

Educational Robotics: Towards a Structured, Interdisciplinary Definition Based on the Curriculum in Greek Schools

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Abstract — Educational Robotics (ER) will shape the future of education. However, there are many limitations in the existing literature on this topic, mostly related to its definition and its possible fields of application. Previous studies have mainly focused on existing equipment for ER and the variety of educational scenarios that can be developed with it, along with their potential benefits for a child. Despite this interest, to the best of our knowledge, few studies have investigated classifications of a structured definition for ER along with all the domains that can be easily connected with it. The following research is based both on a review of the existing literature as well as results from studies conducted by the authors and aims to provide a structured interdisciplinary definition of ER. Specifically, the authors conducted two different studies based on the official curriculum of the Greek Schools. Through these studies, the influence of ER in cultivating pupils' digital and social skills was investigated and the results will be presented below. Moreover, as usually ER is considered a subset of STEM or STEAM, this research aims to identify possibilities of applying ER in every course of the School Curriculum.

Keywords — Educational Robotics, Engineering, STEAM, Robots in Education.

I. INTRODUCTION

Since the early 2000s, ER domain has evolved rapidly and a variety of research publications have highlighted the benefits of using ER in the educational process (i.e., both formal and non-formal). According to the literature, the most important benefits of ER are the development of critical and computational thinking and the understanding of the design and implementation of algorithms for problem-solving. At the same time, ER contributes to the cultivation of students' soft skills, as they learn to work in groups while existing studies claim that ER can benefit children's self-confidence and self-esteem through the designing and implementation of robotic scenarios. Therefore, many studies have concluded that ER prepares children by developing the necessary digital skills, shaping the citizens of the 21st century [1]–[3]. Despite the spread of ER, to date, there is no precise definition of ER, and the boundaries between educational robotics and the introduction of robotics into education are blurred [4], [5]. Moreover, it is not possible to conclude from existing studies, whether there is an optimal age for a child to be introduced to ER. Specifically, several lines of research have suggested that students should have prior knowledge of various subjects (e.g., electronics, electrical circuits, mathematics, etc.), to understand in-depth the principles applied while constructing

and programming a robotic solution. On the other hand, many publications argue that a child can be introduced to ER directly after kindergarten. Furthermore, there is a controversy regarding the integration of ER into the school curriculum as few researchers believe that it should be a new and independent course, some people support that ER should be considered as a subset of STEAM, whilst others believe ER should be integrated into existing curricula and providing the necessary experimental tools [6], [7]. The following research aims to form a more structured, interdisciplinary definition for ER, which can be applied and therefore benefit almost all the subjects in the school curriculum. The experimental scenarios, which will be analyzed below are based on the Greek School Curriculum, but the definition can be easily adapted worldwide.

II. THE RESEARCH DESIGN

At first, a literature review was performed based on several studies related to ER. Specifically, the importance of integrating robotics in the school curriculum as a tool for efficiency with a theoretical and practical field of application has been highlighted [8], [9] and some studies try to forecast the future of ER in schools [10]. However, only limited studies investigate the definition of ER. There are studies [5] that highlight several questions mostly related to the most common approach of ER, as a tool to be applied in a few courses. For instance, the authors raised questions such as: "What is the role of the robot in the tool?" or "Who is responsible for better developing this tool?". The authors also analyze three different fields that are integrated with ER along with their interfaces. Education, Robotics, Human-Computer Interface). Therefore, they concluded that ER cannot be considered only as a tool but instead as a whole research field. and their proposed definition for ER was: "*ER is a field of study that aims to improve the learning experience of people through the creation, implementation, improvement, and validation of pedagogical activities, tools, and technologies, where robots play an active role and pedagogical methods inform each decision*". Lastly, other studies emphasize the fact that ER should be both a learning object and a pedagogical tool [11]. This research aims to combine all the research questions that were raised through the available literature to structure a formal, interdisciplinary definition for ER.

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III. MATERIALS AND METHODS

The authors conducted two individual studies trying to define a more interdisciplinary approach for ER, aligned with the official Greek School Curriculum. The designed educational scenarios were based on the introduced Topics during the Modern Greek Language Course and the age of the students varies for each scenario. Additionally, principles from the STEAM Courses were also adapted to develop the scenarios properly. Each scenario was fully implemented in 3 months (i.e., 60 teaching hours), however, this time period varies as it depends on both the difficulty of the ER scenario and the percentage it covers from the syllabus. According to the authors' approach, ER should be considered as a process, which consists of six interconnected stages as presented in Fig. 1. These stages lead to the creation of a final prototype that fulfills the educational goals set by the teacher. This approach is based on Project and Problem Learning and it aims to develop necessary 21st century digital and soft skills [12]–[14]. Specifically, ER can be redefined as: **“The process of Designing, Creating and Conducting a Research for a robotics idea that satisfies a specific educational purpose, developing appropriate algorithms”**. In other words, ER can be described as a whole process including the brainstorming and researching for a robotic idea aligned with the educational curriculum goals, which will be designed, constructed, programmed, and continuously evaluated in order to result in a final prototype. The educational curriculum refers to both formal and non-formal educational activities. In Fig. 2 some examples are also provided at the bottom of each step, regarding courses where ER can find applications. For instance, the research can be implemented during the sociology course to set qualitative research metrics and/or during the mathematics course, where quantitative data that are extracted from the research can be analyzed. A prerequisite for the ER process is the conduction of specific guidelines by the educator before the brainstorming session. The guidelines aim to ensure that the robotic ideas proposed by the students, will be aligned with the educational goals of each curriculum.

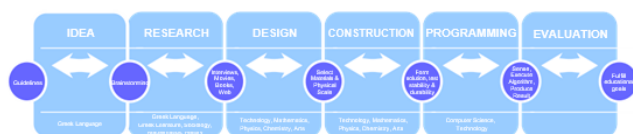


Fig. 1. The interconnected stages of the ER process.

A. Analyzing Each Stage of Er

The authors proposed an alternative approach to ER not as a tool but instead as a structured procedure. At first, students should be divided into different teams, each one consisting of 4-5 people (i.e., depending on the number of the students in a classroom, which in Greece is usually between 15 and 25 students).

1) Idea

The first step in such a procedure would be finding the initial idea, well-aligned with specific chapters/sections of the Curriculum. The educator should set the guidelines and the students will then have a brainstorming session based on them.

2) Research

Research should be considered a fundamental step in defining Educational Robotics. The students, guided by the educator, could search for technological solutions through the web, but they should also be encouraged to interview people (i.e., their target group, the beneficiaries) to understand their needs and wants. Moreover, visits to NGOs, Public Services, or museums could be arranged so that the students can be fully informed about their focus group and the challenges and difficulties they face. The research process can take a few weeks and it will finish with a draft idea of the robotic solution, which is going to be implemented by the students. Lastly, movies, books, or theater performances related to the idea can also be suggested by the educator to the students. The students can watch them or read these books as homework or as part of the Literature Course.

3) Design

The third important step during the ER process is to design the proposed robotic solution. At first, the solution can be drafted on paper, and afterward, when the materials are selected and the physical scale is decided, the design is suggested to be implemented using appropriate computer software (e.g., draw.io, AutoCAD, etc.). If the solution requires 3D printed parts, these parts should also be included in the draft designs. At the end of this step, a list with the required materials and tools for the implementation should have been selected properly. Optionally a business plan (e.g., business model canvas) can be drafted along with the design so that the students can have a better understanding of the implementation steps. By creating a business plan ER can also be connected with entrepreneurship, which is recently included in the Greek School Curriculum as part of the New Skills Labs [15]. Additionally, in the designing process, the required tools can be selected during the Technology course and the decision about physical scale can be made during the Physics course. Lastly, the materials can be decided during the Chemistry and Physics courses.

4) Construction

At first, students are required to draft a cost analysis of their idea. There, they should include all the materials they will use, along with their prices and an explanation, analyzing the reason why they decided to use it. The goal of this step is to ensure the conduction of appropriate research, which will lead to the creation of a cost-efficient prototype. Afterward, the students can start the construction. During the Arts or the Technology courses the students can learn how to use specific tools (e.g., soldering iron, saws, hot glue, etc.) and during the courses of Chemistry and Physics students can understand the fundamentals of each sensor and motor. Basic principles and concepts like for instance Newton's laws of motion or Momentum and conservation of energy, Dynamics can be explained by the corresponding educators during this stage. The educators should also highlight the importance of stability, strength, durability, and safety as important parts that lead to efficient construction. This step is interconnected with the previous one, as the design will determine the scale, form and final result of the construction. During this entire step, the design can be appropriately changed and updated so that the end-product will be similar to the one in the final design.

5) Programming

In this step, two different things should be created. Firstly, the Flowcharts and/or UML diagrams of the algorithms that will be developed. Several online tools can offer guidance to students to create the above, and terms like space and time complexity can be analyzed during this specific stage. The students should design algorithms, which will be efficient in terms of execution time and memory usage. Secondly, the programming language, which is going to be used should be decided. For elementary school students, Scratch is a common solution selected by many educators worldwide. LEGO Mindstorms, MakeCode, or WeDo software is also widely used as an alternative. For older students, other solutions like Python, C/C++, or JavaScript may be chosen depending on the project, which needs to be carried out. The professor of the computer science course can decide the programming language based on both the students' skills and the annually pre-set educational goals. Most of the microprocessors that are currently available in the market and used for educational purposes can be programmed using a plethora of programming languages, allowing teachers to cultivate different hard skills for the students.

6) Evaluation

This stage includes both the evaluation of students' learning outcomes through working on a specific educational scenario, as well as the final evaluation of the robotic prototype. The learning outcomes should be measured both qualitatively and quantitatively and appropriate forms and questionnaires along with discussions during the class can be followed as evaluation methods. In each course the evaluation metrics are different. For instance:

- For the Greek Language Course or Literature, important metrics are the familiarity of the students with the research topic before and after the project.
- For the Technology course, it is crucial to measure the expertise of students in using different tools after finishing the prototype.
- For Physics, questionnaires regarding the principles applied in the project can be created.

In terms of evaluating the robotic prototype, the goals of each stage should be accomplished. An optional metric for evaluating each step would be a Gantt Chart, drafted at the beginning of the project (i.e., at the design process). The project should be evaluated by the students until they achieve the designed robotic solution. The end-users can also test and evaluate the prototype in order to give appropriate feedback. Additionally, the educator should evaluate if the completed prototype satisfies the educational guidelines, which were given at the beginning of the process. During this step, many modifications can be done to every one of the aforementioned steps. The most common would be improvements in the software/algorithms and the construction. The design should be also appropriately changed to better demonstrate all the necessary improvements/moderation. Before the design of an ER scenario, the educator should carefully consider the required teaching hours that can be spent on it, to ensure that the scenario can be fully implemented during them. For this reason, the suggested time-slots, to be spent in each stage of ER are presented in Table I. For instance, in the following scenarios, the authors decided to dedicate a total of 5 hours per week for 3 months. For the total time that can be spent on

a scenario, the educator can read the teaching instructions which are provided by the Greek Ministry of Education and include management and indicative planning guide for each chapter/topic of all the school courses [26].

TABLE I: SUGGESTED TIME DEDICATION IN EACH STAGE OF ER PROCESS

Stage	Required Spent Time
Idea	5%
Research	15%
Design	20%
Construction	25%
Programming	25%
Evaluation	10%

IV. ER FOR ACCESSIBILITY

A. Idea

The following scenario was designed for middle school students (i.e., 13-14 years old). Specifically, it aims to address the following topics, which are introduced in Sections 7 and 8 of the Modern Greek Language Course in 8th Grade [17].

- Section 7: Understanding problems of daily life,
- Section 8: Discussing contemporary social issues.

In the proposed scenario, the specific guidelines provided by the educator before the brainstorming were to focus on daily transportation problems and identify social groups that are more vulnerable to them. Even though many ideas were proposed by each team highlighting transportation problems for people with disabilities or elders, the selected focus group was decided to be the visually impaired people.

B. Research

In the proposed scenario the students interviewed visually impaired people and became familiar with the main challenges they face during their daily transportation. Furthermore, visits were arranged to NGOs focusing on promoting accessibility and advocating for the rights of people with disabilities. In terms of movies and theater plays, the students watched the Canadian film: "If You Could See What I Hear" and the play: "Butterflies Are Free". The next step was to search on the internet about existing robotic solutions for their target group and analyze all the pros and cons of them, along with possible improvements. After gathering all the necessary information, the students ended up with the idea of creating a robotic cane for the visually impaired.

C. Design

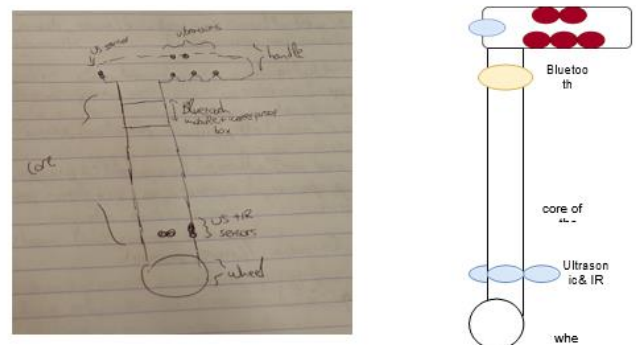


Fig. 2. On the left, the students' design on paper for the robotic cane is presented and on the right, the computer-aided design for the robotic cane.

For the proposed scenario one of the paper drafts is presented in Fig. 2 (left side), whilst the final computer-aided design is demonstrated in Fig. 2 (right side). In both Figures, one can understand which sensors are selected to be used and where they are placed. For the implementation, Arduino processors were used, infrared and ultrasonic sensors, a Bluetooth module as well as vibration motors.

D. Construction

Regarding the materials, in the list below the materials decided to be used are presented. The goal was to create a robotic cane cost-efficient for the selected target group.

- Arduino Processors*3;
- Vibration Motors*5;
- Ultrasonic Sensors*4;
- IR Sensors*2;
- Bluetooth;
- Buzzer;
- Foldable Cane for Elders;
- Waterproof Boxes.

The total cost was estimated to be 80 euros.

The foldable cane for elders was modified in order for all of the sensors and microprocessors to fit inside the cane. The Bluetooth module was placed inside a waterproof box along with a rechargeable battery and a buzzer. On the low level of the cane, a wheel was placed to improve the quality of transportation. An important factor during the construction was to keep the weight of the cane less than 700 gr. so that the user can easily adapt the cane in his/her daily activities. Afterward, holes were created at the handle of the cane to place the vibrations. At the bottom of the cane as well as at the top of it Ultrasonic sensors and Infrared sensors to detect obstacles were placed. Last but not least, the cane was colored white in order to be similar to the white canes for the visually impaired.

E. Programming

As Arduino processors were selected to be used, the students developed all the required algorithms using the Arduino Integrated Development Environment. For the different modalities of the cane, for instance, the low-level obstacles recognition or the Bluetooth tracker, different flowcharts were created. The flowchart for the Bluetooth system is presented in Fig. 3. Moreover, the part of the developed software that corresponds to the Bluetooth tracker is presented in Fig. 4.

F. Evaluation

The robotic cane was tested in a real environment (i.e., outdoors, in a street). During the evaluation step, modifications were performed in order for the final prototype to be as functional as possible. Moreover, a few visually impaired people had voluntarily tested the cane and shared their thoughts with the students for future improvements, so that the final prototype to be implemented as presented in Fig. 5. The project also won first place (i.e., Gold Medal) at the International Robot Olympiad in Korea 2020. The goal of this scenario was to familiarize students with the transportation problems that the visually impaired are facing daily and to increase their confidence in applying ER to solve critical daily challenges.

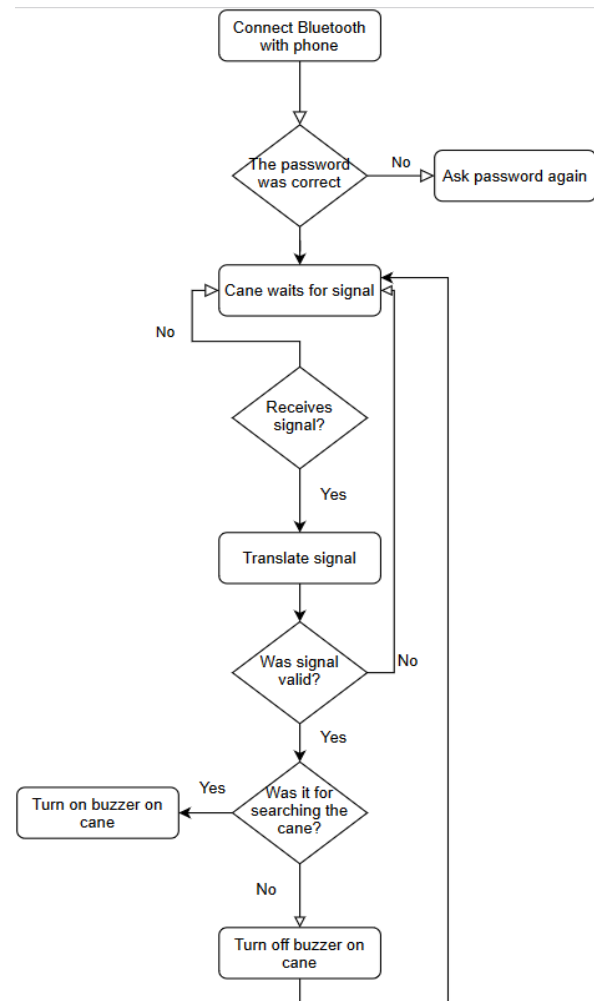


Fig. 3. Flowchart for the Bluetooth system.

Ultrasonic | Arduino 1.8.19 (Windows Store 1.8.57.0)
File Edit Sketch Tools Help

```

Ultrasonic
const int trigPin = 5;
const int echoPin = 7;

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(13, OUTPUT); //50v707070
  pinMode(12, OUTPUT); //7x707070
}

void loop() {
  // put your main code here, to run repeatedly:
  if(Serial.available() > 0){
    char value= Serial.read();
    if(value=='o'){//open
      digitalWrite(12,HIGH);
    }
    if(value=='c'){//close
      digitalWrite(12,LOW);
    }
  }
  long duration;
  long cm;
  pinMode(trigPin, OUTPUT);
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);

  digitalWrite(trigPin, LOW);
  pinMode(echoPin, INPUT);
  duration = pulseIn(echoPin, HIGH);
  cm = microsecondsToCm(duration);
  if(cm<92){

```

Fig. 4. Arduino Code for Robotic Cane.

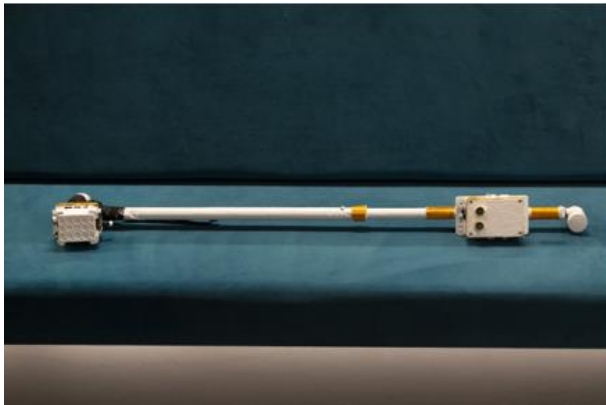


Fig. 5. The final Prototype of Robotic Cane.

V. ER FOR BLOCKCHAIN TECHNOLOGIES

A. Idea

The following scenario was designed for middle school students (i.e., 9th grade). More specifically, it aims to address the following topic which is introduced in Section 8 of the Modern Greek Language Course: “Towards the Future”.

By reading Chapter 8 of the above book carefully, one can highlight Alvin Toffler’s [18] quote back in 1982: “With the current rate of knowledge development, when a child that will bear today will graduate from the University, then the amount of knowledge worldwide will be four times greater than the one it the child’s birth date. Furthermore, when the same child turns thirty years old, 97% of the knowledge acquired worldwide will have been developed after the child’s date of birth”. Having considered the above, the presented scenario was developed. Prior to introducing students to Blockchain Technologies, the ‘Distributed Ledger Technologies’ and Defi (i.e., Decentralized Finance) were explained. Regarding Defi, the Gartner Hype Cycle [19] was presented as displayed in Fig. 6, according to which Defi will be applicable in the following 5 years.

1) Introduction to Distributed Ledger Technologies (DLT)

DLT is a protocol that ensures the secure functioning of a decentralized digital database. It does not require a central

authority to protect the safety of transactions. DLT systems were first presented in 2008 [20] when Satoshi Nakamoto introduced a peer-to-peer version of digital currency, based on Blockchain. The concept was not new as it was first investigated in 1991 by the researchers Stuart Haber and Scott Stornetta [21]. The name of that electronic currency is now well-known as Bitcoin. However, Blockchain is a whole research domain, which also includes the Emerging Technologies Sections, and therefore a brief definition of it will be given below. Blockchain is a system where records of transactions made by cryptocurrencies or other digital cash flow, are maintained across several computers that are linked to a peer-to-peer network. For the presented scenario, students should understand that all Blockchain networks are DLT systems but not all DLT systems are Blockchain Networks. For instance, other DLT systems are DAG (i.e., Directed Acyclic Graph), Hashgraph, Holochain, and Tempo. Blockchain is an important domain for several sectors like Banking and Finance, Transportation, Education, etc. In each transaction currency, information and contracts can be safely stored [22].

2) DLT in our daily lives

During the brainstorming session, the students were introduced to the above definitions of both Blockchain and DLT and afterward, they proposed ways, where a DLT system can solve daily social issues. A guideline was given to the students, in order to propose ideas for applications based in Greece, as this is the target country for this research. An application called Token was proposed as a basis, in order to overcome the bureaucracy and vulnerabilities in the Greek Public Sector. In general, the token project takes advantage of Blockchain Technologies in order to implement applications, which will transform the public administration sector towards a more collaborative direction. It is important that token technologies will be applied for the first time in Greece as part of the collaboration between the Municipality of Katerini and the National Center for Research and Technological Development – Institute of Information and Communication Technologies.

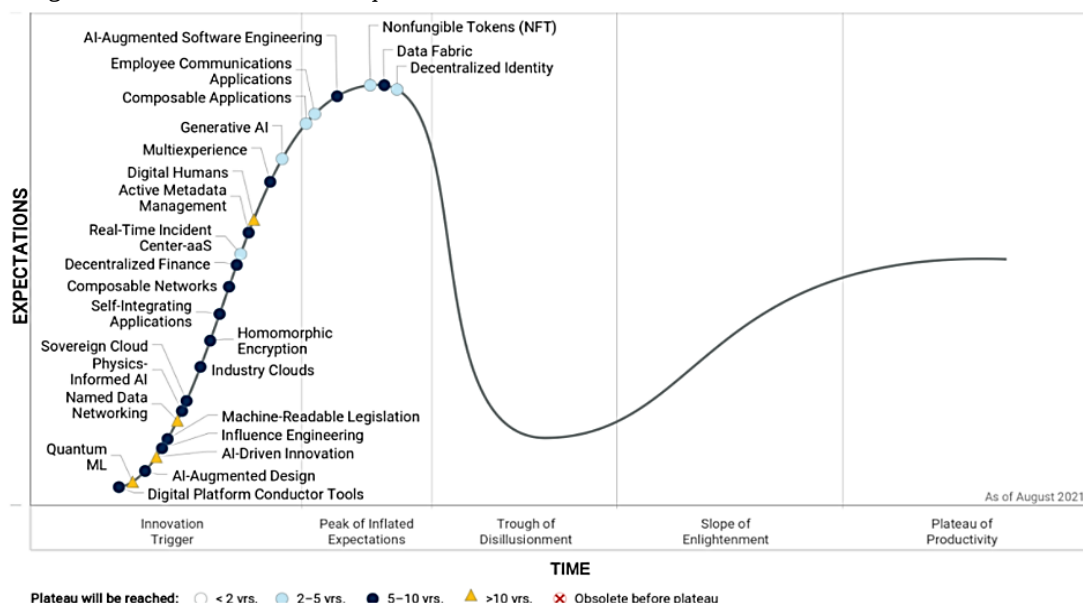


Fig. 6. Gartner Hype Cycle of Emerging Technologies [15].

3) Analyzing contemporary social issues in Greece

Especially after the widespread of covid19, modern societies were required to adapt to a new situation requiring a digital transformation. Handshakes and other physical one-to-one contact were reduced or even annihilated, and the work environment was rapidly changed from in presence (i.e., going to the office), to remote working (i.e., from home) using teleconference applications. Having that situation (i.e., digital transformation) in mind, guaranteeing the security of digital transactions is more important than ever, especially for the digital illiterate people. Therefore, with the students participating in the scenario, the rising need for security and the importance of educating people about the appropriate use of digital platforms were discussed. Specifically, the importance of DLTs for societies in this digital era was highlighted

B. Research

Several communications were organized with NGOs aiming to provide cybersecurity and educate people on how to safer and more secure web browsing. By doing that students understand the importance of DLT and more specifically Blockchain use in small and medium-sized enterprises. As the next step, we participated in the Digital SME Blockchain Summit 2021. In addition, we participated in webinars emphasizing the importance of Blockchain. Furthermore, the following movies were selected to be watched: "Cryptopia: Bitcoin, Blockchains and the Future of the Internet" and "CryptoRush". A book was also selected and read by students, entitled: "Blockchain by example". The next step was to search through Google Scholar for white papers and reliable publications, as well as browsing tech-related blogs to gather more information about DLTs and Blockchain, cryptocurrencies, and token mining. After gathering the required information, students end up with the idea of creating a private Blockchain network for students' peer-to-peer communication and engagement.

C. Design

After finalizing the idea, the first sketch was made as shown in Fig. 7 (right side). This was the first design performed on the classroom's whiteboard. Moreover, in Fig. 7 (left side) the selected hardware is presented, which was decided to be used to develop the required algorithm for our

scenario. In Fig. 7, we can have a clear understanding of the selected microprocessor.

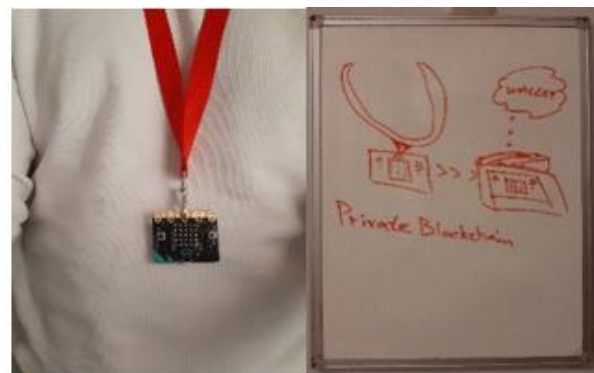


Fig. 7. On the right the students' final design is presented, and on the left the first white-board prototype.

D. Construction

The first step during the construction was for the students to perform budgeting for the selected materials. Except for the materials required to create the prototype, students wanted to design a necklace strap case to put the Micro:bit platform inside. To achieve that, guidance from the Art teacher was required to create unique designs in collaboration with students. The creation and combination of Art and Technology, cover the widest range of STEAM. Students learned how to use glue, scissors, and other tools to design their neck cases. The final cost of the prototype can be analyzed as follows:

- Micro:bit bbc Platform V1: 17.01 euro per unit or Micro:bit BBC Platform V2: 25 euro per unit.
- Case and Neck holding around 10 euros per Student.
- MakeCode: Free Online Software.

E. Programming

To develop the appropriate algorithm concepts from both Physics and Mathematics were required to be adapted. Specifically, mathematics was applied to identify the ID of the radio transmission. The radio transmitter is used to develop the private peer-to-peer network, which will afterward be used for private coin mining. The algorithm was developed based on Python and the Microsoft MakeCode free online editor was used for that purpose. In Fig. 8, the developed algorithm is presented.

```

1 def on_gesture_shake():
2     led.stop_animation()
3     basic.clear_screen()
4     basic.pause(200)
5     if randint(0, 10) + randint(0, 10) == randint(0, 10):
6         radio.set_group(7)
7         blockchain.add_block(1)
8         basic.show_icon(IconNames.SMALL_SQUARE)
9     else:
10        basic.show_icon(IconNames.SAD)
11 input.on_gesture(Gesture.SHAKE, on_gesture_shake)
12
13 def on_button_pressed_a():
14     global privatecoin
15     led.stop_animation()
16     privatecoin = len(blockchain.values_from(blockchain.id()))
17     basic.show_number(privatecoin)
18     basic.show_string("\nPRIVATE CRYPTO COIN\n")
19     radio.send_string("\nWELCOME TO PRIVATE BLOCKCHAIN\n")
20 input.on_button_pressed(Button.A, on_button_pressed_a)
21
22 def on_received_string(receivedString):
23     basic.show_string(receivedString)
24 radio.on_received_string(on_received_string)
25
26 def on_button_pressed_b():
27     led.stop_animation()
28     basic.show_number(blockchain.length())
29     basic.show_string("\nPRIVATE BLOCKS\n")
30 input.on_button_pressed(Button.B, on_button_pressed_b)
31
32 privatecoin = 0
33 basic.show_string("\nSHAKE=MINE IN PRIVATE NETWORK A=CREATES PRIVATE COIN B=SEE THE LENGTH OF PRIVATE CHAIN\n")

```

Fig. 8 Code for ER of Blockchain.

F. Evaluation

During the evaluation step, the functionality of both construction and algorithm were tested in real-time by the students. After the required modifications to the software and the internal blockchain, the prototype was ready. At the end of the project, the students understand the value of cryptocurrencies and the DLT technology architect. The goal of this scenario was to assist students so that they understand the existing network architectures and their differences. In addition, through the implementation of their private network, students learned the benefits of using cryptocurrencies and how decentralized networks may revolutionize daily processes as we know them today. Students had the chance to familiarize themselves with a range of Emerging Technologies and adapt them to ER by collaborating with the educator and their classmates. Finally, by creating their cryptocurrency, students were introduced to the rapidly evolving industry of Financial Technology.

VI. RESULTS

Before the beginning of the project, the students are required to fill out a questionnaire so the educator can realize their familiarity with their focus group and the topic in general. A questionnaire or another similar measure technique is suggested to be adapted in every course, which contributes to the ER process (e.g., technology, chemistry). For example, in the Computer Science course, the programming skills of students can be assessed in advance to easily measure the learning curve of students after successfully completing the programming stage for their robotic idea. At the end of each scenario, the students should

again complete a second skill assessment (e.g., a questionnaire), to assist the educator to understand the learning outcomes of each scenario. For the aforementioned scenarios, parts of the questionnaires are presented below.

A. Draft of Questionnaire A Priori

The questionnaire should include questions that will lead to both quantitative and qualitative information. Fig. 9 presents samples of questions that were used for the scenario mentioned in ER for Accessibility. The questionnaire was created using Google Forms and it includes both free-text and multiple-choice questions. In total, 21 students participated in the aforementioned project and below their answers prior to starting the project are analyzed. In the question presented in 9a, 67% of the students replied, "Nowhere", whilst 14% of students replied, "I am not sure". In question 99b, 57% of the students answered that they know what the Braille Alphabet is, but they are not aware of how to recognize it. Following that, in the free-text question 9c, the most frequent answer was related to transportation but other answers such as studying, or socializing were also given.

According to questions targeted to Arduino Processor which are presented in 9d, 52% of the students ranked with equal or less than 3 their familiarity with the processor, whilst 76% of the participants ranked their familiarity with IDE (i.e., Arduino Integrated Development Environment with less than 3. The reason for the above unfamiliarity is that most of the students have used Scratch or Building-blocks type of software before this project. Furthermore, 43% of the students used to believe that ultrasonic sensors are based on vision principles and less than 29% of the student's expressed confidence with more than 4 in proposing a robotic idea for the visually impaired.

Figure 9 displays four sample questions from a questionnaire, labeled (a) through (d).

(a) Where can you see Braille code?

- ☐ School
- ☐ Public Transport
- ☐ University
- ☐ Supermarkets
- ☐ Restaurants
- ☐ Shops
- ☐ Nowhere
- ☐ Museums
- ☐ I am not sure

(b) Do you know what is the Braille Alphabet?

- ☐ Yes
- ☐ No
- ☐ Yes, but I do not know how to recognize it
- ☐ I am not sure

(c) What are the main challenges that visually impaired are facing?

Your answer

(d) How familiar are you with Arduino?

How familiar do you feel with Arduino?

1 2 3 4 5

Not at all ☐ ☐ ☐ ☐ ☐ I have used it many times in the past

How familiar are you with IDE?

1 2 3 4 5

Not at all ☐ ☐ ☐ ☐ ☐ I have used it quite a lot

How often do the following occur in Greece?

Rare Often Never Always

Cars illegally Parked in front of Ramps ☐ ☐ ☐ ☐

Obstacles (for example chairs and tables) placed on Tenji Blocks ☐ ☐ ☐ ☐

Traffic Lights without embedded noise signals ☐ ☐ ☐ ☐

Cars crossing a street with a red traffic light ☐ ☐ ☐ ☐

An ultrasonic Sensor is based on what of the following?

Daily ☐ Sound

☐ Light

☐ Colour

☐ Vision

How confident do you feel to propose a robotic solution for the visually impaired?

1 2 3 4 5

Not at all ☐ ☐ ☐ ☐ ☐ A lot

Fig. 9. Sample questions focusing on the selected target group (a, b, c) and the Arduino processor (d), were given to students prior to starting the project.

For ER for blockchain Technologies, another questionnaire was formed, with the goal of pre-assessing the familiarity of the students with the topic and with the platform Micro:bit in general. In Fig. 10, a sample of questions from that questionnaire can be found. The questionnaire was formed using Google Forms and included only linear scale and yes/no questions. In total 15 students participated in this scenario and therefore, their learning outcomes will be analyzed in this section. Before they participated in this scenario, 73% of the students were not familiar with using the Micro:bit Platform and none of them were familiar with Blockchain Technologies. Furthermore, 80% of them were not familiar with the term: "Cryptocurrency" and 53% of them were not familiar with Bitcoin. From the above, it is quite clear that the students did not know most of these terms, prior to being involved in the ER scenario, except the term: "Bitcoin". This most probably happened because on many different platforms in Greece (e.g., media, web) one can hear about Bitcoin quite often.

B. Results from the Feedback a Posteriori

After the final evaluation of the project for the scenario explained in ER of Accessibility, a questionnaire was given to the students in order to evaluate their progress and their familiarity with the topic and the target group. A few questions of the questionnaire are presented in Fig. 11. Around 90% of the students marked with more or equal to 4 their confidence to propose solutions for visually impaired people after involving in the project, which is about 3 times more than it was before starting the project. Additionally, 81% of the students are willing to use Arduino for future projects. Moreover, students were able to analyze the challenges that blind people are facing in Greece in more detail than before being involved in that project and 71% of them feel more aware of how to assist visually impaired people. Regarding the free-text questions presented in 10a, there was a huge heterogeneity in students' favorite parts of the project. However, most of the students concluded that the biggest challenge was either the research itself or the construction of the robot.

Are you familiar with the term Bitcoin?

☐ Yes
☐ No
☐ Maybe
☐ Other: _____

How familiar are you with the Micro:bit platform?

1 2 3 4 5
 Not at all ☐ ☐ ☐ ☐ ☐ I have used it for several educational projects

Are you familiar with the term Cryptocurrency?

☐ Yes
☐ No
☐ Maybe
☐ Other: _____

How familiar are you with the term Blockchain? *

1 2 3 4 5
 Not at all ☐ ☐ ☐ ☐ ☐ I am familiar with Blockchain and its operations

Are you familiar with Microsoft MakeCode?

1 2 3 4 5
 Not at all ☐ ☐ ☐ ☐ ☐ I have used it for several projects

(a)

How familiar are you with the Distributed Ledger Technologies (DLT)?

1 2 3 4 5
 Not at all ☐ ☐ ☐ ☐ ☐ I know the architectures and the importance of DLT

(b)

Fig. 10. Sample questions focusing on the required terms for the project and the Micro:bit platform, which were given to students prior to starting the project.

What was your favorite part of the project?

Your answer _____

What are the main challenges that the visually impaired are facing in Greece?

Your answer _____

Are you more aware now on how to assist these people in their daily lives?

1 2 3 4 5
 Not at all ☐ ☐ ☐ ☐ ☐ A lot

(a)

How confident do you feel to propose a robotic solution for the visually impaired?

1 2 3 4 5
 Not at all ☐ ☐ ☐ ☐ ☐ A lot

Are you confident to use Arduino for other projects?

☐ Yes
☐ No
☐ Maybe

What was the biggest challenge in the creation of the robotic cane?

Your answer _____

What was your favorite part of the project?

Your answer _____

(b)

Fig. 11. Sample questions to evaluate the learning outcomes of students.

How familiar do you feel with Blockchain Technologies?

1 2 3 4 5

I am still not able to understand the term ☐ ☐ ☐ ☐ ☐ I am able to understand the term and its functionalities and architectures

How familiar do you feel with the DLT?

1 2 3 4 5

I still do not understand the term ☐ ☐ ☐ ☐ ☐ I understand the term and its possible applications

Did Microsoft MakeCode helped to develop Python and Javascript Algorithms?

☐ Yes

☐ No

☐ Maybe

☐ Other: _____

(a)

How familiar are you with the term Cryptocurrency?

1 2 3 4 5

Not at all ☐ ☐ ☐ ☐ ☐ I understand the term and its differences with the common coins

How familiar are you with the term Bitcoin?

1 2 3 4 5

Not at all ☐ ☐ ☐ ☐ ☐ I understand the term and its possible applications

(b)

Fig. 12. Sample questions focusing on the required terms for the project and the Micro:bit platform, which were given to students during the evaluation stage of ER.

Regarding the second scenario explained in ER of Blockchain Technologies, a questionnaire was given to the students after the evaluation of the project. The goal of the questionnaire was to assess the progress and the familiarity of the students with Blockchain Technologies and the DLT. By analyzing students' answers the authors concluded that: Microsoft MakeCode was an understandable educational software for 80% of the students, whilst 73% of them, mark with more or equal to 4 the assistance of MakeCode in order to use JavaScript and Python in their classrooms. Moreover, 73% of the students were able to understand the meaning and architecture of Blockchain Technologies as well as the term: "Cryptocurrency" after the completion of the scenario, and 60% of them are now familiar with the DLT technologies. The sample questions for this questionnaire are presented in Fig. 12. To conclude, after the completion of the project, students were able to understand the usage of DLT in everyday lives as well as how DLT/Blockchain/Cryptocurrencies can be combined to improve daily problems and challenges.

VII. DISCUSSION

With the new era of the 4th Industrial Revolution, educating the young generation on how to use technology is of critical importance. ER can have an important role in that, however as complicated problems require complex solutions, a more interdisciplinary approach to the ER is required. Students need to understand how to form an idea by taking advantage of all the knowledge they have from the school curriculum. But they also need to understand how to perform thorough research as well as how to cooperate not only with the creators of the technology (i.e., developers, engineers) but also with its end users. ER should prepare the citizens of the 21st century by cultivating both the required hard and soft skills. The above research was the first approach of the authors to raise a more interdisciplinary approach to the ER and to highlight the importance of forming solutions

collaboratively with different industries. In such a way, the importance of ethics can also be pointed up. These students will be the future workforce and they will develop solutions for society. Therefore, there is a constantly increasing need for these people to understand the responsibility that comes with creating or proposing technological solutions. The development of a Failure Modes and Effects Analysis during the stage of Design in ER, in order to highlight this responsibility, will be analyzed in future research. Furthermore, what is required to be investigated is the relationship between industrial robotics and ER and the required infrastructure to allow every educator in Greece to apply the aforementioned ER approach to his/her classroom. By adapting the aforementioned structured definition, ER can be considered as an interconnected set with both the sets of STEAM and Language and Literature Courses. Specifically, each one of the different stages of the process of ER is intersected with the other sets as shown in the Venn diagram in Fig. 13. At first, the educator sets the Educational Goals based on both the curriculum of STEAM Courses for each students' age group and the topics of Language and Literature Courses. Afterward, the process of ER begins with brainstorming and the research for the final idea. Then, all three sets are intersected in order to design the proposed ER solution. Furthermore, both construction and programming are connected with both ER and STEAM. Lastly, for the evaluation of the proposed solution, all three sets are intersected again. Therefore, ER should not be considered only as a subset of STEM or STEAM, being there to provide experimental tools to complete these courses/fields. ER should be considered as a whole interdisciplinary process aiming to prepare students to be active citizens in a rapidly changing society.

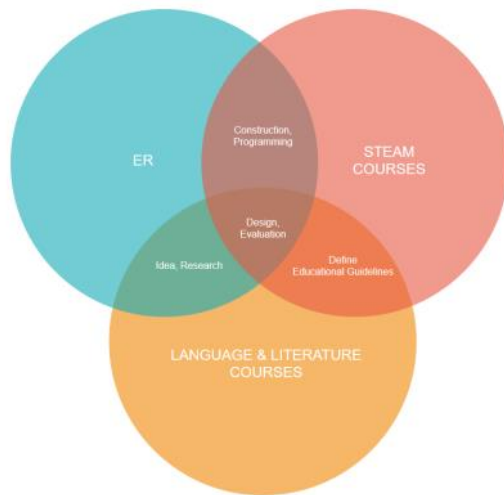


Fig. 13. The intersections between ER, STEAM and Language and Literature Courses.

VIII. CONCLUSION

Through this research, the authors have tried to set a comprehensive definition, which will be able to better reflect the importance and benefits of ER. This approach can also guide the educators in case they want to apply the ER in their courses. The definition is well-aligned with the Greek School Curriculum, but it can be globally applied. The definition is based on dividing ER into a sequence of interconnected steps (i.e., Idea, Research, Design, Construction, Programming and Evaluation) totally aligned with the educational goals.

Along with the proposed definition, two developed research scenarios are analyzed in the paper. These scenarios were inspired by the Modern Greek Language course. Through these educational scenarios, the students were able to fully understand the connection between ER and both STEAM fields and Humanitarian Studies. They enriched their knowledge and practiced the concepts taught in the respective sections of the Modern Greek Language Course. Before and at the end of each scenario, questionnaires were given to the students in order for the educator to assess the consolidation of the concepts and the educational outcomes of the specific educational scenarios. Through this interdisciplinary approach to ER, multiple courses of the school curriculum were combined.

The next step would be to apply the technique of Unified Theory of Acceptance and Use of Technology (UTAUT) [23] which is widely recognized as an established tool for determining the acceptance and use of innovative technologies combined with the proposed ER definition.

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