 towards developing the FERTILE methodology.

The primary resources used to gather available physical robots, simulators, and learning methodologies and to describe how ER was included in the educational institutions' curriculum come from:

- Scientific journals.
- Webpages of robot manufacturers or simulator developers,
- Project team members' experiences and official education curricula in different countries.

This document has been organized into five sections beyond this introduction.

[1] https://fertile-project.eu/about/
[2] https://fertile-project.eu/results/

The first section reviews the set of tools currently used in Educational Robotics worldwide. They have been divided into (i) programming languages, (ii) physical robots or robot kits, and (iii) robot simulators. Aiming to take note of contemporary tools, we note that we do not use past tense as typically used in reviews but opt to use the simple present tense to highlight our focus on up-to-date tools.

The second section reviews the major trends combining ER and Arts, presenting many illustrative experiences and organizing them according to several art-specific fields such as painting, music, literature, scenic arts, and performing arts.

The third section reviews some relevant theoretical learning models and methodologies proposed in the scientific literature and followed in education centres to foster Computational Thinking using ER.

The fourth section describes how ER and its combination with arts are taught in the four partner countries of the project at all levels: pre-primary education to secondary and higher education. In higher education, future teachers are the focus, and the section describes the robotic practices used in teaching these future teachers.

The fifth section recaps the main conclusions of this document.

1. EDUCATIONAL ROBOTICS

Educational Robotics (ER) have used both physical and simulated robots as a tool to teach Computational Thinking and robotics in Primary, Secondary, and High Schools. This section presents an updated review of current ER practices, emphasizing educational practices that combine robots and art. The goal of this section is to review the most widely used and interesting ones. The resources used to prepare this section include the scientific literature survey, the webpages of robot manufacturers, and other reviews of robotics in school education (Kubilinskiene et al., 2017) (García-Peñalvo et al., 2016) and (Barreto et al., 2017).

We noted that the robots are typically composed of hardware and software. They have a mechanical body, sensors, actuators and onboard computers on the hardware side. The sensors allow the robot to measure or perceive its environment or some internal physical property. Indicative sensors used are distance sensors such as sonar or laser, cameras, infrared sensors, touch sensors, or microphones. The actuators allow the robot to move, say something, or turn on a light. For instance, electrical motors, speakers, or LEDs. On the software side, robots can commonly be programmed in a particular language and typically run on the onboard computer. The software determines how the robot reacts and behaves.

In actual engineering applications, robots perform useful tasks such as vacuum cleaning, autonomous driving, or moving goods in warehouses. In education, they are tools helping students to acquire skills in Computational Thinking, Robotics, or even other subjects.

There are many teaching frameworks used to teach robotics to students. Some focus on primary education, while more powerful ones are oriented on secondary education/high schools. They are usually composed of a concrete robotic platform, i.e., a robot typically programmed in a particular language using software tools (SDK –Software Development Kit– , or IDE –Integrated Development Environment–). In addition, different exercises, challenges, or projects are then proposed to students (practice activities). They teach the basic operation of sensors, actuators, and the rudiments of programming. These teaching frameworks are used as a tool within a specific way of teaching robotics classes, i.e., of a particular methodology. Consequently, we identified four elements that characterized the numerous methods of teaching robotics to students and the most used frameworks: (i) the hardware platform, (ii) the software language and infrastructure, (iii) the concrete practices, and (iv) the methodology.

This section presents the most widely used languages for robot programming in ER. In addition, we review many examples of physical robots used in ER and some of the SDKs used to program them. They are an instrument for teaching ER and one of its main components. In recent years, robot simulators have become an essential tool in robotics engineering and have also started to be used in ER. Such applications provided some advantages and also caused some limitations in this area. Furthermore, in this section, we review the most widespread robot simulators. Before going into physical and simulated robots used in ER, we recap the most pervasive software languages to program them.

1.1 Programming Languages for ER

Typically, each robot in ER has a software environment (SDK, IDE) that allows programming it in a particular language. The software environment usually includes code editors, utilities to download in real robots, and even simulators on some occasions. Programmed robots are the most common ones, but robots intended for primary or pre-primary education do not have to be controlled by software. For instance, some move only by remote control, such as Botley Robot (https://www.learningresources.com/media/botley).

As for languages, simple languages are used to facilitate programming by students and include instructions for ordering commands to actuators, reading sensor measurements, loops, and conditional and sequencing instructions. There are *text-based languages* such as Python, C++, Arduino, etc. And, there are also *visual programming languages* (VPL), mainly based on combining graphical blocks, such as Scratch, Snap!, Blockly, ScratchJr, etc. When used with robots, the programming languages, or some of their modules, include text instructions or visual blocks to get sensor readings and to order commands to the actuators beyond instructions and blocks for logic and computing.

Pye Tait Consulting (PyeTaitConsulting, 2017) analyzed the use of programming languages in UK schools by surveying teachers of Technology (Figure 1 and Figure 2). The most widely used language in primary education was Scratch (38 %). It was Python (21 %) in secondary education, followed by Scratch (19%).

The most widely used language for programming in ER has been reported to be **Scratch** language (Beyers et al., 2017; Olabe et al., 2011; Plaza et al., 2017) and its variants such as **Blockly** (for example, with the robot RoBOBO (Naya et al., 2017)), Bitbloq (for BQ-Zowi) or VPL (for Thymio (Shin et al., 2014)). Typically, all these languages have graphic blocks connected in sequence in a graphical editor.

Snap! is a free, educational visual programming language inspired by Scratch, but with more powerful features. It is free, block-based, and includes a web editor and a running environment in the browser. Beyond using it in animations, games, and stories, it has also been extended to program robots (Newley et al., 2016).

Another successful option consists of the graphic languages from LEGO, specific to their robots, for example, the old **RCX-Code**, RoboLab (built within LabVIEW, the graphical language designed for engineers and scientists from National Instruments), NXT-G, and the latest EV3-software. All contained blocks of action, sensors, flow control, operations with data, etc.

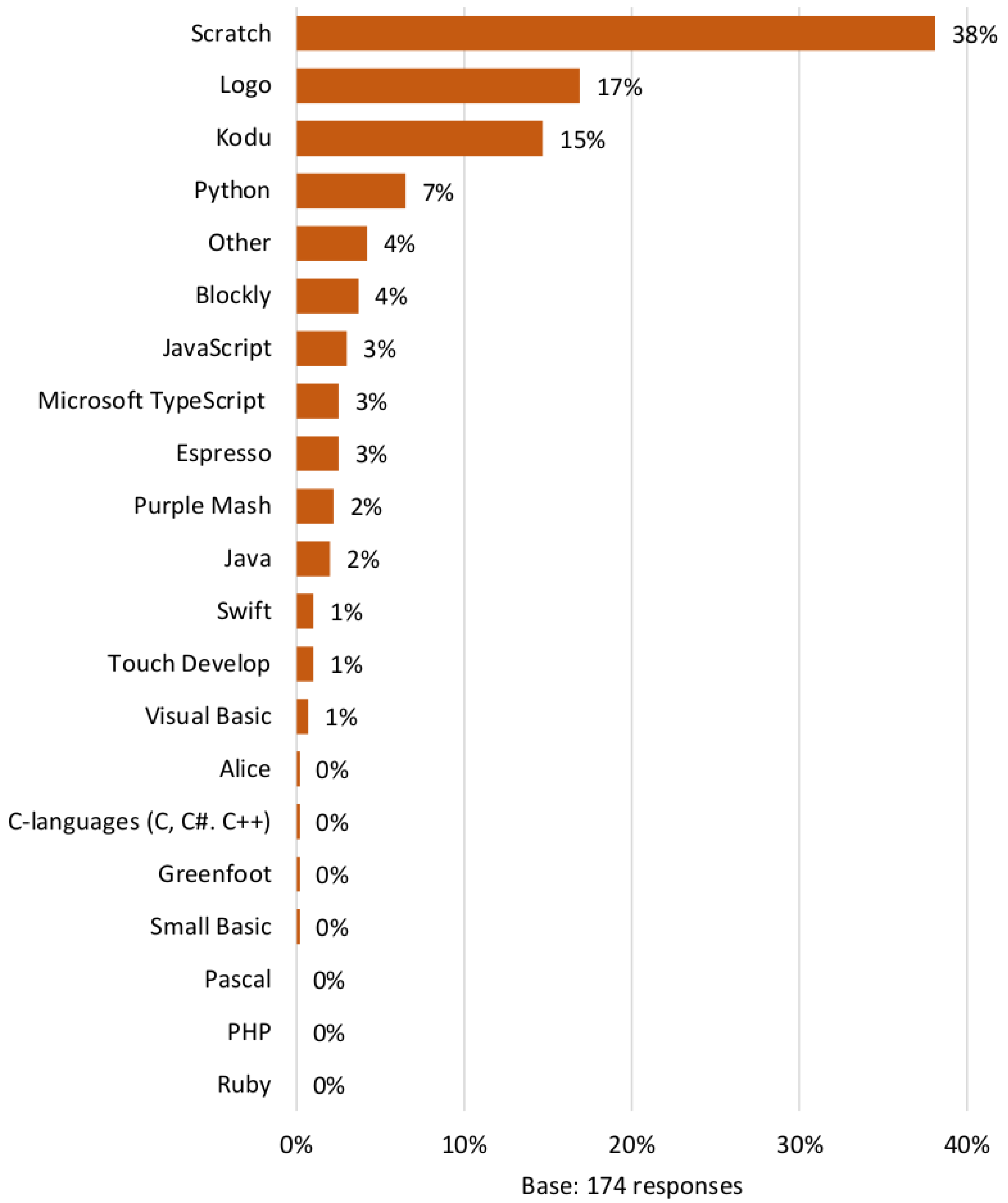

Fig. 1. The programming languages used in UK primary schools (Pye Tait Consulting, 2017).

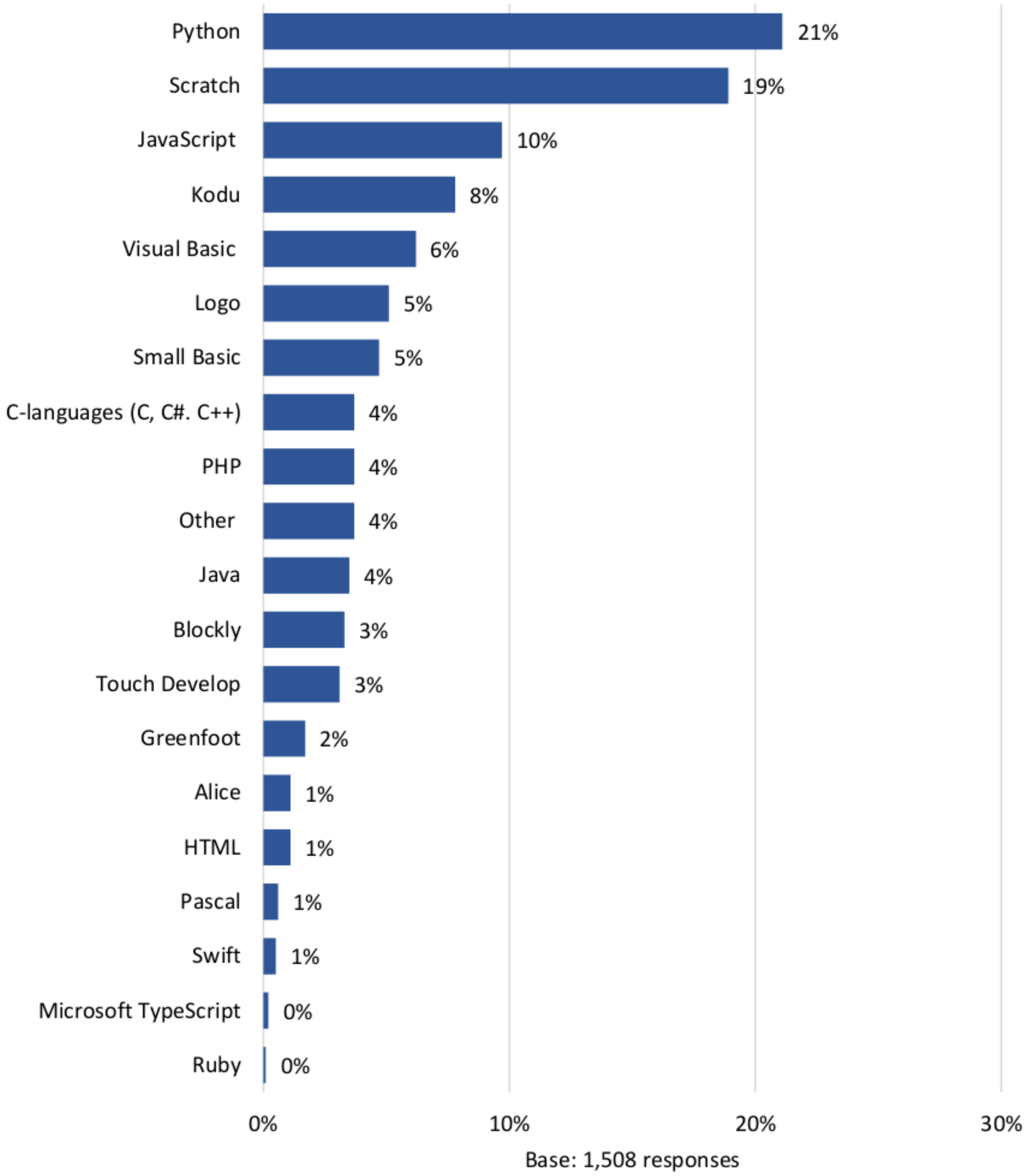

Fig. 2. The programming languages used in UK secondary schools (Pye Tait Consulting, 2017).

Python (https://www.python.org/) is a high-level, textual, general-purpose programming language. Its design philosophy emphasizes code readability with the use of significant indentation. It is dynamically-typed and garbage-collected. It supports multiple programming paradigms, including structured (mainly procedural), object-oriented and functional programming. It is widely used in higher education with an extensive collection of specific libraries. It is considered more straightforward to learn compared to other languages and, therefore an excellent candidate to introduce students to Computational Thinking beyond visual block-based languages. This language has been widely used in many contexts, from ER with students (Saito et al., 2019) to robotics at universities and other programming fields.

Languages such as **C/C++** are used successfully in higher education but are not recommended for adolescents due to their complexity. However, similar languages to C have been used without object orientation. For example, NXC for LEGO robots (Navarrete et al., 2016). In this line is the ROBOTC environment, which uses the C language and a graphical variant of it (ROBOTC-graphical) to program robots from different manufacturers (VEX IQ, VEX CORTEX, LEGO EV3, LEGO NXT, and Arduino) and simulated robots in RVW. In particular, it has been used in the Carnegie Mellon Robotics Academy (Witherspoon et al., 2017) with different exercises and competitions. In addition, the Arduino programming language for the Arduino processor is a text-based language similar to C.

Kodu is a visual programming tool by Microsoft's FUSE Labs which intends to teach basic coding using blocks and pictures. The user programs characters' behaviours in a 3D world and programs are expressed in a high-level sensory paradigm consisting of a rule-based system or language based on conditions and actions. Simple languages such as **Logo** or **Kodu** have been common for teaching Computational Thinking to students, but their combination with robots has not been consistent. The same seems to have occurred for other languages such as Java, JavaScript, or TypeScript.

1.2 Educational Robots

While reviewing the literature, we found many robotic kits used for educational purposes. These kits allow creating different learning designs applying different learning methodologies. Various kits have different features from mechanical, structural, and functional points of view. The following paragraphs overview the different robotic kits and their characteristics. Also, we present a comparative table of the robots sorting them by the educational level they are used to, the programming environment they are programmed and the tool that simulates them.

In the remaining part of the first section, we refer to robots meaning physical, tangible robots, or robotic kits. On the contrary, in the second section, we refer to robots as simulated or virtual robots.

Alpha Bot2 (https://www.robotics.org.za/W12911) robot supports a great variety of hardware, such as Arduino and different models of Raspberry Pi hardware. It has different robot functions with a highly integrated modular design, which makes it easy to assemble. Educational research has reported this bot having been used by students with various disabilities. For instance, the robot was used by students with reading disabilities for them to acquire reading skills (Luo, 2017). Moreover, Alphabot was also used by students with Autism Spectrum Disorder in different teaching sessions to increase students' level of attention (Zamin et al., 2019).

Artie (https://www.learningresources.co.uk/artie-3000) is mainly a drawing robot aiming to introduce students to real programming languages. Typically, students can be assigned to program Artie with a remote controller or by using programming languages such as Blockly, Snap, Python, or Javascript. Artie has an online simulator allowing students to test their programs.

Bee-Bot (https://www.tts-international.com/bee-bot-programmable-floor-robot/1015268.html) is usually used to introduce students to coding and computational thinking. This robot can remember up to 40 commands. Therefore, it allows students to create simple algorithms while developing their problem-solving skills in a learning environment. In contrast to other robots mentioned in this section, Bee-bot is directly programmed by clicking the commands that users want to execute through its physical interface. Bee-bot is mostly used in primary and pre-primary education due to its simplicity. Several studies have reported utilizing Bee-bot to introduce students to coding and computational thinking skills, increasing their interest in this area and promoting their creativity to solve the tasks at hand (Vargová et al., 2021; Papadakis et al., 2022).

Blue-bot (https://www.tts-international.com/blue-bot-bluetooth-programmable-floor-robot/1015269.html) is a robotic programmable floor device. Similarly to the Bee-bot, users can program the Blue-bot by using the directional buttons located on its back. However, an additional feature, compared to the Bee-bot, is programming through BlueTooth by using its app on a tablet computer or a mobile phone. Like Bee-bot, Blue-bot has been mainly used in primary and pre-primary educational settings to introduce students to coding and teach them computational thinking skills. Many studies supported its use for these tasks, pointing out that students' interest increased and their motivation was high when interacting with this robot (Miková et al., 2021; Ricart et al., 2019; Angeli et al., 2019).

Boe-Bot (https://www.parallax.com/boe-bot-robot/) is a robotic kit that uses the BASIC Stamp2 Microcontroller Module[3]. The educator can use extra sensories and accessories, such as the gripper kit, to perform different tasks. Students may utilize this kit to build several other robots using an engineering-style approach. There were studies in the literature in which the Boe-Bot was used to increase the STEAM outreach in elementary education (Ubben, 2019) and to teach electricity fundamentals in University Settings (Tims et al., 2011).

Cubetto (https://www.primotoys.com/) is a wooden robot aiming to have preschool students learn to code. Cubetto has its own coding language based on physical blocks. Each block represents an action that the robot needs to perform. The blocks are placed in a control board that sends those actions to the robot. The set includes maps and books to create different activities. Cubetto has been tested in many studies which involved preschool students (Anzoategui, 2017; Alsina and Acosta, 2022). These studies stated that working with Cubetto helped the students develop their systemic process and CT.

The **Edison robot** from Meet Edison (https://meetedison.com) is a low-cost robot expandable by LEGO bricks. It uses pre-programmed activities to train students in computational thinking and coding. This robot's applications in higher education reported students' enthusiasm while approaching the basic programming principles revealing that this robot was appropriate to train students in computational thinking and to promote language skills and science literacy (Ververi

[3] https://www.parallax.com/product/basic-stamp-2-microcontroller-module/

et al., 2020). In Karageorgiou et al., (2019), the Edison robot was used in an escape room game to teach students STEAM concepts. These students found Edison robot programming very easy to use and even provided many ideas about its possible use in an escape room.

Escornabot (https://escornabot.com/es/index) is an open-source/hardware project aiming to familiarize students with robotics. Students can build their own Escornabot using an Arduino and different components that can be downloaded from the project repository. (https://github.com/escornabot/). This robot focuses on being used by primary school students. Since it is Arduino-based, students can program it using C.

Fable (https://www.shaperobotics.com/) is a modular construction system used to create different types of robots. With Fable, students can combine several modules to create different configurations. Likewise VEX robotics, students can start programming the robots using blocks and, once more experienced, they can transit to a textual programming language (Python). We note that we could not find any study evaluating how students learning outcomes vary when using this robotic kit. However, there is a study in which the authors stated that building the robot was an easy task done in around 20 seconds, allowing the students to quickly try and test different mechanics, thus increasing the interaction level with the robot (Pacheco et al., 2013).

GoPiGo (https://www.dexterindustries.com/store/#gopigokits) is a Raspberry Pi robot aiming to help children explore computer science and connect coding to real-world problem-solving. As with many educational robots, there are two ways of programming its behavior. The users can program GoPiGo using a block-based programming language (Bloxter), or the user can program the robot using a text-based programming language (Python). Liesaputra et al. (2020) used this robot in a workshop promoting middle-school and high-school students' computational thinking skills. These researchers supported it is crucial to organize activities around societal issues' solutions when using robots as educational tools. However, their findings revealed not having been able to measure the students' understanding of each computational thinking concept.

KeyBot is a low-cost STEM robot from KEYSTUDIO company (https://wiki.keyestudio.com/Ks0353_keyestudio_KEYBOT_Coding_Education_Robot_for_Arduino_STEM), based on an Arduino processor and compatible with mbot1.

LEGO Mindstorm (https://www.lego.com/es-es/themes/mindstorms) is a programmable robotics kit based on Lego bricks with robotics parts. The kit includes servo motors, sensors, wheels, gears, axes, connection and interface cables. Also, the kit allows attaching pens for drawing tasks, among others. All these parts can be combined to build robots and automated systems. This kit is among the most widespread tools for teaching robotics and programming. In Zygouris et al. work ((2017), the researchers have used this kit to increase the academic performance of elementary students, achieving good results.

LEGO has a long history in Educational Robotics Kits. From the RCX (1998) to the NXT (2006), EV3 (2013), and the most recent Spike (2020), as illustrated in Figure 3. Their robots are very robust but pricey. A typical feature is allowing many mechanical pieces to be assembled in different robot designs. LEGO provides a well-developed programming environment for all its robots, including LabView.

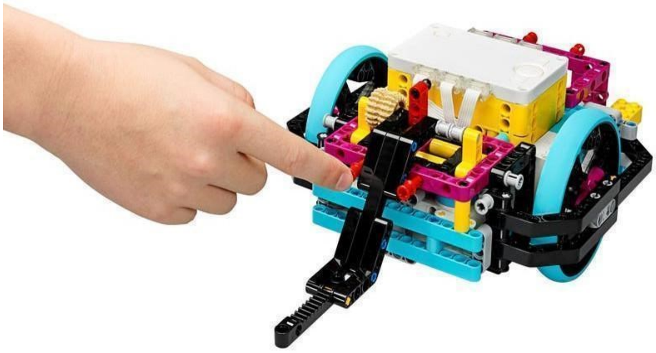

Fig. 3. LEGO EV3 (top) and Spike (bottom) robots

Linorobot (https://linorobot.org) is a suite of open-source ROS-compatible robots aiming to provide a low-cost platform based on the popular Robot Operating System (ROS). Students are supported to create their own robots using accessible hardware. We note that we could not find any studies supporting this robot in educational settings.

Makeblock Ultimate Robot Kit (https://www.makeblock.com/project/ultimate-robot-kit) allows the creation of complex robots aiming at "robotic world" exploration (see Fig. 4). The constructed robot can be controlled using a smartphone or tablet computer with a Bluetooth connection. The same company has been providing several other robots, such as Mbot, Mbot-Neo, and Neuron. **Mbot** is a widespread and robust robot with an Arduino processor, US and IR sensors. **Mbot-Neo** robot is its successor, including a better on-board computer named CyberPi, motors with encoders and enhanced wifi connectivity. Makeblock provides the online mBlock (https://ide.mblock.cc/) web place for block-based programming of its robots. Python is also supported in Mbot-neo. **Neuron** is a robotic system with sensors and motors which can be programmed using physical blocks connected to each other. Neuron has a mobile app that can program the robot using the Scratch language. Some studies have used these three kits to introduce students to robotics (Candelas et al., 2016; Herias et al., 2019) and to train computational thinking skills. These researchers reported that the students in their study had fun while performing the activities and fulfilling the intended learning goals. Consequently, these researchers supported that the Mbot robot was appropriate for introducing students to robotics.

Fig. 4. mBot (top) and mBot-Neo (bottom) robots from Makeblock

Makey-Makey (https://makeymakey.com/) is an electronic board that converts daily life items to touch panels programmable with Scratch. By knowing Scratch and having some conductivity knowledge, the users can create artefacts of any type, including art, sciences, and literature. Studies such as the one by Fokides and Papoutsi (2020) suggested that Makey-Makey could be used to teach electricity concepts. These researchers have also recommended teachers' reflection on whether this device has clear advantages over other tools. Authors such as Tanik Onal and Saylan Kirmizigul (2022) have integrated existing learning methodologies to implement STEAM activities using Makey-Makey. These researchers applied an activity with Makey-Makey in their study and reported that Makey-Makey was very effective for science education in preschool children.

Matatalab (https://matatalab.com/en) is a robot programming kit providing students with a block-based, screen-free and tangible programming environment. The robot's programming set allows students to control the robot through a nature map with a Bluetooth-enabled commando tower, control board, wheeled robot, and coding blocks. The robot's coding manual offers entity modules and visual recognition to achieve simplified programming so that children can control robot's movement to play music, draw pictures and play games. This robot has been mainly used in primary and pre-primary settings to promote computational thinking skills (Yang et al., 2022; Gribble et al., 2020; Papadakis, 2020).

Micro:bit (https://microbit.org) The Micro:bit (see Fig. 5) is a small, open-source computer with a programmable ARM processor, also referred to as the Micro:Bit or the BBC Micro:Bit. It has several built-in sensors, including an ambient light sensor, a temperature sensor, an accelerometer, and a compass. There are various robotic kits designed for micro:bit, like Nezha Inventor's kit, which is compatible with Lego bricks and contains multiple additional sensors.

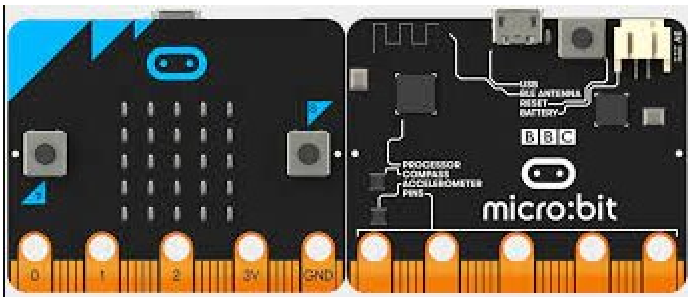

Fig.5. Micro:bit board

The **MiniSkybot** (http://www.iearobotics.com/wiki/index.php?title=Mini-Skybot) is a mobile robot. The robot can be built directly by printing 3D parts that are available for everyone, being fully open-source. Therefore, this kit does not only allow students to learn robot programming but also to modify the robot parts and create custom parts. We note that we could not find any empirical evidence about using this robot in educational settings.

mTiny Coding kit (https://education.makeblock.com/mtiny-discover-kit/) from Makeblock is an educational robot incorporating a tap pen controller and an interactive map. It intends to train young students' -even from 4 years old-computational thinking skills. It follows a tangible programming interface in which the user joins the blocks and then touches them with the tap pen controller to send the instructions to the robot. Regarding its use in educational settings, we could not find relevant literature on which this robot has been used.

NAO (https://www.aldebaran.com/es/nao) is a humanoid from SoftBank Robotics (see Fig. 6). It is a 58cm tall bipedal robot introducing new and attractive pedagogical topics and applying PBL (Project-Based Learning) approaches. Its friendly shape and movements have been carefully designed to create empathetic links with users. Its design aims to to inspire and promote its users into physical and intellectual exercises thatdevelop social and emotional skills. Its omnidirectional microphones and speakers trigger users' engagement in enriched dialogues and interactions. NAO's features include listening and understanding many situations and being able to speak fluently in more than 20 languages. It is equipped with two 2D cameras to recognize shapes, objects, and even people, thus enhancing interactivity with its users. It also incorporates touch sensors and several coordinated movements. NAO is programmable using the SDK in Python, in Java, and visually with Choregraphe IDE (Integrated Development Environment) using an easy drag-and-drop interface. Educational research has reported NAO's applications in primary, secondary, and special needs education.

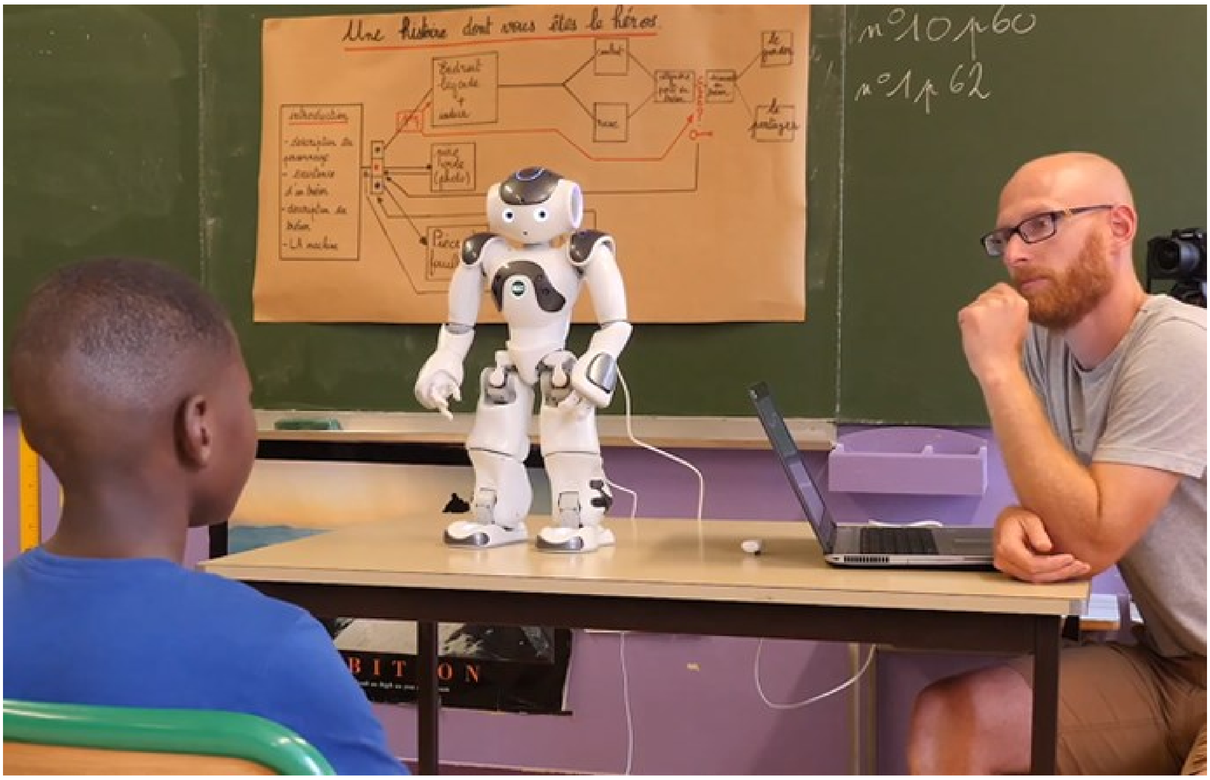

Fig. 6. NAO humanoid (from SoftBank web page)

Ozobot (https://ozobot.com/educate) is a robot moving on two wheels and using colour sensors to follow lines and recognize colour codes. There are two ways of programming it: programming with colour codes and using the block-based programming language Ozoblockly. Ozobot has been developed to achieve computer science skills in a playful way to enhance teamwork, collaboration, and social skills. Several studies have reported using Ozobot in educational settings. For instance, Tengler et al. (2017) used it to measure primary school students' creativity by evaluating how well the contents were designed. Other studies focused on promoting students' computational thinking skills and manifesting how students were motivated when working with the robots (Tengler et al 2021; Piqueras et al., 2018; van der Linde et al., 2018). Ozobot has also been used for specific tasks, such as teaching kinematics to high-school students (Balaton et al., 2020).

Robotis premium (https://emanual.robotis.com/docs/en/edu/bioloid/premium/) is the updated version of BIOLOID. This kit aims ford students to learn the basics of structures and principles of robot joins. One of this kit's main characteristics is allowing the humanoid robots' creation. We note that we could not find any study utilizing this kit in elementary education. However, we found one study in higher education in which the students' perceptions reported their satisfaction when using this kit in a course about advanced robotics (Perez et al., 2019).

Sphero (https://sphero.com/) is a white spherical robot controlled through an app on a smartphone or tablet computer. This app supports a block-based programming language. Sphero is a robot able to move in any direction and at various speeds. Thanks to this feature, researchers have utilized it in several studies. Sphero has been used to teach the notion of speed in kindergarten settings (Ioannou et al., 2017). It has also been used in a more generalistic way to teach STEAM skills (Athesam et al., 2020) in a higher education setting.

The **Speechi robotics** sets (https://www.speechi.net/en/home/robots-en-2/) were designed to learn coding, robotics, electronics, and how robots can be used in daily life. They have different programming interfaces, allowing the students to program the robots using an icon-based interface, Scratch, Arduino, Python, and Microsoft MakeCode. We note that we could not spot any study utilizing this robot in educational settings.

Tello drone (https://www.ryzerobotics.com/es/tello) from Ryze Tech is one of the most popular drones used in educational settings. Its safety features, flight stability, accuracy, programming options, low cost and ease of purchase have gained its users' appreciation and resulted in being widely sold in many technical shops. Also, the variety of accessories available for this drone is worth mentioning. Another asset of using the Tello drone is the fact that it can be programmed in either Scratch or Python, the two most popular programming languages in educational settings. Consequently, we found studies at different educational levels in which this drone has been used successfully to spark students' interest in the STEAM area. For instance, Tezza et al. (2020) used this drone in K-12 settings during STEAM courses. Yepes et al. (2022), used this drone in high-school settings, and Duraj et al. (2021) used Tello at higher education.

The **Thymio** robot (https://www.thymio.org) is an easily programmed ground robot . Its basic features include 7 pre-programmed behaviours, and the option to attach Lego bricks to it (see Fig.7). Also, it provides a basic set of sensors and several LEDs enabling users to program it into carrying out different tasks.

Fig. 7. Thymio robot

Turtlebot 3 (https://www.turtlebot.com/) is a low-cost robot programmable by open-source software. This robot has a Raspberry Pi 3 board serving as the operation centre. In addition, it incorporates a 360º laser scanner, an accelerometer, a gyroscope, a magnetometer, and the motors allowing the robot's movement. Turtlebot has been used in higher education (Amsters et al., 2019; Quickley, 2021), but we have not found evidence of its use in primary or secondary education.

VEX robotic platform (https://www.vexrobotics.com/) was designed to improve students' problem-solving creativity. This company has been providing several physical robotics kits such as 123, GO, IQ, EXP, and V5, focusing on several age ranges. These robots allow students to control them both in a direct and automated way. The robots can be programmed using blocks, and after reaching a certain level of expertise, they can transition to a more advanced programming language such as C++. The user can test their codes with Robot Virtual Worlds, a virtual environment allowing robots' programming without having an actual robot. These kits have been used in robotics competitions (Dwivedi et al., 2021), achieving high satisfaction results, and in several undergraduate courses to teach digital concepts (Ma, 2021). A combination of both direct and indirect assessment methods demonstrated this platform's effectiveness

Table 1 summarizes the main features of the aforementioned physical robots. Many of the robots have been used in research studies to test their effectiveness in different educational settings. Since the FERTILE project aims to develop a blended learning methodology, we added an extra column depicting whether the robot's simulated environment could be used in online settings.

Table 1. Main features of physical robots

Robot	Description	Educational Level	Programming environment	Simulator
Alpha Bot2	Arduino and different models of the Raspberry Pi hardware	Learning disabilities	Python, C	https://github.com/ssscassio/alphabot2-simulator
Artie	Robot with a platform that can hold colour markers		Blockly Snap (block-based coding environment) Python JavaScript	No
Bee-Bot	Robotic programmable floor device	Pre-primary and primary education	Directly programmed through its physical interface	https://beebot.terrapinlogo.com/ https://www.roboticavirtual.com/tts
Blue-bot	Robotic programmable floor device	Pre-primary and primary education	Directly programmed through its physical interface or BlueTooth by its app	https://www.roboticavirtual.com/tts
Boe-Bot	BASIC Stamp2 Microcontroller Module to	Primary, Higher education	Blockly, C (Arduino),	No

	which sensories and accessories are attached		Pyhton, PBasic (PBASIC is a variant of familiar BASIC, with special commands for monitoring and controlling circuits)	
Cubetto	A wood robot that can be programmed using wooden blocks (without screens)	Pre-primary and primary education	Wooden blocks	No
Edison	Small, car-like robot. Lego bricks can be added to the robot.	Primary and secondary education	EdBlocks, EdScratch (scratch) and EdPy (python)	Open-Roberta, Miranda software
Escornabot	Hardware and software open-source project for a floor robot. Based on Arduino	Pre-primary, primary and secondary education	Directly programmed through its physical interface. It can be programmed using Arduino IDE	No
Fable	Modular construction system		Fable Blockly	No
GoPiGo	Kit to build a robot car. Based on a Raspberry Pi	Primary, secondary, and higher education	Bloxter (drag-and-drop language for beginners), Python	Kibotics
KeyBot	Car-like robot based on Arduino processor and compatible with Mbot1	Secondary Education	Arduino, Mixly (free open-source graphical Arduino programming software)	Kibotics
Lego Mindstorm	Robotic kit based on Lego bricks with robotic parts (sensors, motors, actuators)	Primary, Secondary, Higher education	Scratch, EV3 classroom, Lego Mindstorms EV3 environment, WEDO	EV3 Microsoft Makecode, Open-Roberta, Miranda software, TRIK Studio, Virtual

			environment	Robotics Toolkit
Lego Spike	Roboti kit base on lego bricks	Primary education	Scratch	Kibotics
Linorobot	Open-source ROS compatible robots	No literature. Probably higher education	ROS, C++, Python	No.
Makeblock Ultimate Robot Ki	Mbot is a robot with an Arduino processor with US and IR sensors	Primary and secondary education	Arduino IDE, mBlock, App, Python	Miranda software https://www.roboticavirtual.com/mBot OpenRoberta Kibotics
Makey-Makey	Board with a layout of "buttons" that can function as a substitute for a keyboard or mouse, allowing commands to be sent to the computer to which it is connected. Instead of pressing the keys, the circuit is closed by means of contacts or crocodile clips obtaining the same input as pressing a button.	Primary education	Scratch	No
Matatalab	Robotic programmable floor device without screens	Pre-primary, primary	Card-based programming. Cards are ordered on a board. The control board connects with the robot to send it the program.	Scratch simulator https://www.roboticavirtual.com/matatalab
Micro:bit	A pocket computer having a LED light display, buttons, sensors, and many input/output features. The new micro:bit includes sound adds (a built-in microphone and a	Primary and Secondary Education	MakerCode (block-based) Python Scratch	Open-Roberta, Microsoft Makecode micro:bit Miranda also includes simulation for Maqueen robot

	speaker) and an extra input and power button.			(based on Micro:bit)
MiniSkybot	A mobile robot fully open-source	no empirical evidence	PIC Microcontroller	No
mTiny Coding kit	Robotic programmable floor device without screens	Pre-primary, primary education	Card-based programming. Using a pen-device, cards are recorded, and the program is sent to the robot.	No
NAO	Humanoid from SoftBank Robotics	Primary, Secondary and Higher education	Python, Java and Choregraphe IDE (Integrated Development Environment) using an easy drag-and-drop interface	OpenRoberta Webots
Neuron	Neuron Inventor Kit based on blocks that can be magnetically connected to become multifunctional electronic solutions.	Primary education	App Scratch mBlock App and PC	No
Ozobot	Tiny floor robot	Primary education	ColorCodes (using markers or stickers that the robot reads). Ozobot Blockly	Miranda software
Robotis premium	Basics of structures allowing the creation of humanoid robots	Primary	C	No
Sphero	White spherical robot	Pre-primary, primary	Block-based programming language	No
Speechi robotics	Arduino card with electronic parts	Primary, ++	Icon-based interface, Scratch, Arduino, Python, C++	No

			and Microsoft MakeCode	
Tello drone	Drone with several accessories	Primary, Secondary, and Higher Education	Scratch and Python	Miranda software Kibotics
Thymio	Ready with motors, sensors and actuators, compatible with Lego bricks	Primary, Secondary, and Higher Education	VPL, Scratch, Blockly, Aseba	Thymio Suite, Webots, Miranda software
Turtlebot 3	Raspberry Pi 3 board to which sensors and motors are attached	Higher education	Python, C++, ROS	Rviz and Gazebo
VEX robotic platform	Several physical robotics kits, such as 123, GO, IQ, EXP, and V5, according to several age ranges	Primary and secondary education	Blocks C++ Python	VEX code

1.3 ER Simulators

Some of the physical robots mentioned in Table 1 are complemented by a robot simulator enabling working with that robot model without actually having its physical implementation**.** A robot simulator is a piece of software emulating the behaviour and operation of one or several robots in a given scenario. Typically, robot simulators include a physics engine, which considers gravity, inertia, friction, forces, collisions…, and a rendering engine, which allows users to see the simulated world on the screen. The simulation also includes robot sensors (distance sensors, cameras, infrared, touch, etc.) and robot actuators (motors, sounds, lights, etc.). The simulated world may include one or several robots, static objects and dynamic objects. The simulators may be 2D or 3D. They may simulate a single robot type or support different types. Physical robots have been extensively used in robotics engineering. In the last years, they were also used in educational robotics at higher education and pre-university levels (Tselegkaridis et al. , 2021).

Physical robots are considered similar to videogames. However, a key difference refers to robot simulators focusing on being realistic by emulating real sensors and actuators and authentic movements. Typically, robot simulators simulate existing tangible robots and attempt to precisely represent physical robots' properties and phenomena.

The following paragraphs, included in this section, overview the various educational robot simulators and their characteristics. Also, we have a comparative table matching the simulators with the physical robot they simulate and the programming environment they integrate. And we note whether they are free or not.

It is worth mentioning that some simulation environments, such as Minecraft from Microsoft[4] or the Tactode programming system[5], are intentionally left out of this review as they do not involve any robot or realistic sensors or actuators. In addition, the robotic simulators involved only in higher education and engineering degrees are not included. For instance, this is the case of Gazebo[6] or Usarsim[7] simulators.

AlphaBot2 Simulator (https://github.com/ssscassio/alphabot2-simulator) is an open-source simulator created for AlphaBot2. It includes basic features like the robot identifying obstacles and following a line. The robot uses two infrared sensors to avoid the barriers and five infrared sensors for line recognition and tracking.

The **EUROPA** platform (Karalekas et al., 2019) supports simulating a robot programmed using Python. The simulated robot is based on a Raspberry Pi3 B+ board, and it includes a raspberry pi camera, ultrasonic sensors and light detection, and ranging sensors. This simulator mainly targets secondary school students and has usually been used to teach trigonometry and physics. Although the EUROPA platform has been tested with secondary school students, no statistical evidence about its benefits was reported (Karalekas et al., 2019).

GearsBot (https://gears.aposteriori.com.sg) is a free 3D Robotics simulator. It supports programming in blocks (Blockly), auto-conversion of blocks into Python code, and direct programming in Python. The generated Python code can run on both the simulator and a real robot with little or no modifications.
GearsBot is based on an Open-Source project downloaded from https://github.com/QuirkyCort/gears. Being open-access allows modifications to create one's own instance of the platform. It includes 9 different robots and 13 different worlds. Each world provides a task for the user to complete. In addition, the user can overcome various challenges in some of the worlds. Recently, the platform has also included blocks to perform painting tasks.

Open Roberta Lab (https://lab.open-roberta.org/#) is a cloud-based programming environment allowing users to program robots by using blocks. To program robots, it uses the programming language NEPO. NEPO is a free, open-source metaprogramming language that anyone can use. It is a graphical programming language based on Blockly. To the best of our knowledge, Open Roberta does not allow programming with languages other than NEPO.
Open Roberta allows working with 21 different environments, although most of the worlds are the same for many of them. However, it allows uploading simulation settings and new images.
To use Open Roberta the code can be downloaded from https://github.com/OpenRoberta/openroberta-lab.

Webots is a platform offering open-source software for simulating robots. Webots uses ODE (Open Dynamics Engine) for collision detection and dynamic simulations. Robots can be programmed using C++, Java, Python, MATLAB, and ROS. It includes 22 different robot models.

[4] https://www.minecraft.net/es-es
[5] https://repositorio-aberto.up.pt/bitstream/10216/135616/2/487641.pdf
[6] https://gazebosim.org/home
[7] https://ieeexplore.ieee.org/document/4209284

The platform can be downloaded at https://cyberbotics.com/#download, and its code can be found at https://github.com/cyberbotics/webots. The platform works in Linux, Windows, and MacOs. The platform allows creating worlds for setting up different activities.

Vexcode project provides a simulation environment allowing the programming of two different robots either by using blocks or by programming with Python. It has many different scenarios which can be used to set up different activities (such as with GearsBot) without needing much technical knowledge.
Not being open-source, the platform can be tested at https://vr.vex.com/. It only allows the programming of two virtual robots, provides 16 different maps and allows painting.
Vex code was used in an online competition to increase the interest of girls in Computer Science and STEAM (Naz et al., 2021)

The **Miranda software** (https://www.miranda.software/) facilitates educational robots' integration into educational practice. This software allows the users to perform virtual simulations in Scratch or Python for many robot models. Simulation is done entirely online using a browser, thus ensuring simplicity of implementation and use by students and teachers. It allows the programming of robots such as mBot or Drone Tello, among others, two of the most famous robots used in educational settings.
The Miranda software allows teachers to reuse the platform's challenges or create and share their own. This allows the creation of customized robotics competitions.

Kibotics (https://kibotics.org/) is a web environment for teaching robotics and programming. Providing an attractive interface for basic technical concepts supports users' introduction to robotics. It follows a practical approach, giving the user several challenges to overcome. Kibotics requires a browser to run and allows programming both simulated and real robots. The robots can be programmed using Blockly or Python. It also provides challenges related to computer vision.

Simspark (http://simspark.sourceforge.net/) is a generic physical multiagent system simulator. It uses the Open Dynamics Engine (ODE) library for its realistic simulation of rigid body dynamics with collision detection and friction. ODE also supports modeling advanced motorized hinge joints used in humanoid agents.
Any platform supporting TCP socket communication can be used for programming the agents. However, many libraries are providing the basic functionality to carry out this programming. Many are written in C++, but languages such as Java, .NET and Javascript can also be used.

MakeCode (https://www.microsoft.com/en-us/makecode) is a basic web environment allowing coding for microcontroller units. MakeCode uses the open-source Blockly and Monaco editors for users to code. It enables a simple progression from visual block-based programming to text-based programming while leveraging C++ on the backend for efficient use of the microcontroller resources.
To code the micro-controller units, users can choose between two ways of programming: they can either use visual block-based programming implemented through blockly or text-based programming language in Static TypeScript.

In addition, users using Microsoft Makecode can also learn coding with physical computing devices such as Micro:bit https://makecode.microbit.org/ and Lego EV3 https://makecode.mindstorms.com . It supports the simulated Micro:bit, including LEDs, motors and shaking.

TRIK Studio (https://trikset.com/en) is a free development environment allowing programming robots using either simple visual diagrams or professional high-level programming languages (JavaScript, Python, C#, Java/Kotlin). A distinctive feature of TRIK Studio is an interactive simulation mode. The environment also supports the programming of other robotics kits: quadcopters GEOSCAN PIONEER, LEGO Mindstorm NXT 2.0, and EV3 robots.

Virtual Robotics Toolkit (https://www.virtualroboticstoolkit.com/) is an environment where users can build, program, and simulate a virtual Mindstorms robot. VRT affords a high level of realism, and users can experiment with (i) how various physical forces act on the robot, (ii) changing the friction on the playing surface, or (iii) messing with gravity to see how the robot would behave in a weightless environment. The Virtual Robotics Toolkit supports many sensors such as MINDSTORMS EV3-Ultrasonic, colour, touch, IR and Gyro sensor, and HiTechnic-Infrared and compass sensor.

TinkerCAD (https://www.tinkercad.com/) is a free web app for 3D design, electronics, and coding. Users can easily connect, code, and simulate circuit components with Arduino and micro:bit microcontrollers. Through "Tinkercad Classrooms", teachers can assign activities, send and receive assignments, invite co-teachers, and monitor student progress from their dashboard. There are also lesson plans and starters available for students to get started with 3D CAD design, electronics simulation, and block-based programming.

RoboBlockly (http://roboblockly.org/) is a block-based computing environment for learning coding, robotics, Arduino, and math. Based on Google's Blockly, it uses a simple puzzle-piece interface to program both hardware and virtual Linkbot from Barobo, Inc. and Lego Mindstorms NXT/EV3 and to draw and animate for beginners to learn robotics, computing, science, technology, engineering, and math. Blocks can be executed in debug mode step-by-step. RoboBlockly can also directly control the Arduino board. It allows teachers to manage their classes, add student accounts, assign homework, grade student-submitted homework, and provide feedback.

Beebot simulator (https://beebot.terrapinlogo.com/) is a free online simulation environment in which users can guide the Beebot to move through one of the available environments (mats) via the buttons provided.

Thymio suite (https://www.thymio.org) is an application that can be installed in any operating system allowing users to program the Thymio educational robot. If the application is not connected to a physical robot, it provides a simulator mode with several playgrounds (backgrounds) for the virtual robot to move around. Although it does not allow programming different robot models, it offers different programming interfaces to program the Thymio Robot, such as VPL, Scratch, Blockly, Aseba. The Thymio research team is currently working on including Python.

In contrast to physical robots, finding studies in the literature research in which teachers have used robotic simulators in primary or secondary education is not common. Simulators are usually used when teaching robotics to higher education students (Roldán-Álvarez et al., 2021). However, we spotted some studies utilizing engineering students (Tselegkaridis and Sapounidis, 2021). Considering those studies and the questionnaires and focus groups carried out in T1.2, we have compiled Table 2. This table shows simulators that teachers can easily access to incorporate blended learning when creating robotic projects. Each row shows a simulator, the educational level it aims at if there is a physical robot associated with it, the programming language the simulator uses (if any) and if it can be accessed free of charge.

Table 2. Features of robot simulators used in education

Simulator	Educational Level	Supported Physical Robots	Programming language	Free (Yes/No)
AlphaBot2	Secondary education	AlphaBot2	n,s	Yes
EUROPA	Secondary education	EUROPA robot	Python	n/s
GearsBot	Primary, Secondary Education	No	Blocks, Python	Yes
OpenRoberta	Primary, Secondary education	No	Blocks (NEPO)	Yes
Webots	Secondary, Higher education	Yes	C, C++, Java, Python, Matlab, ROS	Yes
Vex Code	Primary, Secondary, Higher education	In advanced version	Blocks, Switch, Python	Basic version
Miranda Software	Primary, Secondary, Higher education	No	Scratch, Python	No
Kibotics	Primary, Secondary, Higher education	Yes	Blockly, Python	No
Simspark	Higher education	No	C, C++, Java, Python, Javascript	Yes

MakeCode-Micro:bit-EV3	Primary, Secondary education	No	Blocks, Javascript. Python	Yes
Trik studio	Secondary, Higher education	No	Javascript, Python, C#, Java, Kotlin	Yes
Virtual Robotics Toolkit	Primary, Secondary education	No	Lego Mindstorm EV3	No
Tinkercad	Primary, Secondary Higher education	No	3D design	Yes
RoboBlockly	Primary, Secondary education	No	Blockly	Yes
Beebot simulator	Pre-Primary education	No	Keys	Yes
Thymio Suite	Primary, Secondary education	No	VPL, VPL3, Scratch, Blockly, Aseba, Python, Ros	Yes

2. MAJOR TRENDS IN ER AND ART IN EDUCATION

Even if there are a lot of tools available for teachers to include robotics activities in their classrooms, finding concrete evidence of its use is a difficult task, mainly because teachers do not disseminate their findings as if they were researchers. Although scientific works related to educational robotics and computational thinking have increased notably in the literature in the last decade, we noted that there are not many published studies combining arts, educational robotics, and computational thinking.

The growing importance of soft skills, specifically creativity, has recently opened the door to consider how students' creativity can be improved through ER. An overview of existing research using ER to foster creativity is included in Gubenko et al. (2021).

Despite not having a plethora of studies joining arts and robotics education, their number is steadily increasing. Those studies have followed mainly two approaches. The first approach includes robotics implementations whose objective was to teach arts, and the robots were used as a motivational tool (Han et al. 2009). It has been recognized that this approach is fascinating and promising, especially in those cases where robotics can be a differential element in learning, such as in students with autism (Shahab et at., 2022, Taheri et al., 2019). The second approach includes robotics implementations whose objective was twofold. They aimed to utilize robotics to teach arts and promote CT. In this section, we focus on studies following the second approach.

This section is divided into subsections related to the type of art combined with ER: painting, music, literature, scenic arts, or performing arts. The resources for synthesizing this section have been scientific papers, experiences collected from teachers associated with the FERTILE consortium, and reported implementations on different web pages.

The most common implementations were those incorporating art as a side activity. Robots or technological artefacts were built and they were carefully decorated. Aesthetic aspects were taken into account. A study developing a science-arts integrative STEAM program aiming to develop elementary school students' scientific problem-solving ability and artistic sensitivity through educational robots was presented by Kim et al. (2016). Lavicza et al. (2018) utilized the Arduino-based ReBOT Kit. This kit, together with 4Dframe robot kits, BBC micro:bit tools, and GeoGebra software, enabled making robots from simple, recycled cardboard materials, such as milk boxes.

2.1 ER and Painting

We have divided the educational implementations related to robots and painting found in the literature into two groups:

1. Implementations **incorporating the artistic aspects of plastic art in the construction of the robot's body.** As seen in Fig. 8, common materials used were cardboard, waste

materials such as milk cartons and shoe boxes, and other decorative elements (Serrano et al., 2019, Lavicza et al., 2018). In other implementations, **students just decorated the robots using different materials**: in Sullivan et al. (2018), students decorated the commercial robot platform to represent the various ethnicities in Singapore. Several studies have incorporated plastic arts in robots' decoration and personalization, although the final objective was to work with another artistic discipline, such as literature or the performing arts (Hamner et al., Cross 2013). In Yanco et al. (2007), the University of Massachusetts Lowell (UML), the Revolving Museum, and Lowell High School collaborated in the "Artbotics program", a project-based learning program where students used existing technologies including the Super Cricket, a small processing board for building robots and moving objects. Their products were then exhibited at a local museum.

Fig. 8. Examples of robot building

2. Other implementations **have used robots to paint**, incorporating an actuator capable of holding, raising or lowering a marker, brush or coloured pencil, or simply fixing this element to the robot chassis (for instance, with rubber bands). It is worth mentioning that some researchers have called this idea "using robots to create artwork" (https://artsintegration.com/2017/01/13/using-robots-create-art-dot-dash-edition/). Thus, when the robot moved and performed a trajectory with a particular pattern, it painted a figure on the ground or on the support it moved (Kim et al., 2016, Barnes et al., 2019). In the previous web page, Lauren Hodson described an implementation of creating artwork with Dash and Dot robots in her art class in Middle School. Antonio Ruiz, a teacher at the CEIP Miguel de Cervantes (Leganés, Madrid, Spain), described several ideas for implementations of arts and crafts using robotics and technology (shown in Fig 9.) in his blog "Plasticatronica" (http://jueduco.blogspot.com/2017/09/forma-color-robotica-y-mas.html)

   It is worth noting that commercial products, like Dash and Dot, Artie, OzoBot, Thymio and mTiny Discover Kit are already prepared to use colour markers.

Fig. 9. From "Using Robots to Create Art: Dot and Dash Edition"
(https://artsintegration.com/2017/01/13/using-robots-create-art-dot-dash-edition/)

RobotArt (https://robotart.org/) refers to a competition of paintings created by robots. The paint/colour is applied with one or more physical brushes by a robot system. The competition is ideal for students or professionals involved in robotics, machine learning, and image processing – especially those who appreciate art (or artists with a tech side). On the RobotArt web page, one can see pictures of participants and videos of previous winners in action. Although not intended to be an educational event, RobotArt holds the potential to inspire teachers and students.

Souliotou (2019) presented a series of activities involving drawing with artbots in different learning contexts and participants of different ages and social and cultural backgrounds. As shown in Fig. 10, the drawings were related to artists of the abstract expressionism movement.

Fig. 10. Drawings created by a)undergraduate students b) primary school students c) young refugees

A Greek Primary School developed an interesting school project. As shown in Fig. 11, 1st and 2nd-grade students created a body-pencil case with their 3D printer to make their Beebot draw a painting (Tzagkaraki et al., 2021). (https://blogs.e-me.edu.gr/hive-TPEeme/2021/10/20/%CF%81%CE%BF%CE%BC%CF%80%CE%BF%CF%84%CE%B9%CE%BA%CE%AE-%CE%BA%CE%B1%CE%B9-%CE%B6%CF%89%CE%B3%CF%81%CE%B1%CF%86%CE%B9%CE%BA%CE%AE/)

Fig. 11. Beebot drawing.

ARTY has been a week-long program for middle school students aiming to teach them the programming of robots and allow them to express themselves artistically (Burhans et al., 2017). Robots were used as vehicles for artistic expression. Students had to build the robot, and once it was finished they attached a drawing pen to it to produce a robot Artwork. They improved the robots by adding sensing capabilities and being able to produce more complex artwork. The program finished with a robot parade and a Robot Artwork Gallery.

2.2 ER and Music

Some educational projects have used robots to produce music. One of the most complex projects found in the literature was the Robot Music Camp 2013 (Chung et al. 2014). The researchers aimed to promote STEAM and Computer Science through this project. They combined music based on Lego NXT robots and Java MIDI programming. This approach allowed them to teach STEAM subjects in-depth and create interactive musical robots by emphasizing the computer science behind them.

In Barate et al. (2017), the researchers used musical media to vehiculate some aspects of computational thinking. They used the Google Blockly interface to code music. An example of this build is shown in Fig. 12.

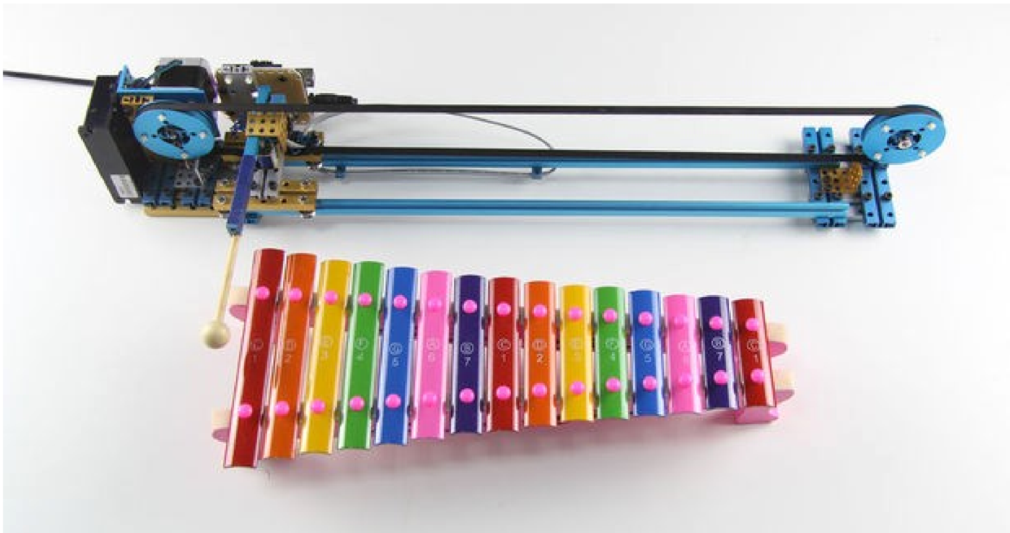

Fig. 12. Makeblock robot designed to play the Xylophone (https://youtu.be/HV-Ijkdk3p0)

Baek et al. (2020) organized group activities with music and robotics using Lego Mindstorms EV3. In these activities, students had to convert the musical notes of existing songs, use different music concepts such as keys and scales, create repeating rhythm patterns and finally compose their song.

Plenty of music projects can be found in the literature using Makey Makey invention kit for creating music (See Fig. 13). For example, Rosenbaum, one of the inventors of Makey Makey, used it in his PhD thesis as a tool for introducing "musical tinkering" (Rosenbaum, 2015). Abrahams (2018) used Makey Makey to create authentic musical sounds and instruments from everyday objects that can be conductive. The official Makey Makey platform includes detailed instructions and a wide range of music software suggested to teachers and students to create their own musical instruments. Scratch environment is considered the most popular programming environment for Makey Makey music projects as it includes a library of sounds and music loops, an audio recorder and editor, and other features related to music. There are thousands of students' and teachers' projects with music and Makey Makey in the Scratch community. In June 2022 Makey Makey joined the "Make Music Day" celebration held in more than 120 countries to promote collaborative music making and learning through play.

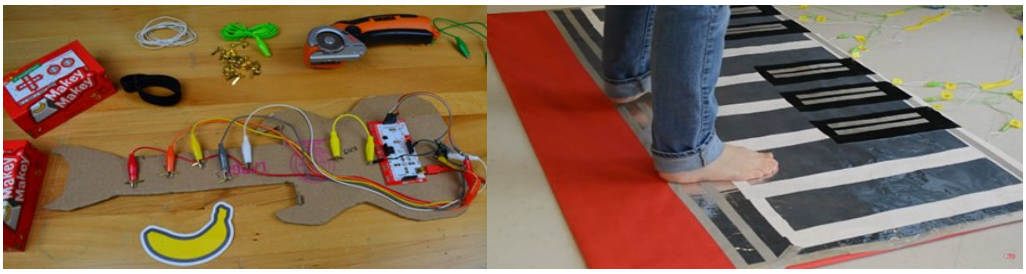

Fig. 13. Creating music with Makey Makey.

2.3 ER and Literature

Hamner et al. (2013), Cross et al. (2015), and Hamner et al. (2016) reported students having used robots to work on concepts from other subjects, including literature. Students were assigned to analyze a poem and design and then build and program a robot theatre expressing the poem. They were also intrigued to learn History and English by selecting a historical figure, researching the life of their chosen figure, writing the biography and building robotics models for their historical figures. Students worked in teams to construct anatomical models of the human arm. Servos, triggered by a sensor, controlled the movement of the elbow and wrist joints.

IToye et al. (2022) organized a program divided into three main sections: (i) history and uses of robots, (ii) components of robots and (iii) design of robots. In every section, an activity (called "Authentic Learning Task" by teachers) focused on language arts. Students were asked to write their opinion about robots and society, a detailed description of the robot they wanted to design, and an evaluation of the designed robots.

In Mehrotra et al. (2009), the researchers described their efforts to develop an exciting and motivating activity utilizing technology to counteract the tendency toward passive learning in secondary education. They chose puppetry as their medium and created a unit that involved student teams in writing stories to be communicated by puppets, designing and constructing the puppets, and presenting puppet shows. They pilot-tested the unit in three diverse cultural settings and were successful in integrating creative writing with the designing and making activities as well as in successful public performances of the shows.

Antonio Ruiz also used robotics to teach Spanish to students (see Fig. 14), making robots to represent each of the main characters of the famous Spanish novel "Don Quijote de la Mancha" (https://www.educa2.madrid.org/web/aprendemos-con-bots/libros-y-robots).

Moreover, "Introducción a la robótica: ¿Pensamos entre piezas?" (Introduction to robotics: Do we think between pieces?) (http://www.colegioportocarrero.net/index.php/robotica-en-el-aula) was a project of Cristina Martínez Fuentes, a teacher at Colegio Portocarrero (Aguadulce, Almería, Spain). Among other activities, students wrote poems related to robotics.

Fig. 14. Robots representing the main characters of "Don Quijote de la Mancha" (QuijoteBot). Taken from https://www.educa2.madrid.org/web/aprendemos-con-bots/libros-y-robots

2.4 ER and Scenic Arts

2.4.1 Non-explicitly educational projects

In this section about robots and scenic arts, we include some initiatives which are not explicitly educational. Our rationale is that some of them partially contemplate educational aspects, and all of them hold the potential to inspire combining ER and Arts in educational settings.

The Teatronika project (https://teatronika.org/principal/) was initiated in 2015 by Martí Sánchez-Fibla (researcher in Artificial Intelligence and Robotics at Pompeu Fabra University). It aimed to extend existing experiences in using 5 NAO robots for playing football to interpreting theatrical scripts written by the participants of the Teatronika Contest. Teatronika has self-published two books:

- The first book (Sánchez-Fibla, 2015) included essays, the 9 winning scripts from the 2015 edition, and a research dossier explaining insights on how they staged the construction site with the NAO robots.
- The second one (Sánchez-Fibla et al., 2016) presented a compilation of the ten winning scripts and four essays.

The world-famous "robotic poetry" by Amit Drori (https://amitdrori.com/) involved teaching the art of puppetry at the Jerusalem Visual Theater School. Drori's idea was to mix traditional puppets with homemade robots, which he designed with Noam Dover. Together with his group of puppeteers, who have become amateur engineers, he travelled around the world with this electronic staging.

An interesting website maintained by Dr Louise LePage, a lecturer in Theatre at the University of York, is available at https://www.robottheatre.co.uk/ and includes information and discussions about robots as performers and dramatic characters on twenty-first-century stages.

2.4.2 Social Robots and art

We argue that introducing social robots in education and their combination with scenic arts has created a new learning environment. How the students interact with the robots depends on the robot's role in the procedure. The robot can be a tutor, partner, or learner, and the activity design may offer different learning opportunities (Bravo et al., 2021). Students can either (i) write the story and program the robots to be storytellers, (ii) collaborate with the robots as actors in an already created story, or (iii) interact with social robots with a specific role and change the storyline.

An indicative example involves an implementation in Virginia Tech's university campus, where female high school students worked in teams to create a script and performed a short theatre play requiring the use of 4 different programmable robots Nao, Pepper, Aibo and Alexa (Nadri et al., 2020; Fig. 15).

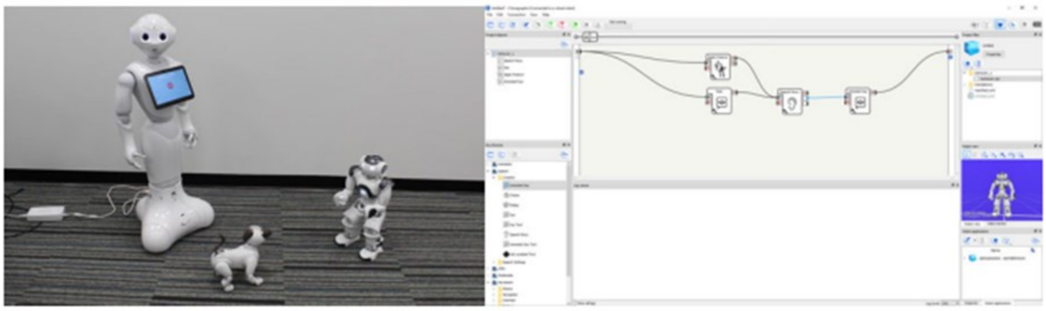

Fig. 15: Theater with NAO, Pepper, Aibo, and Alexa.

2.4.3 Educational projects

Some examples mentioned above about combining robotics with music or literature also included scenic arts, like in Mehrotra et al. (2009), where students presented public performances.
In Sullivan et al. (2018) research, preschool children in Singapore programmed a KIBO robot to perform different world dances. Preschool students collaborated in small groups to design, build, and program a cultural dance originating from around the world. All groups used at least two motors and successfully integrated arts, crafts, and recycled materials to represent their chosen dance. Several examples are shown in Fig. 16.

Fig. 16. Public performances using robots.

Another implementation in an after-school program involved K-5 students in an activity including acting, dancing, music, and drawing with the robots around the fairy tale Beauty and the Beast (Barnes et al. 2019). The research team of Ko et al. (2020) has developed a robot-theatre framework using interactive robots to integrate the arts into STEAM and robotics learning. In Cápay et al. (2019), two different activities were designed in which students used the micro:bit LEDs matrix to create images as animation frames.

Bravo et al. (2021) carried out two activities which combined storytelling, drama activities, robotics, and science learning. These researchers suggested a new methodology for this integration. In the first activity actualized in the context of an afterschool club, students created scripts to prevent water pollution. They used line follower robots as characters and craft materials for the robots' appearance. In the second activity actualized in a Technology class, students dramatized the story of the inventor Thomas Edison. They used line follower robots to add screens with RGB LEDs to show characters' expressions and Bluetooth speakers to play audio files.

Special mention deserves research in teacher education related to robotics education and arts since such research is very scarce in the literature but at the same time, quite essential for robotics integration in education. This research was conducted in a pre-service teacher education course that integrated crafts, physics, drama, and ICT. Craft designing process and creation of innovative artefacts (smart textiles) were enriched by ideas from physics and drama education (Kallunki et al. 2019).

An Italian school implemented an exciting project combining robotics and drama. The students were intrigued to creatively understand and process the literary text of the Wizard of Oz by Baum. They performed a show with robots and students on stage. Their methodology followed in this project was to align the four computational thinking concepts with the project's phases organized (https://marilina.edublogs.org/2017/05/17/__trashed/).

The 1st Panhellenic Online Educational Robotics Competition, although originally planned for 2020, due to the lockdown imposed by the Covid-19 pandemic, went online. Students of all ages were asked to use their imagination and represent spring by making robots dance like insects, animals, and humans. The prerequisites included using any technology and robotic kit they preferred, dressing their robots, making authentic music and making the robots dance. The competition's motto was " Dancing...in the Spring! Get inspired... and Create!" (https://wrohellas.gr/dancing-in-the-spring-get-inspired-and-create/?lang=en#1586161233097-5f94b6fb-6941).

There are implementations having set objectives explicitly related to arts. For instance, in Catlin et al. (2010), the students created a puppet movie with robots, using robots to design a theatre and express a poem. Similarly, Sullivan et al. (2018) intrigued preschool children to program robots perform several world dances.

Aalborg University (Denmark) conducted one of the few implementations in higher education in the context of an undergraduate course in art and robotics. Aiming to integrate fundamental concepts of computer science, robotics, and art installation, they attempted to bridge the gap separating humanities from computer science and engineering education to prepare students address real-world problems in robotics, including human-robotic interaction and HCI (Jochum et al., 2015).

2.5 ER and Performing Arts

2.5.1 Performing arts festivals

In this section, along with the individual initiatives, we highlight two festivals organized around performing arts and robotics. We argue that joint activities, beyond class work, motivate students and promote their involvement. There are also activities organized either in performing arts contexts during school theatre festivals or in educational robotics' contexts during competitions such as the WRO (https://wro-association.org/)

"Programa tu obra" (Program your Play) Cycle of Robotics Theater initiated as an educational project where students were taught to work in a group combining technology and art. The Kaleidoscopio (http://elcaleidoscopio.com/wp/pto-2/) has developed this project aiming to introduce teaching practices based on the development of projects in schools, and in this specific case, that of the performing arts and robotics. An example is shown in Fig. 17.

A robotics art festival integrating robotics and arts was launched in Michigan in November 2013 to foster interest and engage students in STEM. Pre-college students participated in computer-programmed interactive robotics projects in two categories: visual and performing arts (Chung 2014).

Fig. 17. Program your Play project. From (https://www.parquecientificoumh.es/es/noticias/el-teatro-robotico-nace-como-una-forma-de-usar-las-tecnologias-en-lugar-de-que-ellas-nos)

In ER contexts, there were also activities incorporating short film recordings. Indicatively, we note Catlin et al. (2010) research, where students were asked to create a puppet movie and replace puppets with Roamer robots. Fig. 18 presents an example of a Roamer robot.

Fig. 18. Roamer Robot cosplay (from http://www.valiant-technology.com/uk/pages/news_photogallery.php?cat=1id6)

Denicolai et al. (2017) reported the results of an experimental study in Media Education and ER. This study was based on integrating the audiovisual language (video), the Robotics language (LOGO), and the ancient theatrical language of marionettes (puppets of the Italian Dynasty of the Lupi Family). This case study was part of a broader research about the role of multimedia language and innovation in Education, Pedagogy, and Anthropology of Media.

As in the case of the scenic arts, we highlight an initiative that, although not directly related to ER, we believe involves a pertinent and inspiring case: the ROS Film Festival. The festival's objective, as stated on its website (http://rosfilmfestival.com/presentacion/) was the following:

> "In addition to establishing a new space for dialogue between art, science and technology, the main aim of the Robotic Online Short Film Festival (ROS Film Festival), is to be able to elucidate how this imaginary we previously referred to is made up, by making creators and viewers reflect on a not so distant society where we share our daily life with social robots, those who are capable of interacting and empathizing with humans or among themselves. Thus, the ROS Film Festival aims to create stories where robots, alone or with humans, are the protagonists. It has one official section and can include any type of robot, whether real (programmable and made with electronic circuits) or fictional (created through animation techniques or represented by actors through characterization). In this section, works will also be accepted if one of the central characters represents an artificial intelligence, with or without physical form".

3. ER FOR THE ADVANCEMENT OF CT

ER increasingly appears in educational settings, as it is useful for promoting Computational Thinking (CT) to students of all ages. According to Bocconi et al. (2022), robotics kits and visual programming environments were considered the most appropriate tools to teach, learn and assess CT. Angeli et al. (2019) and Mikropoulos et al. (2013) emphasized the importance of early exposure to computer science in developing and enhancing all CT skills. The research work presented in this section aligns with this view and attempts to contribute to the current debate on CT cultivation through ER.

In this section, the review includes publications in journals and conferences presenting studies on the cultivation of CT through ER activities. Special attention is paid to the educational approaches used to cultivate CT through ER and the emerging concepts and skills of CT that these researches focused on. Additionaly, in Table 6, we present a comparative analysis of studies according to (i) the robotics technology used, (ii) the educational level at which the research was conducted, (iii) the ER intervention's structure, (iv) the CT skill/dimension cultivated (definition, skills, dimensions, etc.), (v) the means of data collection for the research, and finally, (vi) the main results of the research.

Chevalier et al. (2020) proposed the **Creative Computational Problem Solving (CCPS)** model (see Fig. 19), which consisted of five main consequent phases and an additional sixth one. According to this model, students are asked to

i) understand the problem (subtraction and decomposition) (Phase 2-understanding the problem (USTD)),
ii) propose ideas for solving it (Phase 3- Generating Ideas (IDEA)),
iii) formulate the desired behavior of the robot that solves the problem (Phase 4 - formulating the behaviour (FORM)),
iv) program the robot (Phase 5 - (PROG)),
v) evaluate the solution (Phase 6- (EVAL)).

There is also an additional first phase, which takes into account cases where the person proposing the solution to the problem is not involved in the next phases (task-off behavior (Phase 1-(OFFT)).

This research team stated that the transition of phases corresponding to the most effective transition cycle is USTD-IDEA-FORM-PROG-EVAL-USTD. However, usually, the USTD, IDEA and FORM phases (which are considered essential for the cultivation of CT) are skipped, and students focus on programming (PROG) and evaluating immediately (EVAL), thus adopting a trial-and-error approach. Therefore, the authors suggested that students should focus on the USTD-IDEA-FORM loop without being able to enter the PROG phase of the robot at the beginning, and be gradually introduced to the programming so that they can evaluate the solution they give without being able to control programming the robot's behaviour.

The CCPS model has been modified through the **Educational Robotics System (ERS)** conceptual framework (Giang et al., 2019). According to the ERS, ER activities are usually based on three main fundamental components: (i) one or more educational robots, (ii) an interactive interface allowing the user to communicate with the robot, and (ii) one or more problems to be solved in an environment. The results of the Giang et al. (2019) study showed that (i) a non-instructional approach for educational robotics activities may promote a trial-and-error behavior; (ii) a scheduled blocking of the programming interface may promote cognitive processes related to CT; and (iii) a progressive adjustment of the programming interface's blocking may provide instructional scaffolding.

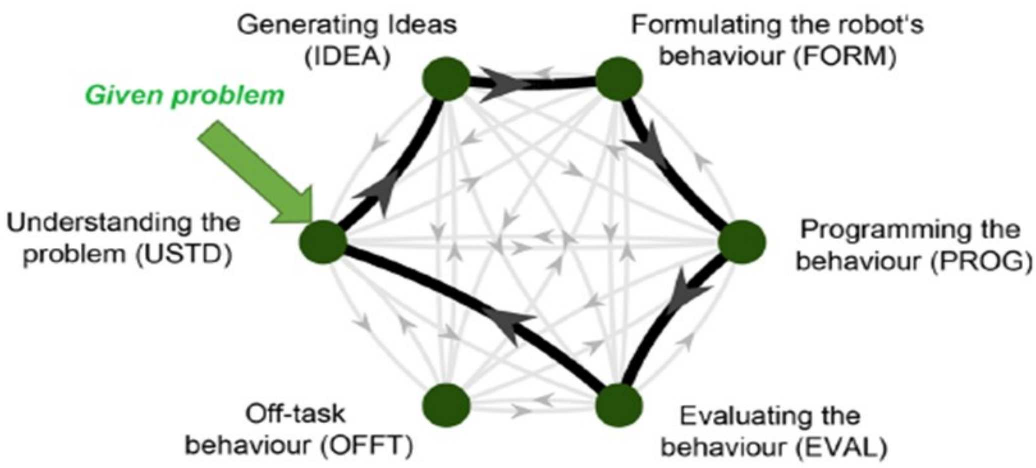

Fig. 19. Phases and transitions of the CCPS model. The theoretically most effective problem-solving cycle is highlighted in black.

Chen et al. (2017), adopting the operational definition of CT (see Table 3) given by the International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) (2011), proposed a five-component instrument for **CT assessment**: (i) Students answered the question using correct syntax, (ii) Students noticed and correctly used the data given in the question, (iii) Students came up with an algorithm that correctly solved the problem, (iv) Students represent solutions in multiple ways that are consistent with each other, (v) Students solved the problem efficiently. The assessment instrument included closed and open-ended items. For the designed robotics activities, this research team implemented a robotics curriculum that was first presented in the Transformative Robotics Experience for Elementary Students project (https://sites.education.miami.edu/trees/). Their findings revealed that the participating students improved their CT through the robotics curriculum to the same extent regardless of their initial performance.

Table 3. CT characteristics according to ISTE and CSTA (2011) definition

CT characteristics according to ISTE and CSTA (2011) definition
Formulating problems in a way that enable users to use a computer and other tools to solve them
Logically organizing and analyzing data
Representing data through abstractions such as models and simulations
Automating solutions through algorithmic thinking (a series of ordered steps)
Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
Generalizing and transferring this problem solving process to a wide variety of problems

Leonard et al. (2016) performed a study focusing on robotics, gaming and computational thinking. They used the Learning-for-Use (LfU) model (Edelson, 2001) to support and reinforce students' learning to motivate participation in STEM/ICT. The LfU model is a learning theory aiming to provide a design framework. The model describes the development of understanding as a three-step process of i) motivation, ii) knowledge construction, and iii) knowledge improvement.

In the robotics context, the course was organized as follows:

Task 1: constructing the robot (vehicle),

Task 2: familiarizing with simple programming concepts for robot motion,

Task 3: using sensors for robot motion (creating maps for robot motion),

Task 4: learning to write advanced code for complex problem solving activities .

In Leonard et al. (2016) study, the screenshots, the programming code, and actual games provided evidence of CT. To measure CT a rubric was created using the "International Society for Technology in Education" (ISTE) definition (https://cdn.iste.org/www-root/Computational_Thinking_Operational_Definition_ISTE.pdf) (see Table 4). The components of the CT rubric were: i) formulating problems, ii) abstraction, iii) logical thinking, iv) using algorithms, v) analyzing and implementing solutions, vi) generalizing and problem transfer, vii) using pop gaming culture. It was found that CT and creativity were less evident when teachers used only instructional scaffolding methods. On the other hand, students' engagement in goal-directed tasks and situated learning by developing games and simulations, taking into account the students' constructs of culture and place, seemed essential for CT development.

Table 4. The three steps in the LfU model with descriptions of the processes comprising each step as proposed by Elderson (2001)

Step	Process	Design Strategy
Motivate	Experience demand	Activities *create a demand* for knowledge when they require that learners apply that knowledge to complete them successfully.
	Experience curiosity	Activities can *elicit curiosity* by revealing a problematic gap or limitation in a learner's understanding.
Construct	Observe	Activities that provide learners with *direct experience* of novel phenomena can enable them to *observe* relationships that they encode in new knowledge structures.
	Receive communication	Activities in which learners receive direct or indirect *communication* from others allow them to build new knowledge structures based on that communication.
Refine	Apply	Activities that enable learners to *apply* their knowledge in meaningful ways help to reinforce and reorganize understanding so that it is useful.
	Reflect	Activities that provide opportunities for learners to retrospectively *reflect* upon their knowledge and experiences retrospectively, provide the opportunity to reorganize and reindex their knowlege.

Sen et al. (2021), conducted a case study examining gifted and talented students' CT skills within the scope of the Engineering Design Process (EDP) (Han & Shim, 2019). As seen in Figure 20, EDP includes (i) identifying and (ii) researching the need/problem, (iii) selecting the best possible solution, (iv) prototyping, (v) testing and evaluating the solution, (vi) communicating, and (vii) redesigning. In line with promoting students' problem-solving "*in consideration of future societal and environmental issues*" (National Research Council, 2013), the EDP holds the potential to provide an appropriate context for CT development..

The ER implementation in Sen et al. (2021) study is given below:

A. Introductory tasks for acquiring experience with EDP, programming, and 3D modelling:

1. Conducting hands-on STEM activities for students to gain experience with EDP.
2. Carrying out 3D modeling activities (tinkercad, 3D modeling, 3D printers).

B. Main EDP-STEM activities

1. Building robots (Lego Mindstorms) organized as a group activity. Problem-solving activity (robot solves Rubik's cube). Emphasis on searching for

possible solutions, analyzing solution steps, and extending the solution for cubes of increased difficulty.

2. Modeling robots (3D modelling with Tinkercad) organized as an individual activity. Identifying a problem, its solution and producing a robot providing the solution. Evaluating the robots' features and suitability for 3D printing.

3. Producing robots (3D printers) is organized as an individual activity. Presenting the properties and working principles of the robots produced. Evaluating the robots and implementing any needed modifications.

The study concluded that the EDP-STEM design activities supported gifted and talented students cultivating creative and CT skills.

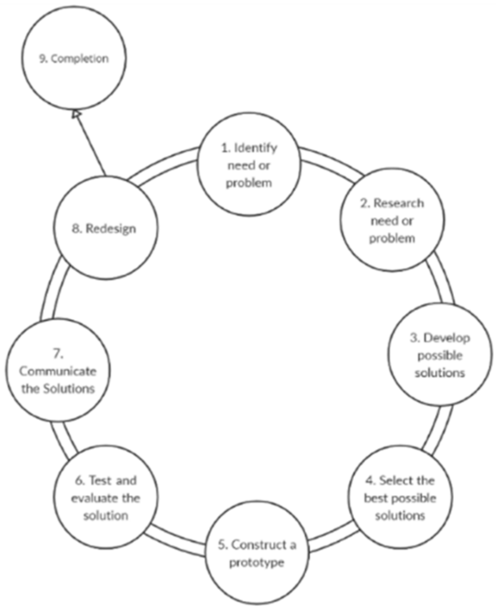

Figure 20. Engineering Design Process (Hynes et al., 2011)

Taengkasem et al. (2020) proposed a robot inquiry-based learning method to foster students' CT. They used the 5E learning cycle method (inquiry-based learning approach) to introduce the MEC-Ed robots as learning material to employ engineering design. Each robot's part was printed with a 3D printer and was connected to an Arduino board. The 5E learning cycle consists of 5 learning phases: engagement, exploration, explanation, elaboration, and evaluation (Bybee, 2014). These authors revised the "Elaboration" phase and called it "Execution" as more appropriate for educational robotics activities (see Figure 21).

Specifically, during the **Engagement** phase, the teacher encourages students by engaging them in real-world problems to motivate them to participate in the learning activity and think about the problem. During the **Exploration** phase, the students explore and propose a solution to the given problem. In the **Explanation** phase, the students explain the problem's solution and justify the methods using appropriate terms. During the **Execution** phase, the students perform the robot's task to solve the problem. Finally, during the **Evaluation** phase, the solution is evaluated.

To evaluate CT outcomes, the research team of Taengkasem et al. (2020) used an observation checklist developed according to the three CT dimensions, including computational concepts, computational practices, and computational perspectives (Brennan et al., 2012). The results showed that all CT dimensions' levels were good.

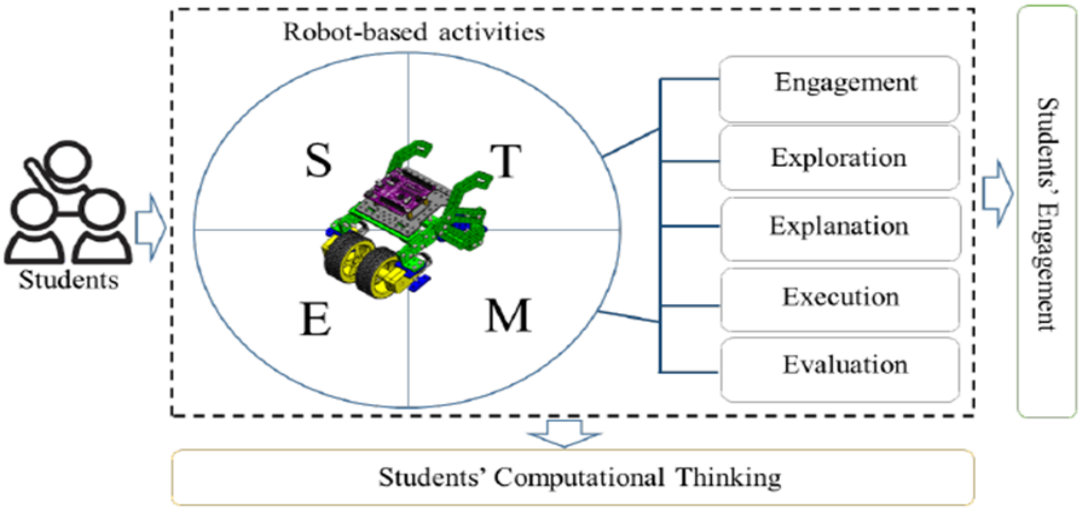

Figure 21. Robot-based activities framework (Taengkasem et al., 2020)

Atmatzidou et al. (2016) used LEGO Mindstorms NXT and employed a CT model incorporating 5 CT skills (abstraction, generalization, algorithm, modularity, and decomposition). They conducted a study in a secondary educational setting to operationalise and explore an ER activity's impact on students' CT skills development, addressing gender implications.

Specifically, these researchers' approach to implementing the theoretical approach to CT in ER focused on five key skills of the broader conceptual CT framework. These were: a) abstraction, b) generalization, c) algorithm, d) modularity, and e) decomposition.

This study was organized in 11 sessions as follows:

Session 1: Introduction of robotics concepts and the functions of the robot. Collaborative program development by students with a robot kit. Emphasis was placed on the concept of algorithms and on the value of precise instructions to solve problems.

Session 2: Familiarization with some basic programming concepts (sequence structure and loop structure) and sensors and robot characteristics. Simple problem-solving activities. Focus on the concepts of abstraction and generalization through reflection in problem-solving activities.

Session 3: Actualization of familiarization activities with programming structures that gradually led to problem-solving activities focusing on modularity and decomposition.

Session 4: Actualization of activities provoking engagement in practising all the concepts of the CT model.

Sessions 5 and 6: Further familiarization with sensors and programming concepts (subroutines, parallel programming) leading to a problem-solving activity.

Sessions 7 and 8: Further familiarization with variable and operator concepts aiming to lead to a problem-solving activity.

Sessions 9 and 10: Actualization of Iincreased-difficulty activities to practice developing CT skills in the context of more complex authentic problems.

Session 11: Problem-solving activity: a challenging robot programming task for teams competing against each other. The winner was the team that proposed an effective and efficient solution to the task (optimized code and faster solution).

How CT skills were cultivated during the previous sessions is shown in Table 5.

Table 5. The CT skills model applied (Atmatzidou et al., 2016)

CT skills	Description	Student skills (The student should be able to...)
Abstraction	Abstraction is the process of creating something simple from something complicated, by leaving out the irrelevant details, finding the relevant patterns, and separating ideas from tangible details [52]. Wing [2] argues that the essence of CT is abstraction.	1. Separate the important from the redundant information. 2. Analyse and specify common behaviours or programming structures between different scripts. 3. Identify abstractions between different programming environments.
Generalisation	Generalisation is transferring a problem-solving process to a wide variety of problems [38].	Expand an existing solution in a given problem to cover more possibilities/cases.
Algorithm	Algorithm is a practice of writing step-by-step specific and explicit instructions for carrying out a process. Kazimoglu et al. [37] argue that selection of appropriate algorithmic techniques is a crucial part of CT.	1. Explicitly state the algorithm steps. 2. Identify different effective algorithms for a given problem. 3. Find the most efficient algorithm.
Modularity	Modularity is the development of autonomous processes that encapsulate a set of often used commands performing a specific function and might be used in the same or different problems [38].	Develop autonomous code sections for use in the same or different problems.
Decomposition	Decomposition is the process of breaking down problems into smaller parts that may be more easily solved. Wing [2] argues that CT is using decomposition when attacking or designing a large complex task.	Break down a problem into smaller/simpler parts that are easier to manage.

The findings indicated that: (i) all students reached the same CT development level at the end of the activity, (ii) CT skills take time to be developed, (iii) girls seem to need more training time than boys to reach the same CT skills' level.

The Keane et al. (2016) study proposed the 4plus4 Model for using humanoid robots to enhance students' curiosity and engagement. The 4plus4 Model describes how students may cultivate CT and coding skills. To this end, it leverages the 4Cs (curiosity, communication, critical thinking, and creative thinking) (see Figure 22). According to the model, CT allows students to "collaboratively develop procedural thinking by breaking complex challenges into smaller tasks that can be solved". The model focused on researching the impact of humanoid robots on students' learning rather **than providing guidelines** for organizing interdisciplinary teaching of ER and CT promotion. Regarding CT, the study's findings revealed that NAO humanoid robots promoted CT and students' acquired skills related to CT, such as: problem decomposition, algorithmic thinking, problem-solving, designing sequences, and testing and debugging. In this particular research, CT is related to coding.

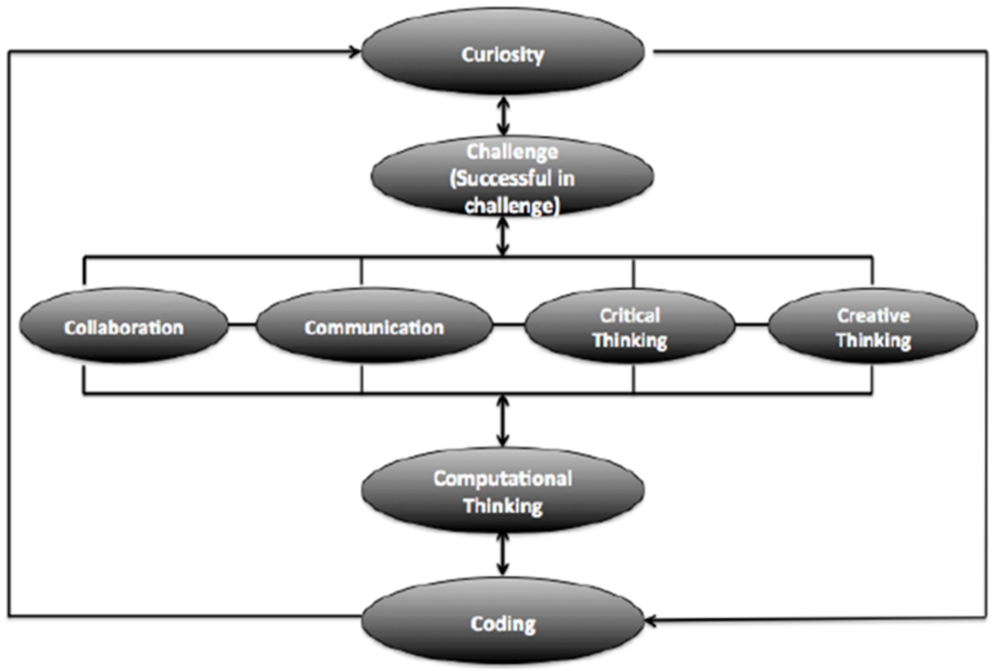

Figure 22: 4PlusModel (Keane et al., 2016)

Table 6 compiles some studies promoting CT through ER activities. The first column includes the authors, the second column contains the educational level of the study's implementation, the third column shows the physical robot used in the study's ER activities, the fourth column includes the CT definitions and components researched in the study, the fifth column identifies the different evaluation methods of each study and the sixth column summarize the main findings of the study. Reviewing this information, it is possible to determine the different approaches to combining ER activities with CT development.

Table 6. Studies aiming to promote CT through ER activities

Authors	Educational Level	Robotic Technology	ER intervention	Computational Thinking Definitions and components	CT Evaluation means	Findings
Chevalier et al. (2020)	Primary	Thymio-VPL	The CCPS (used for CT skills development) modified by the conceptual framework of ERS	Each of the 6 phases of the CCPS model is related to specific CT processes: understanding the problem (subtraction and decomposition), generating ideas, formulating the behaviour, programming the behavior, evaluating the solution, off-task behavior	In situ observations mapping the behaviour of the students through the activities	Evidence on the need for specific instructional interventions in ER activities to develop the phases and transitions of the CCPS model
Chen et al. (2017)	Primary	NAO Physical robot	Combination of virtual and one physical robot (blended learning approach). ER as a learning object organized in three phases: (a) students work first with basic robot actions, b) then with key computer science concepts, c) 4 final mini projects	CSTA based proposed definition: problems' formulation, data analysis, abstraction, algorithmic thinking, implementation of possible solutions and generalization	CSTA based assessment instrument as a pre-post test	The proposed curriculum promoted students' CT skills improvement.

Leonard et al. (2016)	Middle school	LEGO EV3 and Mindstorms software	Learning-for-Use (LfU) model (Edelson 2001)	CSTA based assessment: a) formulating problems, b) abstraction, c) logical thinking, d) using algorithms, e) analyzing and implementing solutions, f) generalizing and problem transfer, g) using pop gaming culture.	Qualitative data showing how students' CT strategies were evident in students' artefacts – CT rubric	Students who participated in holistic game development had higher CT ratings.
Sen, Ay, & Kiray (2021)		Tinkercad, EV3 Lego Mindstorms, robots with 3D printer	Engineering design process (EDP) (Han & Shim, 2019). activities designed by the researchers include four hands-on, one robotics, and four 3D modelling STEM activities.	CT skills: algorithmic thinking, problem-solving communication, cooperativity, critical thinking, and creativity	STEM activity booklet, researchers' fieldnotes, and in-class video recording, inductive approach analysis	The EDP-STEM design activity supported gifted and talented students' creative and computational thinking skills
Taengkasem et al., (2020)	Secondary (High School)	MEC-Ed (Mechatronic Education robot) that are low-cost robots prototype and Arduino board programmed with Scratch	5E learning phases (Bybee, 2014) (engagement, exploration, explanation, execution, and evaluation)	3 CT dimensions: concepts, practices, perspectives (Brennan & Resnick, 2012)	Observation checklist on CT dimensions scale	The framework supports the three CT dimensions (concept, practice, and perspective), and enhances students' engagement with robotic activities

Atmatzidou et al. (2016)	Secondary	Lego Mindstorms NXT 2.0	ER as learning object, 11 sessions of increased difficulty in the context of more complex authentic problems, teacher as facilitator, roles given in every team	CT skills: abstraction, generalization, algorithm, modularity, decomposition	At the beginning: profile questionnaire after the 10th session of the seminar: CT questionnaire, At the end of the seminar: (a) a "think-aloud" protocol implementation (b) a student's opinion questionnaire.	Students reach the same level of CT skills development regardless of age and gender. CT skills in most cases need time to fully develop Girls need more training time The different modality (written and oral) of the CT skill assessment may have an impact on students' performance.
Keane et al. (2016)	Primary, Secondary	NAO humanoid robots	4Plus4 model	Wing's (2008) definition of CT	An online questionnaire, a reflective journal, and a semi-structured interview were given to the teachers	Curiosity is a strong motivator for CT. Students identified related skills like: including problem decomposition, algorithmic thinking, problem-solving, designing sequences, and testing and debugging

4. ER AND ART IN THE EDUCATIONAL CURRICULUM

This section reviews the presence of ER and Art in the official curricula of several European countries. In particular, in all the countries of the consortium: Greece, Slovakia, Spain and Czech Republic; and at all education levels: primary, secondary, higher education, and non-formal education, while higher education is mainly approached regarding teacher training.

4.1 ER in the Greek Educational System

In Greece, an ongoing curriculum reform started in 2018 aiming to integrate CT, ER and New Technological tools in Education (see Table 7 for an overview). As part of this reform, the teaching hours of ICT courses increased, and concepts such as ER and CT were introduced into the new curriculum (Institute of Educational Policy, 2022).

Table 7. ER in the Greek Educational curriculum

Country	Educational Level	Concept	Subject applied	Grade applied	Hours/Week	Related Units
Greece	Primary	ER	ICT	1st to 6th	1 hour	• Algorithms • Programming • Problem solving with programming tools (Robotics and Automations)
			"Skills Workshop"	1st to 6th	2 hours	• STEM / Educational Robotics
		Arts	Music	1st to 6th	1 hour	• Collaborative activities of the three subjects based on experiential and inquiry-based learning. • Dramatization of poems, fairy tales etc./ • Role playing / Theatrical performance
			Arts and crafts	1st to 2nd 3rd to 6th	2 hours 1 hour	
			Drama	1st to 4th	1 hour	
	Lower Secondary (1st – 3rd grade)	ER	ICT	1st 2nd to 3rd	2 hours 1 hour	• Implement research projects with ICT. Educational Robotics"
			Technology	1st to 3rd	1 hour	• Mechatronic / Robotics • Physical world and Technology
			"Skills Workshop"	1st to 3rd	1 hour	• Educational Robotics
		Arts	Music	1st to 3rd	1 hour	• Interdisciplinary projects that meet the philosophy of STEAM • Image and sound (Music and cinema) • Create music
			Arts and crafts	1st to 3rd	1 hour	• Animation, • New Technologies/ Current forms of Visual Arts, (Abstraction)
	Upper Secondary (1st – 3rd grade)	ER	Computer Applications	1st	2 hours	• Implement research projects with ICT. Educational Robotics"
			Introduction to the Principles of Computer Science	2nd	2 hours	• Programming Languages / AI
		Arts	-			

4.1.1 Primary Education

Educational Robotics

ER is included in the Greek Primary Education from 1st to 6th grade in the **ICT** subject planned for 1h per week. The ICT subject's curriculum includes a separate section called "Algorithmic and

programming computer systems" with three different units. "Algorithms", "Programming", and "Problem-solving with programming tools (Robotics and Automation)".
Starting in September 2021, the new subject, "**Skills Workshop**", was added, including STEM/Educational Robotics among its thematic fields. While implementing this workshop's practices is proposed to involve using simple educational material (construction materials, unplugged programming activities, open and free digital resources).

Arts

Arts in Greek Primary Education is called **Aesthetics Education,** divided into three subjects: **Music, Arts and crafts,** and **Drama**.

Despite the different topics in these three subjects, emphasis is placed on collaborative activities based on experiential and inquiry-based learning. Some methodological approaches suggested are role-playing and game-based learning. The subject of **Music** is taught from 1st to 6th grade once per week. **Arts and crafts** subject is applied to 1st till 2nd grade twice per week, and from 3rd to 6th grade once per week. **Drama** subject is applied to 1st till 4th grade once per week.

4.1.2 Secondary Education

Educational Robotics

In **Lower Secondary Education,** ER is addressed in three different subjects.
In the subject of **Informatics** from 1st to 3d grade as part of the unit "Implement research projects with ICT. Educational Robotics". In the 1st grade, Informatics is applied for 2 hours per week, whereas in the 2nd and the 3rd grade, for 1 hour per week) .
In the subject of **Technology,** thematic units are introduced, such as a) Analog and Digital World, b) Energy, c) Mechatronic / Robotics, and d) Physical world and Technology. In all grades, Technology is applied for 1 hour per week, while the learning objectives emphasize the holistic approach of STEAM.
From September of 2021, as in the primary level, ER is introduced in the new subject "**Skills Workshop**" as part of one of the thematic fields concerning "Digital Skills: STEM/Educational Robotics".

In **Upper Secondary Education** and specifically in the 1st grade, the subject "**Informatics Applications**" is applied for 2 hours per week where various programming environments are provided to students (according to the suggestions of the curriculum) for developing applications. The curriculum of Informatics subjects in the 2nd and 3d grades is unrelated to ER.

Arts

In **Lower Secondary Education,** two Art subjects **are** applied once per week, **Music** and **Art.**
In the subject of **Music,** thematic units are introduced, such as a) Understanding the concepts and elements of music, b) Recognising the types of music, c) Connecting music with other arts, instruments, and science, and d) Music in life inside and outside school. In all grades, Music is applied for 1 hour per week, and the primary teaching approach emphasizes to deploying

interdisciplinary projects that meet the philosophy of STEAM for enhancing collaboration, creative thinking, and innovation.

In the subject of **Arts and Crafts,** which is applied once per week, thematic units are introduced to cultivate creative thinking, critical thinking, and collaboration through a jigsaw learning strategy.

In **Upper Secondary Education,** until September 2021, Art subjects were optional in the curriculum**.** However, the last reform did not include any art subjects in the curriculum.

The ministry's official instructions to teachers for all the above subjects, include generalized teaching approaches that a) encourage concepts such as collaboration and CT, and b) provide some examples of teachers' best practices. However, no methodology is provided focusing to support teachers in such a new field. Therefore, teachers are practically on their own to implement the curriculum, as mentioned earlier. Regarding the infrastructure needed, starting in September 2022, 177.000 robotic kits are scheduled to be distributed to public schools for preschool, primary and elementary students, i.e., from 4 till 15 years old. The equipment and the related software will be categorized according to students' age.

4.1.3 Higher Education

In Higher education, courses on Educational Robotics are offered at the undergraduate level as distinct courses or as topics in the syllabus of courses on ICT in Education or STEM/STEAM, mainly at (a) departments in the area of education sciences such as Departments of Education preparing teachers for Primary Education, or Departments of Preschool Education, or Departments on Educational Policy and Special Education, (b) departments in the area of Computer Science and Informatics.

At the postgraduate level, courses on Educational Robotics are offered in the curriculum of Master of Science Programs focusing on STEM or digital technologies in the educational practice like the MSc "Digital Transformation and Educational Practice" co-organised by the University of West Attica, University of Athens and ASPETE.

There are also initiatives at various universities offering courses on Educational Robotics as lifelong learning, usually focusing on specific technologies or the introduction of robotics in educational practice or the context of STEM, STEAM, and Informatics, such as:
The University of Macedonia - Center for Training and Life Long Learning - STEAM for Educators
The University of Macedonia - Academy of Robotics
The University of Thessaly - Educational Robotics with Lego WeDo 2
The University of West Attica - Center for Training and Life Long Learning - Informatics, STEM and Robotics at Primary and Secondary Education
The University of West Attica - Academy of Robotics
The University of Aristotle University - FutureLAB
The University of Athens - Center for Training and Life Long Learning - Educational Robotics
The University of Patras - Center for Training and Life Long Learning - Educational robotics, STEM & Coding

4.1.4 Non-formal level

At a non-formal level, plenty of extra-curricular activities are often conducted after the formal school schedule. They are organized by teachers, non-profit or profit organizations and use various ER kits such as Lego Ev3 Mindstorms, Arduino, WEDO 2.0, and RASPBERRY (Karypi, 2018). Greek students' participation in many Robotic Competitions and festivals is high. Competitions organized by WRO Hellas and, First Lego Leauge, and Robotic Festivals (https://openedtech.ellak.gr/, https://mfr.peiramak.gr/index.php?lang=el) are supported but not organized by The Greek Ministry of Education.

4.2 ER in the Slovak Educational System

In Slovakia, the 2008 education reform (National Institute for Education, 2022) introduced a new compulsory subject, Informatics (ISCED-1, 2008; ISCED-2, 2008; ISCED-3, 2008). Its objective was to ensure the development of digital literacy and logical and computational thinking. The national curriculum set out the educational areas and, in them, the performance standard and the educational standard. That is, at what level and to what extent pupils should have knowledge of a given subject at the end of each educational level. The Informatics curriculum at all levels of education is divided into 5 areas: Representations & Tools, Communication & Collaboration, Software & Hardware, Information Society, and Problem Solving. Problem Solving includes topics such as Problem analysis, Logic, Algorithmic Problem Solving, Solution interpretation, Debugging, etc. Within the Algorithmic Problem Solving area, topics such as Direct control of a command executor, Sequence of commands execution, Planning, and others were also included, which could be fulfilled by Educational Robotics. However, educational robotics is not mandatory in the curriculum, and schools can decide what environments, programming languages, or command executors to use in the classroom.

Based on the national curriculum, schools develop a sxchool curriculum that may vary slightly in the number of lessons or subjects. An overview of the ER in the Solak curriculum is shown in Table 8. For all educational levels, one teaching hour lasts for 45 minutes.

4.2.1 Primary Education

The primary level of education includes grades 1-4 of primary school (9-year study) in Slovakia (ISCED-1, 2022).

Robotics

ER is not a compulsory subject in the curriculum of primary education. Robotics is just one possible means of teaching programming, which is part of the subject of Informatics. Informatics is taught in primary education from the third year. However, schools can include it in their curricula from the first year. Robot as an executor of commands in algorithmic problem solving is mentioned in the curriculum in the 4th year of primary school.

Arts

Art is taught in primary education in two subjects: art education and music education. **Art** education mainly includes drawing, painting, and handwork with various materials and aims at developing imagination and fantasy, observation and expression abilities, and skills in working with tools and materials. Art education is taught for 2 lessons a week in the first two years and in the third and fourth years for one lesson a week. **Music** education focuses on singing, active listening, playing basic instruments, music and movement activities, and music and drama activities. It is taught in one weekly lesson in all 4 years of primary education.

Table 8. ER in the Slovak curriculum

Country	Educational Level	Concept	Subject applied	Grade applied	Hours/Wee	Related Units
Slovakia	Primary (grades 1-4 of primary school)	ER	Informatics	3rd-4th (optionally 1st-4th)	1 hour	• Algorithmic problem solving • Programming
		Arts	Arts (painting and handicrafts)	1st-2nd	2 hours	• Development of imagination and fantasy, observation and expression abilities and skills in working with tools and
				3rd-4th	1 hour	
			Music	1st-4th	1 hour	• Singing, active listening, playing basic instruments, music and movement activities, music and drama activitiess
	Lower secondary (grades 5-9 of primary school)	ER	Informatics	5th-8th	1 hour	• Algorithmic problem solving • Programming
		Arts		5th-9th	1 hour	• Fine arts, photography, design, architecture, video and film • The expressive means of visual arts and basic literacy in their use
			Music	5th-8th	1 hour	• Acquiring musical skills through musical activities, • Implementing musical activities on the basis of acquired musical abilities, • Learning specific knowledge of music theory and history based on their own experience
	Upper secondary (4 years)	ER	Informatics	1st - 3rd	1 hour	• Algorithmic problem solving • Programming • Software and hardware
		Arts	Art and culture		overall 2 hours during the whole 4-year study	• Cultivating artistic, aesthetic, visual, acoustic, language and movement literacy • Expanding experience with active creation within projects in the field of various arts and media • Distinguishing the main artistic and cultural directions, movements and types

4.2.2 Secondary education

The lower secondary education level includes grades 5-9 of primary school (ISCED-2, 2022). The Upper secondary level refers to high school (4-year study) (ISCED-3, 2022). Schools at the secondary education level are also free to develop their school curricula, which may differ slightly from the national curriculum.

Educational Robotics.

Even in secondary education, Educational Robotics is not a compulsory part of the national curriculum but can be included in the school curriculum. Robotics may be used in Informatics classes taught at the lower secondary level in 5th-8th grade of primary school for 1 weekly lesson and the upper secondary level in 1st-3rd grade of high school (also 1 weekly lesson). Secondary schools also offer elective Computer Science seminars, which focus mainly on programming and are often offered in the 3rd and 4th high school years.

Arts.

Art is taught at the lower secondary level in the same way as at the primary level - in the subjects of Art and Music. Art is taught in grades 5-9 in one weekly lesson and incorporates visual arts, photography, design, architecture, video and film, expressive art media, and basic literacy. Music is taught at the lower secondary level for 1 weekly lesson in grades 5-8 and focuses on musical skills acquisition through musical activities, the implementation of musical activities based on acquired musical skills, and achieving specific knowledge of music theory and history based on personal experience.

At the upper secondary level (high school), there is only one subject, Arts and Culture, focusing on arts. It aims to cultivate pupils' artistic, aesthetic, visual, aural, linguistic and motor literacy, broaden their experience of active creation in various arts and media projects, and develop their appreciation of the main artistic and cultural movements and types. Its hourly allocation is only 2 hours during the whole 4-year study.

4.2.3 Higher Education

There are 34 colleges and universities in Slovakia. In the last few years, universities have responded to the importance of robotics, and a few fields of study have emerged, focusing on robotics as a scientific discipline. ER is mainly taught at faculties training future teachers. Five universities provide teacher training for primary schools. Primary school teachers teach almost all subjects. Since, this study is not divided according to subjects, estimating the degree that the universities have included informatics or robotics in teacher training is not addressed.

Nevertheless, teacher training includes training in digital technology and, depending on the equipment of the school and the specific university teacher, they may also encounter robotics. Five universities provide training to future computer science teachers for secondary education. These universities have included robotics in their studies, each in a different way. Some have one or two compulsory subjects reserved for ER. In contrast, other universities have ER integrated into other subjects or let students organize leisure time activities directly at the faculty. Art is taught at other faculties and is also divided into pedagogical and scientific directions. Although there is no connection with ER, there are exceptions when individuals, for example, teach children to program music, but this is only a connection between CT and music.

4.2.4 Non-formal level

It is challenging to integrate ER into the typical educational process for several reasons. For example, constantly changing robotics kits, few educated teachers, very little training in robotics for teachers, tight budget, time consumption, and so on. Perhaps these are why the most common ER implementation in Slovakia has been activities outside the official educational process. These are activities with robots in leisure centres and various contexts around schools - extracurricular activities, competitions, and related training. There was not much for the first grade, as the pupils tended to engage in activities for older students and learn from them.

Most competitions and summer camps are for children aged 8-9 to 18, or for older students. And related meetings, where students in mixed (age and conscious) groups prepare for these competitions. For example, FLL (www.fll.sk/), Summer Robotic League (https://liga.robotika.sk/), RoboCup Junior (https://junior.robocup.org/), RBA Košice(https://robotickybattle.sk/), G-ROBOT (https://g-robot.gvpt.sk/), RoboRave (www.roboraveinternational.org/), Trenčín Robotics Day (www.trencianskyrobotickyden.sk/) and others.

4.3 ER in the Spanish Educational System

In Spain, the primary educational law is Ley Orgánica de Modificación de la Ley Orgánica de Educación[8] (LOMLOE), published in April 2022. LOMLOE is now the effective educational law in Spain. Nevertheless, the establishment of the LOMLOE will take 5 years. LOMLOE repeals the LOMCE (which became effective on 02/03/2014).

The ER presence in official curricula has been described by Ministerio de Educación (2018). In addition, the current situation of Arts education in Spain has been recently analyzed by Sumozas (2021). At the time of this document's writing , the curricula of the different levels for the new course have not yet been published. References correspond to the current system unless otherwise indicated.

Table 9 summarises the situation of robotics and the arts in the Spanish educational curriculum. As educational legislation is transferred to the Autonomous Communities, the variation between different regions is significant. Therefore, the table should be read considering that the information is summarized and that the details concerning the different regions will be found in the text below.

Table 9: ER and Arts in the Spanish curriculum

Educational level	Concept	Subject applied	Grade applied	Hours per week	Related units
Primary	IT	Robotics and Technology (optional for schools)in some spanish regions	Any primary grade (1st to 6th)	0.5 to 3	• Computational thinking • Mechanics-Engineering (Design) • Electricity • Artificial Intelligence • Internet of Things • Virtual or Augmented Reality
	Arts	Arts and crafts and music	Any primary grade (1st to 6th)	1 to 4	• Recognition, reception and sensory, visual, auditory and and corporal observation. • Creative expression of ideas, feelings and emotions through

[8] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2020-17264

					the exploration, knowledge, execution and creative use of different code ● Instruments, materials, media, resources, supports, programs, applications and cultural techniques
Secondary	ER	Technology (Madrid)	1st to 4th (in some regions)	2 to 3	● Robotics ● Programming
	ER	Digitalization (Extremadura)	2nd, 3th and 4th (Extremadura)	2	● Digital devices, operating and communication systems ● Digitization of the personal learning environment ● Digital security and well-being ● Critical digital citizenship
	Arts	Plastic, Visual and Audiovisual Education	1st and 3th	3/2	● Artistic and cultural heritage ● Formal elements of the image and visual language. Graphic expression. ● Artistic and graphic-plastic expression. Techniques and procedures. ● Image and visual and audiovisual communication.
Baccalaureate	ER	Technology and Engineering (elective in technological baccalaureate)	1st and 2nd	4	● Computer systems and programming ● Automatic systems
	Arts	Fine Arts, Image and Design Baccalaureate	1st and 2nd	16	● Four Fine Arts, Image and Design specific subjects in each grade
		Music and performing Arts baccalaureate	1st and 2nd	16	● Four music and performing specific subjects in each grade

4.3.1 Primary Level

Educational Robotics

Concerning primary education, the Royal Decree 126/2014, of February 282 establishing the primary curriculum of this educational level applies ICT in several core subjects (Natural Sciences, Sciences Social Studies, Spanish Language and Literature, Mathematics and First Foreign Language) as (artistic education, physical education and social and civic values). Nevertheless, these references are fundamentally limited to some specific aspects of information and content creation of digital competence and are not related to programming, robotics, and CT.

However, regions have relative freedom in defining some subjects called "free autonomic configuration". For example,

- In the Region of **Madrid,** the subject of "Technology and digital resources for the improvement of learning" is considered. Although it does not have robotics content, it does contemplate programming. In **Catalonia,** they have included a new subject as well.
- The Autonomous Community of **Navarra** has included contents of these skills in 4th and 5th grade of Primary education, specifically, integrating them into mathematics.
  - 4th grade of Primary education. The aim is to integrate information technologies and communication, as well as programming languages and tools, in the learning process. Programming tools and languages are used to model and solve problems. In a guided way, a programming project is employed where students have to describe the algorithm, decompose the problem into smaller parts and code it with a formal visual programming language (like Scratch).
  - 5th grade of Primary education. The aim is to integrate information technologies and communication, as well as programming languages and tools, in the learning process. Programming tools and languages are used to model and solve problems. Program projects are designed and carried out where students use scripts, loops, conditionals, variables, as well as different forms of data input and output (interaction with the computer).

The new law, LOMLOE considers among the essential competencies of primary education the following: "Develop basic technological skills and start using them for learning, developing a critical spirit before their operation and the messages they receive and elaborate. "

Arts

Arts is a so-called specific subject and could be offered depending on the regulation and programming of the educational offer established by each educational administration and, where appropriate, the educational centres offer. Art Education has been divided into two parts: Plastic Education, and Music Education.
In the different Spanish autonomous communities, variable numbers of hours are devoted to arts and crafts subjects:

- Aragon, Baleares, Galicia, Navarra:
  - 2h per week in every grade of primary school.
- Asturias:
  - 3h per week in the 1st, 2nd, 3th, 4th and 5th grades.
  - 1,5h perweek in the 6th grade.
- Murcia:
  - 2h per week in the 1st, 2nd, 3rd and 4th grades.
  - 1h per week in the 5th grade.
- Canary Islands:
  - 4h per week in the 1st, 2nd and 5th grades.
  - 3h per week in the 3rd, 4th and 6th grades.
- Cantabria:
  - 1,5h per week for arts and 1h per week for music in the 1st, 2nd, and 3rd grades.

    - 1h per week for arts and 1h per week for music in the 4th, 5th, and 6th grades.
- Castilla León:
    - 2,5h per week, distributed to at least 1h for music in the 1st and 4th grades.
    - 1h per week in the 2nd, 3th, 5th and 6th grades (at least 1h for music).
- Castilla la Mancha:
    - 3h per week in the 1st, 2nd and 3rd grades.
    - 2h per week in the 4th, 5th, and 6th grades.
- Valencia:
    - 3h per week in the 1st, 2nd, 3rd and 4th grades.
    - 2h per week in the 5th and 6th grades.
- Extremadura:
    - 1h per week for arts and 1h per week for music in the 1st and 2nd grades.
    - 0,5h per week for arts and 1h per week for music in the 3rd, 4th, 5th, and 6th grades.
- Madrid:
    - 1,5h per week for music in every grades.
- La Rioja:
    - 3h per week (1h at least for music) in 1st, 2nd, 3rd, and 4th grades.
    - 2,5h per week (1h at least for music) in the 5th grade.
- Euskadi:
    - 2h per week in the 1st and 2nd grades.
    - 1,5h per week in the 3rd, 4th, 5th and 6th grades.
- Andalusia: 3h per week in every grade.

The LOMLOE law considers the following among the essential competencies of primary education: "Use different representations and artistic expressions and start in the construction of visual and audiovisual proposals."

4.3.2 Secondary Level

Educational Robotics

As established by the Royal Decree 1105/2014, of December 264, content related to ER is included at Compulsory Secondary Education (12-16 years old) during the 4th grade of ESO in (i) the subject of Technology (a core-elective subject in the applied science section for initiation to Vocational Training), and (ii) in the subject of Information and Communication Technologies (a specific-optional subject both for the academic and applied studies section). At Baccalaureate (16-18 years old), there are two specific-optional subjects, Industrial Technology and Information and Communication Technologies, both in the 1st and 2nd grades.
Andalusia, Asturias, Baleares, Castilla-La Mancha, Castilla y León, Catalonia, Extremadura, Galicia, Madrid, Region of Murcia, La Rioja, and Valencian Community have introduced new subjects of robotics and programming at Secondary Education Level.

- **Andalusia**
    - 1st grade of Secondary Education: Applied Technology (Free regional configuration)
    - 2nd and 3rd grades of Secondary Education: Technology (Specific)

- 4th grade of Secondary Education: Technology (Core subject)
- Baccalaureate: Industrial Technology I and II, Information and Communication Technologies
- Baccalaureate: Programming and Computing (Free regional configuration)

- **Asturias**
  - Since the 2018-2019 academic year, Asturias has launched the subject Robotics in the block of subjects of the autonomous curriculum configuration in the 4th grade of Secondary Education.
- **Baleares**
  - 4th grade of Secondary Education: Technology (Core Subject) content related to the basic concepts and Introduction to programming languages and control and robotics.
  - 1st grade of Baccalaureate: Information and Communication Technologies I (Specific subject) includes programming.
  - 2nd grade of Baccalaureate: Information and Communication Technologies II (Specific subject) also includes programming.
- **Castilla La Mancha**
  - 4th grade of Secondary Education: Robotics (autonomic free configuration).
- **Castilla León**
  - 3rd year of Secondary Education: Control and robotics (autonomic free configuration).
  - 4th year of Secondary Education: Computer programming (autonomic free configuration).
- **Catalonia**
  - 2nd, 3rd, and 4th grades of Secondary Education: Technology that includes robots and programming.
  - 4th grade of Secondary Education: Information and Communication Technologies.
- **Extremadura**
  - 2nd and 3rd grade of Secondary Education: Technology (Specific subject)
  - 4th grade of Secondary Education: Technology (Core subject)
  - 4th grade of Secondary Education: Information and Communication Technologies I (Specific subject)
  - 1st and 2nd grades of Baccalaureate: Industrial Technology I and II (Specific subject)
  - 1st and 2nd grades of Baccalaureate: Information and Communication Technologies I and II (Specific subject)
- **Galicia**
  - 1st and 2nd grades of Secondary Education: Programming including block and web programming.
  - 1st grade of Baccalaureate: Robotics.
- **Madrid**
  - 1st, 2nd, and 3rd grade of Secondary Education: Programming, Robotics and Technology, including robotics, programming, and 3D printing.
- **Murcia**

- 2nd grade of Secondary Education: Robotics (autonomic free configuration).
- **La Rioja**
  - 4th grade of Secondary Education: Technology
  - Baccalaureate: Industrial Technology I and II and Information and Communication Technologies I and II.
- **Valencia**
  - 1st, 2nd, and 3rd grade of Secondary Education: Technology, including robots and programming.
  - 4th grade of Secondary Education and 1st and 2nd grades of Baccalaureate: Information and Communication Technologies.
  - 1st, 2nd, and 3rd grades of Secondary Education: Computer Science is offered by schools as an optional subject for students.

Art

In the first 3 grades of Secondary education, it is compulsory to have at least one subject in the artistic field, i.e., music and/or Plastic, Visual and Audiovisual Education. In the 4th grade of Secondary Education, students can choose three subjects between several options, including music and artistic expression.

At Baccalaureate art is included. The Arts Baccalaureate is organized, in turn, in two sections:

- Plastic arts, design, and image.
- Performing arts, music, and dance.

4.3.3 Higher Education

In recent years, some teacher training colleges have incorporated ER subjects as electives while training future primary school teachers, such as Universidad Alcalá de Henares.

Regarding the secondary and baccalaureate teachers' training, some universities include robotics, programming, and computational thinking content in their masters' programs. For example, the Masters Degree in Teacher Training for Secondary Education, Vocational Training and Language Teaching offered by the University Complutense in Madrid include a computer science and technology specialisation.

Some universities and official organizations related to education offer, as well, continuing education courses for teachers in the field of robotics, programming, and computational thinking. For example, the University of Salamanca offers a specialization course called Programming and Robotics in the classroom https://bisite.usal.es/es/formacion/cursos/Program_robotica .

Another initiative is the School of Computational Thinking and Artificial Intelligence, a project organized by the Ministry of Education and Vocational Training in collaboration with the Ministries and Departments of Education of the Autonomous Communities and Cities and Acción Educativa Exterior (AEE). Through programming and robotics activities, this school aims to offer open educational resources and training to scaffold Spanish teachers incorporate such competencies into their teaching practice (https://intef.es/tecnologia-educativa/pensamiento-computacional/)

4.3.4 Non-formal level

At the non-formal level in Spain, many activities are related to robotics and programming. They can be classified as:

- Extracurricular robotics and programming activities.
- Occasional robotics and programming activities such as CodeWeek or activities that are scheduled on the occasion of the European Robotics Week.
- Robot contests like World Robotics Olympiad (https://www.wroboto.es/), First Lego League (https://www.fll-spain.org/) and Eurobot (http://www.eurobot.es/). It is worth mentioning the Robocampeones contest (https://www.urjc.es/todas-las-noticias-de-actualidad/3235-llega-robocampeones-el-torneo-de-robots-para-institutos-madrilenos). It began in 2003 at the initiative of the Universidad Rey Juan Carlos. The championship's inertia led the institutes' teaching staff to join forces in 2010 to continue organizing it with great motivation.

A link providing information about these exciting non-formal education activities is the Hisparob Educational Robotics Thematic Group. This group includes companies, associations and universities related to ER aiming to promote good practices and the development of quality robotics in educational settings.

4.4 ER in the Czech Educational System

The Czech educational curriculum has two levels: national (RVP) and school (ŠVP). That means every school forms its own program concerning the national curriculum's content, the minimum number of hours etc. The national curriculum is a standard for schools, but they can also adapt their focus. It is typical for schools to prefer more hours for languages (or second language) or physical education. In the Czech republic, it is customary to have primary, lower and upper secondary education (high schools, gymnasium) together in formal education. However, gymnasiums may have lower secondary education as well.

In 2021 a new concept of computer science (first in primary and lower secondary, then in upper secondary) was introduced. The aim was to change the approach of computer science from Information and communication technology (focusing on digital competence) to computational thinking. Following this new approach, digital competence as a new key competency was added. Consequently, the need to cultivate digital competencies through other subjects, not just in Informatics, prevails. In general, the Informatics subject is divided into four areas (in all educational levels

- Data, information, and modelling
- Algorithmization and programming
- Information systems
- Digital technologies

Nowadays, the situation is complicated because schools can use both curriculum types. The old one including the subject called Information and communication technology, and the new one including the subject called Informatics). In the following sections, we elaborate on the new curriculum, since all schools have to use this type from the school year 2023/2024 onwards. (Revize RVP, 2022)

4.4.1 Primary Level

In the Czech Republic, primary education refers to the first five years of school attendance. (RVP ZV, 2021)

Primary education	Informatics	At least 2 hours total per week during all 5 grades. It is typical to have Informatics in 4th and 5th grade.
	Arts and Culture	At least 12 hours total per week during all 5 grades. Typically 1 hour of Music and Art per week in every grade. The first two grades have arts for one extra hour per week.

4.4.1.1 Educational Robotics

ER may be integrated into the subject of Informatics, but such integration is optional. It may be included as a part of Algorithmization and programming, with each school using whatever devices and means to teach ER. Therefore, many teachers use different types of robots without a national curriculum or material support. However, national means such as imysleni.cz (project PRIM) provided basic robotic kits including Beebots, Lego WeDo, and Micro:bit. Another typically used ER kit is, for example, ozobot.

4.4.1.2 Arts

Arts is included in the Czech curriculum's subject called Arts and Culture. It is not typical to have Drama or Dance for an hour per week in any grade. This subject's section, called "Man and his world", includes activities that students work with paper or other materials to construct artefacts. Thus, arts are mainly approached through drawing and painting to develop creativity or express feelings and fantasy. Within this subject's context, other activities are oriented on artistic creation, photography, film, printed matter, television, electronic media, and advertising. Regarding music, its content is oriented on rhythm, singing, and playing instruments. Within its objectives is portraying music with movement using dance steps, creating movement improvisations based on individual abilities and skills.

4.4.2 Secondary Level

The Czech secondary education is divided into Lower secondary education (4 grades) and Upper secondary education (3-4 grades). Informatics' application in Upper secondary education depends on the school type. Each type of Training institution or specialized school has its own rules and regulations for Digital technology or the field of Informatics (computer science). For this reason, more attention is focused on Gymnasium education. (RVP ZV, 2021) (RVP G, 2022)
Additional fields include drama education, film education, and dance and movement education. They are not a mandatory part of basic education. They only supplement and expand the educational content in primary or lower secondary education.

Lower secondary education (6th - 9th grade)	Informatics	At least 1 hour per week in every grade

	Arts and culture	At least 9 hours total per week in all 4 grades. Typically 1 hour of Music per week in every grade and one extra hour per week of Arts in the 1st grade).

Upper secondary education (Gymnasium)	Informatics	At least 4 hours total per week in all 4 grades (e.g., one hour per week in every grade).
	Arts and culture	At least 4 hours total per week in all 4 grades (e.g., one hour per week in every grade).

4.4.2.1 Educational Robotics

Lower secondary education: ER can be a part of Algorithmization and programming. Likewise, ER is optional in primary education, and Czech schools can choose any devices/means for its application. However, basic national materials are prepared for Lego EV3 or Micro:bit and are available in imysleni.cz (project PRIM). Another typically used ER kit is for example VEX. However, teachers often prepare their own materials or have inspiration from providers or some educational groups (e.g., GEG, MIEE). ER may also be integrated into the subject called "Human and its work" and specifically in its themes called "Design and construction" and "Use of digital technologies" (PRIM, 2020) (RVP ZV, 2021).
Gymnasium education: Unlike the RVP ZV (national framework for primary and lower secondary education) mentioning ER, there is no mention of ER in the content of the Algorithmic and programming in RVP G (national framework for Gymnasium education). However, alike lower secondary schools, basic national materials are prepared for Lego EV3 or Micro:bit in imysleni.cz (project PRIM (PRIM, 2020) (RVP G, 2022).

4.4.2.2 Art

Lower secondary education is the continuation of primary education, including music and Art education. Students learn more about the theory of music and art, but the aim is the same as in primary school: to develop creativity and fantasy, and interpret some music or artwork. Furthermore, in connection with other types of Arts disciplines, Music education includes a theme called "movement expression of music", and Art education includes the theme "sensory effects of visual representations" (RVP ZV, 2021).
Gymnasium education: Music education triggers students understanding of the art of music. The educational content of Music education, therefore consists of three interrelated and conditional areas of activity – production, reception, and reflection, which enable students to express themselves musically. The educational content of Art education is divided into two primary areas: Visual sign systems and Visual art sign systems. Both disciplines are also connected with using digital technologies as a means of realizing one's own work. (RVP G, 2022)

4.4.3 Higher Education

In the Czech Republic, universities are divided into four basic types: public universities (26), state universities (2), private universities (32), and foreign universities (European and non-European). All schools are registered in the universities' registry (https://regvssp.msmt.cz/registrvssp/Default.aspx). (Register vysokých škol, 2022). Technical universities most often carry out education in robotics (e.g., ČVUT). These fields are usually closely connected with a specific branch of informatics or robotics and make it possible to obtain bachelor's and master's degrees in various specializations. ER is then mostly found at faculties of education. ER is currently available to students of both fields focused on Informatics (or Information and communication technologies), and students of primary and pre-primary education in some courses. Faculties focusing on Art are further specialized, e.g., in acting, music, or other combinations. Due to the current situation in changing the approach to Informatics, the courses that universities (as part of lifelong education) and other institutions (training is provided by e.g. NPI - National Pedagogical Institute) implement are also significant.

4.4.4 Non-formal level

Informal and hobby activities are pretty widespread in the Czech Republic for all age groups. Educational institutions, leisure centres, educational agencies, clubs, cultural facilities, and other entities, including commercial companies, can organize these activities. Competitions and exhibitions focused on informatics or robotics and programming are also starting to appear. For this reason, it is challenging to conduct analyses in this area.

In general, we spotted some usual “technical” activities and divided them into four categories:

- robotics systems (using some type of ER or programmable robotic toys - e.g., Arduino, or virtual worlds - e. g. Minecraft),
- multimedia (e.g., digital photography, 3D print, film, and multimedia production),
- programming (using some type of language, e. g. Scratch, Python, C++),
- technical activities (e.g., making models, aerial modeling, electronics, drone).

5. CONCLUSIONS

This document aims to review the literature regarding ER and how it is combined with Art to promote CT skills. This review, constituting task T1.1 of the FERTILE project, is the first step towards proposing a design methodology for Artful ER projects cultivating CT. Reviewing the available tools, both physical robots and simulators, and the current state of different countries' curricula provide insights into current shortages and possible solutions to the issues that arise when applying ER in educational settings. These insights will be considered along with educators' profiling organized under task T1.2 of the FERTILE project.

This document has been organized into five sections. First, the most widespread ER technologies, from the programming languages to the physical and virtual robots currently available, have been reviewed. In the last years, several simulation environments involving robots have appeared to target the educational needs of several students ages. Those virtual robots can be programmed in the same programming languages as their physical counterparts. We noted that simulated robots' application is growing but is not yet widely spread. Regarding languages, there are visual languages, which typically combine several graphical blocks and text-based languages. Scratch is the most commonly used one. Visual languages prevail in primary education and text-based ones in secondary education. Although the research literature includes several studies, the research reporting learning designs using ER technologies is limited. Moreover, we hardly noticed a common methodology supporting ER activities across the different ER technologies. Consequently, it is up to each teacher to design ER activities and deal with the challenges that this entails.

The second section describes several illustrative examples of combining ER with Art. Several studies organized into five Art types: painting, music, literature, scenic arts, and performing arts have been reviewed. Two underlying approaches emerge from this review. The first approach involves studies whose objective was to teach arts, and the robots were used just as a motivational tool. The second approach involves studies aiming to teach arts andhad also considered CT cultivation while using robots. Our findings also reveal lack of studies using simulators to combine ER with Art.The physical robots in face-to-face settings seem to dominate such ER applications. To this end, research on how simulators can be utilized to create Artful projects with robotics in blended learning contexts is needed.

The third section reviews seven selected publications from journals and conferences presenting studies on the cultivation of CT through ER activities. The influential CCPS model, the ERS, the EDP, the 5E learning cycle, and the 4plus4 Model are included among others. They provide good theoretical models, frameworks, and methodologies to cultivate CT skills. We noted several studies reporting how incorporating ER in the educational process could potentially develop students' CT skills. Moreover, the studies reviewed will provide the FERTILE consortium with insights into different methodologies to be further analyzed toward developing a common methodology that could be used across different educational levels.

The fourth section introduces an overview of robotics and arts in current educational legislation across the different consortium members' countries. The analysis includes all educational levels: primary, secondary, and higher education. Findings in this section reveal the plurality of approaches to robotics' and arts' integration in educational curriculums. Again, spotting common approaches across different countries is critical for forming an appropriate methodology that suits learning objectives and legislation.

Finally, the main conclusions are summarized in this section.

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