

Article

Design Thinking as an Auxiliary Tool for Educational Robotics Classes

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Abstract: The dynamic spread of 3D printing technologies and open-source electronics prototyping platforms has significantly enriched the diversity of instruments used within educational robotics (ER) settings. An active, low-entry-level community offering ready-to-use libraries for a broad variety of devices assists in the development of quite sophisticated projects. However, the flipside of the coin is represented by the current research findings, which reveal that students' interest in science, technology, engineering and mathematics (STEM) subjects has declined across Europe, as manifested in difficulties when approaching scientific topics and dealing with problems and phenomena studied from a multidisciplinary perspective. Consequently, a significant percentage of youths are at risk of social exclusion due to the direct relationship between low academic achievements and school dropout. Moreover, learners lack guidance in applied and life-context skills, such as creative thinking, problem solving, and collaboration, which highlights the need to introduce innovative pedagogical approaches. In this context, the design thinking (DT) methodology was proposed to tackle the problem. Originating in the development of psychological studies on creativity in the 1950s within the educational context, DT is known to foster creative thinking, help develop empathy, promote action-oriented actions, improve meta-cognitive awareness, contribute to problem-solving skills, and enhance students' imagination. The last point supports the students' development of critical thinking, social inclusion, teamwork skills, and academic performance. Thus, this paper introduces a methodological framework combining DT with ER classes. First, to approach the problem, the teachers' survey data were collected and analysed to reveal the respondents' level of integration of the DT methodology into current school curricula. Then, the work focused on the application of this framework in a learning experience by addressing the weakest points established and their elaboration through the combined ER and DT classes in the context of secondary schools.

Keywords: 3D printing; Arduino; educational robotics; design thinking; open-source project; open-source platform



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1. Introduction

According to the latest Eurostat data, in 2020, the at-risk-of-poverty or social exclusion rate for young people aged 15–29 years was 25.4% in the EU, corresponding to about 18.1 million persons [1]. As with every complex phenomenon [2,3], the situation was hugely impacted by COVID-19 [4], and, in many respects, it is also related to school dropout [5,6]. In fact, recent research reveals that the education system has not successfully prepared and maintained teachers and trainers to provide learners with authentic practical and innovation-oriented skills [7–9]. Consequently, learners lack guidance and applicable life context skills, such as creative thinking, problem solving, and collaboration [10]. As a result, lack of motivation and low academic success are responsible for school dropout [11–13], damaging individual self-esteem [14,15] and creating a sense of loss of control [16].

To tackle the problem, schools are constantly seeking new ways to enhance student learning [8,17]. Among the different strategies adopted [18,19], which generally aim at

modernizing school curricula and approaches and placing them in correspondence with the challenges of modern society, design thinking (DT) has rightfully gained significant attention from research and educational communities [20–27].

Stemming from the development of psychological studies on creativity and their techniques in the 1950s [28], by the 2000s, DT evolved into a generalizable approach to technical and social innovation [29]. Its fruitful adoption in education was due to the core of the design concept, which encompasses elements such as thinking, developing empathy, promoting action-oriented prejudices, developing meta-cognitive awareness, being active, problem solving, and using one's imagination. Therefore, the methodology may be considered in the teaching and learning process as a human-centred problem-solving approach aiming to develop key 21st century competencies and enhance creativity and innovation [30]. Moreover, at the pedagogical level, DT can help students develop a growth mindset focused, in addition to the above, on analytic thinking [31–33].

In short, the design-oriented thinking process begins with defining a problem. Then, following research on and ranking of priorities that often compete, it tests the applicability of multiple solutions with prototypes and ends with the social evaluation of objects [34]. As can be seen, every single DT stage can simultaneously appeal to different categories of Bloom's taxonomy in various proportions [35,36]. For example, the testing of the prototype conceived by the DT process is the point where creative and critical thinking skills merge and blend. Should the prototype work improperly, the methodology dictates free iteration of the stages in an arbitrary manner. Thus, critical and creative thinking work together in DT to encourage innovation and foster the generation of problem-solving ideas.

From another perspective, while providing new insights into learning [37], teachers act as the primary designers [38] during the educational process, selecting the appropriate tools and setting the goals to be achieved creatively [39]. In this way, an experience of intense learning is provided [40]. In addition, DT delivers opportunities to respond to unexpected needs in the classroom [41,42] while supporting students' critical thinking, social development, teamwork skills, and academic performance. This last point, in turn, contributes to students' understanding, identification, and analysis processes. Therefore, through design-oriented thinking, the pedagogical repertoire of teachers is essentially expanded [43,44].

Thus, the experience described in this article intends to bridge this gap through training modules based on DT skills and tackle the problem outlined above. Given the European perspective, the project was carried out transnationally due to the ubiquity of the inadequate resources available to teach DT skills and the current rates of early school leaving across Europe. The project aimed to increase the academic success of teachers and educators, support their professional development, empower them with resources to teach DT skills, and equip them with a DT mindset; facilitate the adoption of DT educational practices; strengthen the capacities of educational authorities, policymakers, and decision makers to promote and mainstream DT educational practices; and decrease early school dropout.

The article is organized as follows. First, the initial premise for an approach unifying DT and ER—the research implemented in Italian schools—is provided. Then, guided by the results revealed, the methodological framework and the learning experience achieved within the context of ER classes are described.

2. Teachers' Profile and Their Perception of DT Aspects That Are Lacking in Current Curricula

As a starting point for developing the methodological framework, the authors conducted a survey to reveal the current situation of the understanding of the design methodology and the possible pathways for its integration into ER curricula in Italian schools.

The sample participating in the online survey was composed of 75 teachers who were reached through school networks in order to cover the entire national territory. The respondents' profile is outlined in Figure 1. As can be seen, the majority of the sample was

represented by the middle-age category (31–40 years old), with a significant prevalence of females compared to males (74.7% versus 25.5%, respectively). Regarding the education level, more than half of the respondents (64) had a bachelor’s degree.

The data revealed that the respondents’ prevalent affiliations were lower secondary school institutions (Figure 1e). However, the students participating in the final learning experience were aged between 16 and 20 years old (Figure 1d).

Finally, regarding the disciplines taught, excluding the options marked “Others” and “Sports”, the humanist disciplines dominated the percentages of the remaining responses.

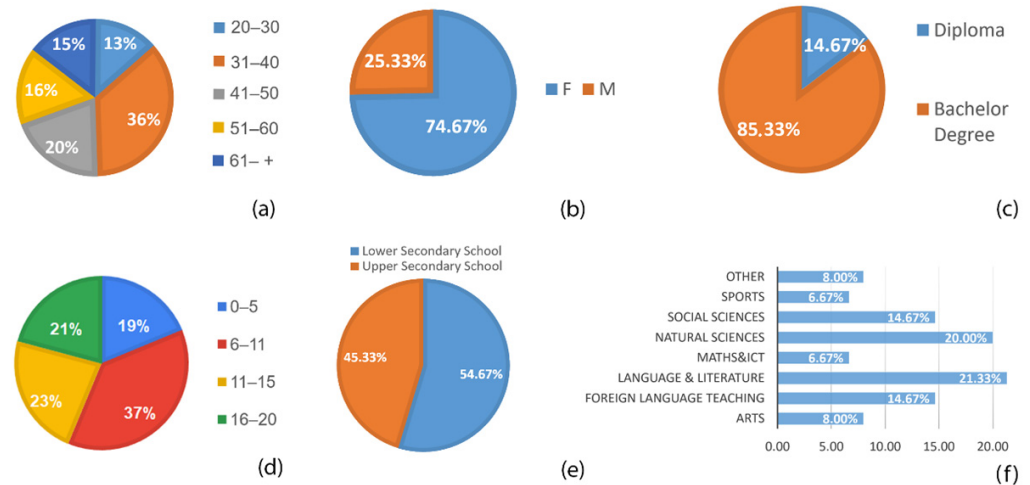
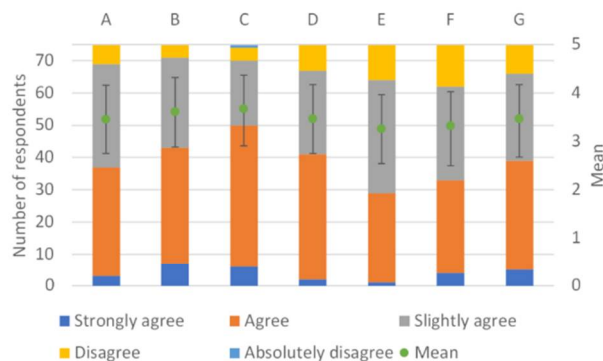


Figure 1. Teachers’ profile: (a) respondents’ age distribution; (b) gender distribution; (c) education level; (d) students’ age groups; (e) respondents’ secondary school level; (f) subjects taught.

The second part of the survey aimed to investigate how the DT methodology could be introduced into classes, mainly into the disciplines taught.

The questions included in this part of the survey were categorized according to the steps of DT and are grouped in Table 1. Following the approach described in [43], the corresponding averages for each dimension were obtained. As can be seen, the qualitative ranking revealed prototyping and testing (bars E and F in Figure 2) to be the most underdeveloped aspects of DT in the curricula. The results can be regarded as quite coherent, given that the phases are the final stages of the whole DT process; i.e., where the educational paths are supposed to converge.



- A - In the current curriculum, students identify problems related to the real life
- B - The ability to do research to understand the problems is included in the current curriculum
- C - The ability to generate ideas for the solution of problems is included in the current curriculum
- D - Decision-making skills for solving problems are included in the current curriculum
- E - The ability to transform the ideas produced for the solution of the problems into products is included in the current curriculum
- F - The use of the manufactured products in problem solving is included in the current curriculum
- G - Evaluations of the effect of the developed product on problem solving are included in the current curriculum

Figure 2. Design thinking skills in the current curriculum (for comments, see the text).

Therefore, according to the general ranking revealed (Table 1), prototyping and testing were hard for both teachers and students to put into practice. In other words, they found it challenging to realize and produce the suggested solution for the issue dealt with during the initial DT phases. In fact, as Table 1 reports, in the testing and prototyping phases, sentences such as “The use of the manufactured products in problem-solving” (testing phase) and “The ability to transform the ideas produced for the solution of the problems into products” (prototyping phase) were ranked the lowest.

Table 1. The ranking of DT steps in the survey.

Steps of Design Thinking	Questions of the Survey Posed to Teachers	The Overall Ranking According to the Points Obtained
1. Empathy	2. The ability to do research to understand the problems is included in the current curricula (B)	2
2. Definition	1. In the education curriculum, students identify problems related to real-life (A)	4
3. Ideation	3. The ability to generate ideas for the solution of problems is included in the current curriculum (C)	1
	4. Decision-making skills for solving problems are included (D)	3
4. Prototyping	5. The ability to transform the ideas produced for the solution of the problems into products is included in the current curriculum (E)	6
5. Testing	6. The use of the manufactured products in problem-solving is included in the current curriculum (F)	5
	7. Evaluations of the effect of the developed product on problem-solving are included in the current curriculum (G)	3

This was the central point exploited in the methodological framework proposed by the authors for the integration of DT with ER activities, as described in Table 2 and Section 3. Using this framework, the students, during the learning experience, were challenged to transform their solutions into a real product, which was, in this specific case, a robotic arm.

Table 2. Educational module description.

Lesson Number	Lesson Duration (Hours)	Didactic Objective	Lesson Outline
1	3	Project presentation to be realized during the course and introduction of the basic concepts of technical drawing	In the first part of the lesson, the target project was described. For this purpose, different robotic arms were presented to show the diversity of models from mechanical and programming points of view. The Tinkercad application for the technical drawing of mechanical parts was introduced in the second part. Students began to explore this tool by experimenting and trying to draw different objects in 3D. The goal was to familiarise students with the task of making objects to be 3D printed with the appropriate device

Table 2. Cont.

Lesson Number	Lesson Duration (Hours)	Didactic Objective	Lesson Outline
2	4	Introduction to Arduino and the related IDE	The second lesson focused on introducing and presenting another essential component of the robotic arm: the programming to be implemented via Arduino IDE. The first part of the lesson focused on the main features of Arduino and the programming of the basic procedures (void set-up and void loop), showing students how two applications (Tinkercad and IDE) could interact. In the second part of the lesson, students were engaged in small projects, both analogue and digital (including the use of Arduino), to familiarise them with such tools and programming. Initially, the students used a breadboard to realize different projects with the following main components: switch, resistors, cables, batteries, and LEDs
3	4	The start of the work for the final project: the robotic arm	The third lesson was divided into two sections to allow the students to start working simultaneously on the robotic arm's mechanical and electronic parts. In the first part, students began to draw the mechanical components in Tinkercad, following the instructions provided with respect to the shapes and dimensions of the objects, keeping in mind the functionality of each, and respecting the volumetric dimensions. For this activity, the students were divided into small groups so that each student was engaged in realizing a single component of the structure. The second part of the lesson was dedicated to further deepening the functionalities of Arduino IDE, such as serial communication and the analogRead, analogWrite, and map functions. In addition, the potentiometer was introduced
4	4	Servo motor programming for the control of the robotic arm	This lesson was focused on the preparation of programming codes for robotic arm control. Students experimented with several servo-motor control methods; in particular, the potentiometer and switch. Specifically, the concept of pulse width modulation (PWM) in its connection to the analogWrite function was introduced. Before using the Servo.h library to contextualize the abovementioned function, the servo motor was controlled through the potentiometer. Later, the cycle with counter and condition (if-then) concepts were introduced. At the same time, the first versions of the mechanical components of the robotic arm were 3D printed based on objects already prepared by the students
5	4	Introduction of different principles for servo-motor control	This lesson focused on preparing the servo motors' programming codes for control of the robotic arm. In addition, as a means of control, the touch sensor was introduced, starting from the simplest projects involving the use of LEDs and proceeding up to more complex tasks involving the introduction of the tactile counter functionality. In this context, the concept of a flag was explained. In parallel, robotic objects were designed, and the mechanical components of the robotic arm were 3D printed

Table 2. Cont.

Lesson Number	Lesson Duration (Hours)	Didactic Objective	Lesson Outline
6	4	The introduction of the operating principles for the stepper motor and the means for its actuation	This lesson was focused on the specificities of a stepper motor, describing all the significant steps starting from the physical structure and proceeding to the programming of movement. To make the movement principle clearer, the corresponding Arduino library was avoided. Instead, a series of procedures for serial controller implementation were introduced (ULN 2003). In addition, such means of control as infrared light remote control and a Bluetooth module to be controlled via a smartphone were introduced. Finally, students carried out a series of projects putting into practice the concepts presented
7	4	The organization of the code for control of the robotic arm	This lesson focused on preparing the programming code for the robotic arm. Due to the complexity of the project, the entire code was divided into sub-procedures to simplify the understanding and organization of the data. In particular, the concept of a tab (new code window) in the Arduino IDE environment was introduced. In detail, the students prepared the code for the robotic arm according to the type of control chosen; that is, via infrared light remote control or Bluetooth. After that, they combined the programming codes for two servo motors (one for the gripper and the other for the movement of the arm) and two motor steppers (one for the rotation of the base and the other for the movement of the arm)
8	3	Assembly of the complete robotic arm and code adjustment	This lesson aimed to assemble the robotic arm and check the functionality of the previously prepared code. The class was dedicated to the gradual assembly of the mechanical parts and organization on a wooden board of all the electronic components, including the breadboard and the power batteries delivered to the students at the beginning of the lesson. The aim was to verify the complete code and modify and/or adapt it according to the needs for mechanical movement

3. Design Thinking within the Context of ER Classes: The Methodological Framework

Being an essential aspect of technological literacy, design is closely linked to engineering practice [45,46]. Moreover, ingenuity and a deep understanding of the essence of the studied phenomena lie at the very core of scientific inquiry and engineering [39,47,48]. Therefore, as the mediators between scientific and social domains, on the way towards transforming fundamental principles into tangible ready-to-use products, engineers are required to balance strictly logical reasoning and creative thinking [49].

Generally, being capable of operating at different levels of problem solving and combining micro- and macro-visions are essential skills for future 21st century problem solvers [27,50]. As numerous examples from the literature illustrate, the inclusion of designing practice in ER classes significantly increases the efficiency of the educational process [47,51,52]. This combined approach accustoms students to creative research instead of leaving them with static knowledge only and depriving them of a network of associative links that the bigger context can provide.

DT within the context of ER may be perceived as an auxiliary tool implicitly orchestrating the students' efforts. Moreover, DT has been rightfully defined as standing at the heart of maker education [53]. On the other side, among the primary benefits that ER brings is the inspiration of curiosity and creativity [54–56]. As was noted, while originating in the development of psychological studies on creativity and its' techniques, the method imposes a regularised framework and approach when dealing with multifaceted tasks [57].

The intricacy of the challenges that must be resolved today and in the future continuously increases. Therefore, the authors claim that beginning from the traditional approach consisting of the consecutive coverage of inter-related arguments from one side and gradually shifting students' attention towards a bigger picture may be preferable. This is because, from a "higher" position, the logical interrelation between the separate topics of a single discipline and adjacent subject areas may be perceived more clearly and fully while also assisting the application-oriented attitude.

In this regard, the fundamental underlying dilemma is to tackle the balanced exposition of separate facts in a regular curriculum and, once these have been acquired, to foster the capacity to operate freely with them in wider macro-contexts. Moreover, while doing this, the application environment may induce students to cover every eventual inquiry related to the problem at hand as a part of independent research [58].

The learning experience presented below attempted to combine ER classes with a DT methodology, mainly in the prototyping and testing phases, as these were the aspects revealed to be lacking during the survey. The main challenge faced was engaging the students in activities where they would be exposed to design and engineering issues in a balanced manner.

3.1. The Introduction of the Design Thinking Methodology

The learning experience path consisted of eight face-to-face meetings of 3–4 h each, with a total of 30 h. The labs were a part of the extracurricular activities held during the regular school year. In total, there were 20 students aged between 16 and 17 voluntarily involved in the classes. They were divided into four teams of five people each. Some participants were invited by teachers from the same school who took part in the online survey. The participants were free to choose an assignment and individual area of responsibility within the groups.

With regard to adherence to the DT methodology, the main stages are outlined below.

First, an open scenario was presented to the students where they were challenged to solve an environmental problem derived from climate change. Therefore, they were guided through the five steps as follows:

Empathy—Students started by investigating the problem submitted, aiming to better understand the main features and causes, by collecting videos, articles, and images describing the problem. Then, they tried to define a potential user profile to address the solution to be suggested;

Definition—Students were invited to specifically define the problem to be solved on the basis of the user profile found by defining the questions "Who", "What", and "Why" focused on the real needs of the end-users selected;

Ideation—Students started to let their ideas flow, aiming to find the final solution to be proposed by using robotics as an instrument that could prevent the damage caused by climate change. In this specific learning experience, the different student teams built robotic arms to be used in different manners in agriculture;

Prototyping—Students were expected to construct the prototype of the solution proposed. In this specific case, they firstly used Tinkercad to design it and later started printing the mechanical elements with a 3D printer and coding in Arduino IDE;

Testing—Students were invited to show their alpha prototype to the classes and at least one expert to collect comments and feedback on the solution developed.

3.2. The Prototyping and Testing Phases

Regarding the prototyping and testing phases, the introduction of ER begun with the definition of a final, well-structured goal—the design and 3D development of a simple robotic arm—and the corresponding work with related electronics was chosen. With this aim, the classes delivered were composed of two parts:

- Electronics fundamentals with Arduino coding;
- Robotic arm 3D design.

The reason for the choice was that multifaceted activities such as robotic arm development can be considered parallel elaborations of different aspects related to mechanics, electronics, and coding. Regarding the connection with design, it has been noted [58] that “... the complex creative feat of the parallel creation of a thing (object, service, system) and its way of working is the core challenge of design reasoning”. In fact, educational robotics offers a lot of room for development of creative skills [52,59].

The meetings for the prototyping and testing phases were organized so that the students’ efforts would allow them to accomplish the task.

Thus, the structure of the meetings consisted of:

- A short (10–15 min) theoretical introduction aiming to reveal the physical basis and the principles of a hardware piece studied at the time with live demonstrations or a brief introduction into a new aspect of 3D shape synthesis in Tinkercad;
- Practice with several coding examples to provide initial experience with a new electronic component or work in the Tinkercad platform to strengthen the skills with the new aspect covered;
- The assignments required independent work and problem solutions based on combinations of the concepts covered during the consecutive meetings.

In Table 2, a description of the educational modules is given.

3.3. Work in Tinkercad

Initially, it was presumed that, once provided with a basic auxiliary model, the students would reproduce it using the Tinkercad platform (Figure 3). As can be seen, the results obtained were quite satisfactory. Nevertheless, for the entire robotic arm to work as a single entity, the integration of the parts designed by different students would require a lot of additional effort, which was unfeasible due to the timespan available, especially taking into account the time taken by the meetings, which took place after the main class lessons in the afternoon. In addition, certain pieces (e.g., the gears of the grippers) could not be left to independent development. Therefore, during the concluding meeting the students worked with the parts printed in advance.

In addition to these practical activities with 3D shape design and manipulation, introductory exposure to 3D printing technology, with the majority of the corresponding nuances of the technology, was provided.

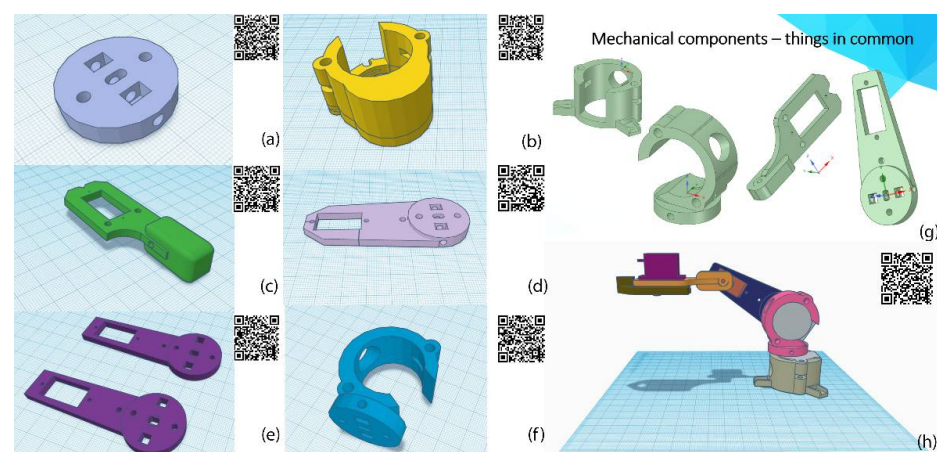


Figure 3. Students’ work (left) during the exercises with the parts of the robotic arm (right). The QR codes contain direct links to the pieces designed in the Tinkercad platform (for access, an account is required). (a) A piece of the arm and the stepper motor base; (b) stepper motor holder; (c) gripper holder; (d) the arm; (e) the arm; (f) stepper motor holder; (g) mechanical components—things in common (a slide from the lesson presentation); (h) robotic arm representative assembly.

3.4. Work with Electronics and Coding

Possessing no prior experience with Arduino, the students were gradually introduced to microcontroller programming only after the completion of several mini-projects with basic electronic components (see Figure 4). At this point, the main goal was to refresh/deliver basic notions concerning electricity and electronics and their relation with fundamental physical principles while enabling the students to become acquainted with a breadboard. On the other hand, dealing with this kind of project before trying the standard LED blinking in Arduino, the authors considered it crucial to help students understand that microcontrollers may be simply overqualified for certain tasks.

Further, when introducing Arduino, the authors considered it important to convey the message that the intrinsic functionality of a microcontroller enables the final user to treat every physical agent measured (and assigned to an auxiliary variable) as a piece of information ready to be used in a wider and flexible context. In fact, the realm of digital electronics emerged from the necessity of storing and processing the bits of information needed to make complex logical decisions [60].

Therefore, once the initial microcontroller-free breadboard projects had been elaborated, standard introductory mini-projects aiming at facilitating acquaintance with microcontroller programming were worked on. It is worth noting that many students with an innate propensity for manipulative work preferred to busy themselves with the breadboard rather than Arduino, at least during the initial phase, when the output of the breadboard projects was comparable in effect with those performed on Arduino. This fact may be reasonably explained by the fuller and more transparent control perceived to exist over the cause–effect link in the first case compared to the second.

Finally, the complexity of the tasks gradually expanded towards different sensor and actuator combinations, which were to be chosen arbitrarily during the last stage of work with the robotic arm.

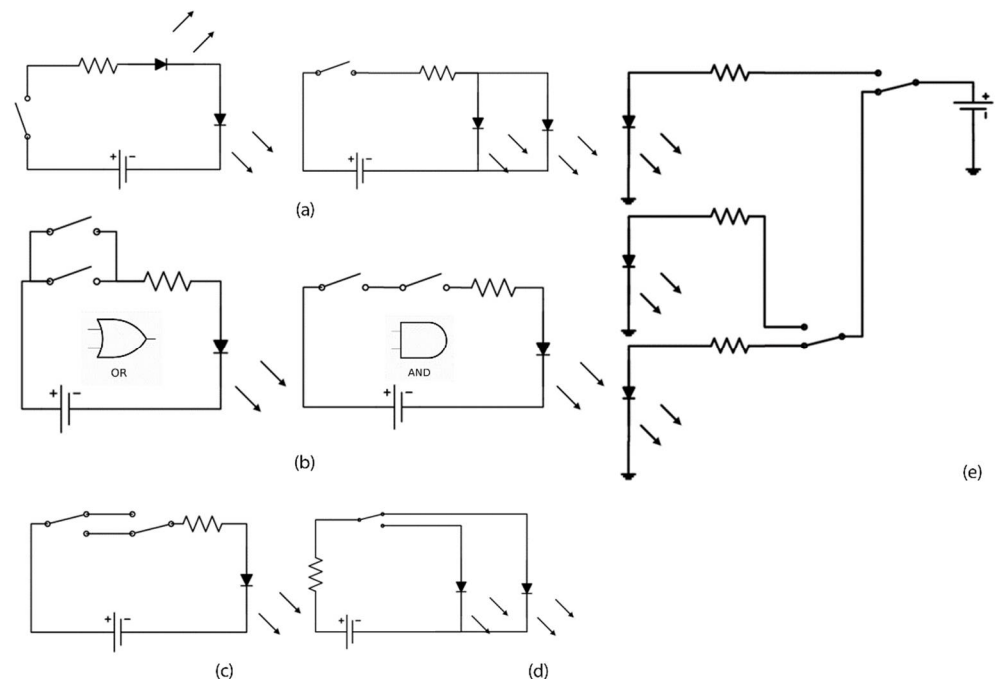


Figure 4. Examples of breadboard exercises offered during the introductory hands-on electricity activities: (a) parallel and serial LED connections; (b) circuitry analogues of the basic logical operators (placed inside); (c) two-way LED switching; (d) LED toggling; (e) traffic light model.

As outlined in Table 2, during the project’s final phase, students were required to put all the components together. Thus, the work performed consisted of:

- The distribution and fixing of the hardware pieces on a wooden board;
- Selection of the control principle (Bluetooth, IR, touch sensor);
- Organization of the electrical interconnections;
- Testing of the power supply;
- Uploading of the code;
- Final system testing and debugging in accordance with the chosen control mechanism.

The photos representing the project's final phase are shown in Figure 5.

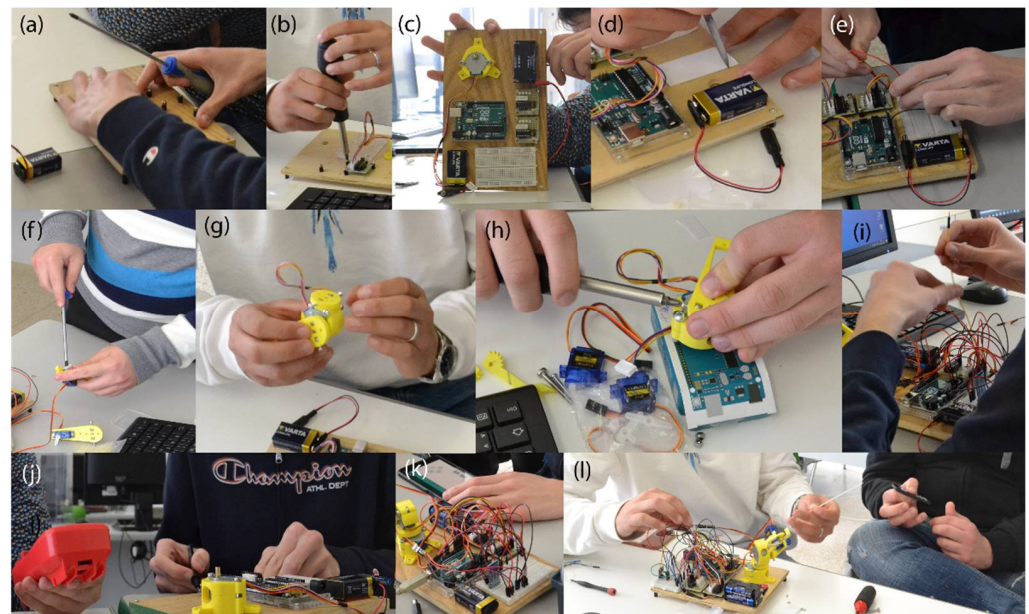


Figure 5. The final phase of the project: (a–e) fixing of the hardware pieces; (f–h) assembly of the mechanical part of the robotic arm; (i) cabling; (j) power supply testing; (k,l) Bluetooth and IR control testing.

4. Discussion of the Results

The described activities concentrated on the combination of DT and ER. As shown by the survey outcomes described in Section 2 and outlined in Table 1 and Figure 2, prototyping and testing were the phases found to be lacking in the current curricula. Therefore, when developing the methodology, the focus was on these aspects.

The fact that all the students were newcomers to Arduino and Tinkercad and the project's time limits both undoubtedly influenced the course's character while facilitating the adoption of DT principles implicitly [61]. Thus, an outline of the connections between the methodological framework proposed and the DT principles in view of the open questions in the current DT literature is given below.

Firstly, in the same manner that every design thinking process starts, at the very beginning of the activities, the participants were provided with a clear goal to define a problem (Table 1, lesson 1). Once furnished, the target aim became a natural fulcrum and supporter of all further activities whilst, at the same time, representing the converging point for all the subsequent “generative design questions” [62]. Further, while analysing a task and its problem space, in the form of the vast variability in the solutions already existing, students were gradually directed towards the solution space—a model capable of performing the bare minimum of movements that would furnish the functionality required while remaining simple and accessible [63]. In this way, a mindset of continuous shifting between two phases—namely, divergent (demonstrating the possible variants) and convergent (focusing on the model to construct)—was adopted [64].

Secondly, the core part of the path was related to scaffolding the background information in relation to the final goal and experimenting with it in different mini-projects [65].

For example, the primary skill set was acquired through experiments with different combinations of electronic components on the breadboard or by working with different sensors and using them in different combinations for servo and stepper motor control. Furthermore, in view of the final goal, each eventual inquiry was supported by a solid contextual framework, given its direct relation with the target task.

Thirdly, when covering different methods of robotic arm control, the students' were exposed to various possibilities to choose from (divergent phase). In this sense, creative freedom was transmitted, which is associated with boosting of the sense of responsibility [66]. However, once the options were assessed and the choice was made (convergent phase), students became motivated because they were capable of choosing and proceeding independently. Similarly, covering the physical principles standing at the base of electronic components and motor functioning served to help students acquire an in-depth overview of the relevant aspects (divergent phase). As the concepts were covered and gradually projected towards a higher perspective of the robotic arm, it became possible to see them as the converging components of a target system (convergent phase).

In addition, as an essential element of every DT process [67,68] and an approach to solving complex problems, it was judged to be suitable to introduce the decomposition principle. For example, the organization of the final code (Figure 6), the explanation of the concepts of a library and a function in programming, and the consistency and algorithmic character of the development of 3D models all fit the needs of beginners when introducing this aspect of the design thinking mindset [69]. Moreover, the Arduino platform was used to help students dive into developing electronics projects and to support the development of a designer's attitude [70]. Furthermore, 3D printing in general [71] and the use of Tinkercad are rightfully considered valuable tools in design thinking and STEM combined activities [72,73].

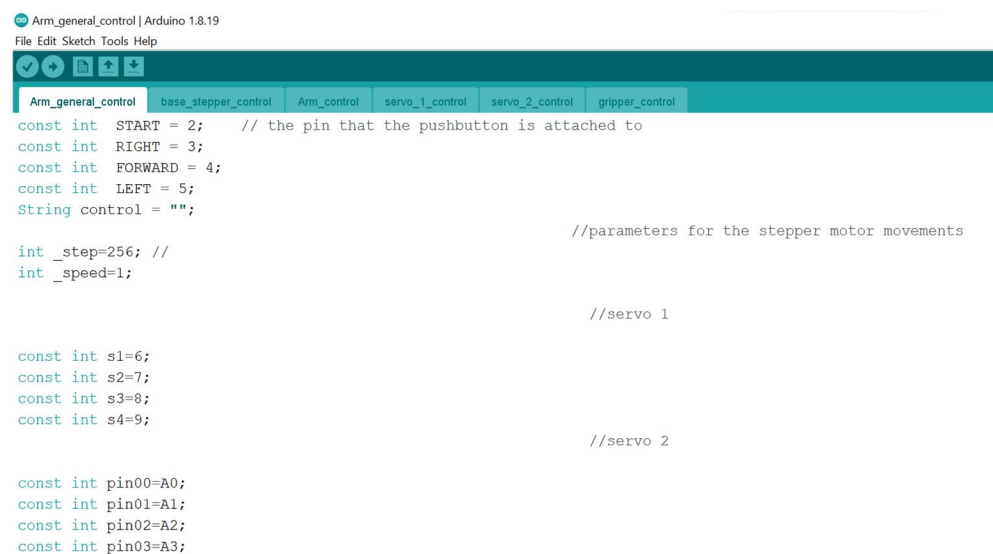
Finally, components of the design process, such as learning from mistakes, can be considered naturally coherent with Arduino electronics prototyping and 3D modelling, considering their flexibility for eventual corrections [74]. In fact, DT by definition does not work without mistakes, rightfully treating them as learning opportunities [75,76].

As this was the first experience of introducing the DT approach within the context of ER classes, the authors gathered qualitative data and feedback from the participants regarding the activities performed through participatory observation and discussion groups organized at the end of the complete learning experience.

Among the positive outcomes and advantages of the proposed methodology, the following items were identified: the possibility of putting into practice one's ideas; collaborating with peers on a real-life project; the opportunity to be original, with room for creativity; realization of a complex object following the technical auxiliary design; and 3D model research (of existing practices) unifying the notions from coding, mechanics, and electronics.

With regard to the negative points perceived, the participants noted that, despite the attractiveness and practical orientation of the classes, it was challenging to follow the regular curricula classes and these extra activities simultaneously.

Nevertheless, as is well-known, DT tasks often have an interdisciplinary character [77]. In this respect, as the literature confirms [23,53,78,79], ER, being inter- and multidisciplinary [80,81], represents a fertile ground for the DT methodology [81].



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Arm_general_control | Arduino 1.8.19
File Edit Sketch Tools Help

Arm_general_control base_stepper_control Arm_control servo_1_control servo_2_control gripper_control

const int START = 2; // the pin that the pushbutton is attached to
const int RIGHT = 3;
const int FORWARD = 4;
const int LEFT = 5;
String control = "";

//parameters for the stepper motor movements

int _step=256; //
int _speed=1;

//servo 1

const int s1=6;
const int s2=7;
const int s3=8;
const int s4=9;

//servo 2

const int pin00=A0;
const int pin01=A1;
const int pin02=A2;
const int pin03=A3;

```

Figure 6. Decomposition principle in action: the organization of the final code in Arduino IDE.

5. Conclusions and Future Perspectives

The continuously evolving technology and converging knowledge that modern society faces sharply contrast with the recent decline in students' interest in STEM subjects across Europe. School dropouts and the risk of social exclusion in the long term should not remain beyond the attention of education policymakers and the teaching community.

Being a complex issue, the problem requires the contributions of many stakeholders acting at different levels. Aiming for a possible methodological teaching remedy, the current work described an approach that involved DT principles within the context of ER classes. As this work described, the fundamental principle related to trying to catch students' attention through multifaceted aspects of a single complex task. In this way, enough space for an audience with various interests to see every single topic covered as an integral part of a broader perspective was provided. Furthermore, once furnished with the essential related background knowledge, students were encouraged to proceed independently during the last stage of the work; in particular, with regard to the selection of the controlling principle of the robotic arm.

In the present work, the authors hope to have demonstrated that the DT methodology may serve as another auxiliary tool that instructors can use to shift students' attitudes towards practical hands-on solutions. It may be thus possible to avoid the mechanistic accumulation of stacks of theoretical knowledge without the possibility of its projection into real-life contexts, therefore addressing what in [82] was defined as "the design-science gap".

As this work suggested, the organization of the experimental phase offered a vast methodological space to embed different aspects of DT. The examples provided aimed to demonstrate that the goal was achievable through the support gained from the DT methodology (as a central guideline) and the instruments used (Arduino and Tinkercad, with their innate propensity for facilitating the development of a DT mindset).

The outcomes revealed significant interest among the participants in the methodology proposed. Despite the extracurricular activities being held in the afternoon, the activities remained attractive enough to keep the students motivated, which undoubtedly speaks in favour of the lessons' content and delivery.

With regard to the project's future development, based on the results gained, the authors propose further gradual development of the functionality and structure of the robotic arm. For example, a set of movements could be preprogrammed or the range of controlling mechanisms could be enlarged. To further favour the assimilation of the described methodology, attention should also be directed at developing assessment strategies.

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