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Research article

Computational thinking and programming with Arduino in education: A systematic review for secondary education

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A R T I C L E I N F O

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A B S T R A C T

The development of programming skills and computational thinking in the formal educational context is one of the most recent horizons set by many educational systems worldwide. Although the first computational thinking initiatives are being applied from the earliest school ages, this research focuses on the secondary education level. Specifically, the objective is the following: to analyse the implementation of Arduino, as well as the benefits and opportunities it brings to secondary school students. For this purpose, documentary research has been undertaken applying a systematic review according to the PRISMA 2020 framework following the PiCoS strategy. Atlas.ti 9 was used to analyse the information. Out of 316 papers identified, 37 were included in the research. In relation to the results, Arduino is primarily used in technology and physics subjects, although it is also used to develop interdisciplinary STEAM projects. As a rule, it is used to learn programming languages, but likewise as a resource to develop science experiments. LED lights, servomotors and breadboards are among the most commonly used resources together with the Arduino board. and Scratch was the most widely used software. The initiatives implemented have yielded both positive and negative results, for example, one drawback is that some projects are very difficult, and some achievements such as: increased motivation towards the contents addressed or also the development of some soft skills, such as problem solving.

1. Introduction

Twenty-first century society is undergoing a plethora of changes and advancements in the social, economic, labour, and technological fields [1]. The speed of these transformations is creating imbalances that, in many cases, are challenging to resolve due to their immediacy. In this changing context, education systems are not exempt from these changes. Educational administrations are undertaking the mammoth task of improvements and adaptations to respond to these changes, which are largely prompted by advanced technologies, and which have a direct effect on classrooms [2]. Thus, responses are being provided to prepare and train citizens for an increasingly digitised labour market [3].

In light of this scenario, education systems are revising the academic curricula of the different non-university educational stages to integrate knowledge, elements and strategies that equip students with the necessary tools to perform competently and thrive in a changing world. For these reasons, As a result, current education systems emphasise the acquisition of competences and not just

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knowledge. Students are expected to apply their knowledge and use same in various contexts in an appropriate and diligent manner. In this regard, taking as a reference the Spanish education law, which was designed based on the Recommendation of the Council of the European Union for lifelong learning, some of the key competences included are: mathematical competence and science, technology, and engineering competence; digital competence; and entrepreneurial competence [4]. Three competences relevant to the subject matter of this research that is, computational thinking, and programming in the formal educational context.

In order to provide training that integrates the three aforementioned competences, a prevalent possibility in educational practices is to apply the STEAM (Science, Technology, Engineering, Arts and Mathematics) methodological approach [5–7], which combines the development of scientific, technological and artistic competences through interdisciplinary collaborative projects in which each student plays an active role in achieving the set objectives [[8,9,10]]. It should be noted that this methodological approach has fostered the development of computational thinking, due to the possibilities it offers, and the skills and cognitive processes involved.

Insofar as computational thinking is concerned, this is characterised by offering a model for problem solving [11[12]] that involves the application of computer science concepts and techniques to approach problems systematically and logically, breaking down complex problems into simpler and more manageable tasks [13].

The idea of introducing computer science in education is not new. Since the middle of the last century, Papert had already conceived this idea by developing the *Logo* programming language and the *Turtle* robot with the objective of teaching programming to students at an early age and, thereby, bringing the world of programming to schools [14]. This author, influenced by Piaget's postulates, developed his own theory of learning, which he called constructionism [[15,16]]. His theory of learning the learner therein is encouraged and motivated to draw his or her own conclusions through creative experimentation and the creation of socially useful artefacts promoting active learning [17]. As can be seen, Papert's vision was more insightful, because his interest went beyond the learning of programming itself, but in the development of other types of skills such as computational thinking, which would allow students to apply these to other disciplines as a more efficient learning strategy [18].

Over the years, this movement and its implications for school curricula declined until its disappearance from academic curricula [19]. It was not until 2006 when Janette Wing, a computer science professor at Columbia University published the article *Computational Thinking* [20] that the need to introduce the acquisition and development of this skill in the classroom was raised again. For Wing, computational thinking is defined as "the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer (human or machine) can effectively carry out" [[21], p. 8]. She likewise emphasised that computational thinking "represents a universally applicable attitude and skill set that everyone, not just computer scientists, would not hesitate to learn and use" [[20], p. 33]. Therefore, it is seen as a skill which goes beyond computer science and that can be integrated as a transversal, interdisciplinary and multidisciplinary element in school curricula [[22,18]], providing students, from an early age, with skills in addition to their analytical capacity [23]. In this way, students can benefit from the acquisition and development of skills such as the ability to decompose a complex problem into smaller, more manageable tasks (decomposition); the ability to identify the key aspects of a problem and simplify same to make these easier to understand (abstraction); the ability to find similarities and patterns in data (pattern recognition); the ability to create a step-by-step plan to solve a problem (algorithms); and the ability to identify and correct errors in the code (debugging). In other words, to equip students with cognitive strategies that enable same to formulate hypotheses, identifying and proposing solutions to specific problems from an analytical and efficient approach.

The integration of these skills into the educational system is possible due to several factors. On the one hand, technological development has led to the availability of more accessible to the general public, both children and young people, and, on the other, the emergence of simpler and more user-friendly programming languages that facilitate the work of less experienced teachers [14] These factors, combined with the need to promote and develop digital competence in non-university students, have facilitated the inclusion of computational thinking in school curricula. In this regard, in an increasingly computerised world, educational administrations at an international level have recognised this need and are integrating computational thinking in the classroom as another competence that students should acquire [[24,25,26]]. In particular, this work is primarily being developed through robotics, virtual programming, and Artificial Intelligence (AI) [[27,28,29,30,31]].

From these approaches, one of the paradigms proposed for the inclusion of technology in educational programmes is the TPACK (Technological Pedagogical Content Knowledge) model [[32,33,34]]. This methodological approach has the versatility of bringing together the curriculum content to be developed, the pedagogical component for its teaching, the characteristics of the target students and the technology involved in the teaching and learning process [35]. This model, together with the Project Based Learning (PBL) methodology [25], provides an ideal framework for fostering and developing computational thinking in the classroom [36]. In this way, it enhances motivation to learn by creating a hands-on learning situation which enables students to work on real and meaningful projects. Papers such as those by Refs. [37,38] have shown the benefits of using this framework to foster computational thinking skills. Furthermore, this methodology provides students with useful skills to deal with real-life problems [39], and promotes collaboration, teamwork, and critical thinking.

In the specific case of the educational stage of secondary education, the most commonly used technology to develop computational thinking is programming software for visual or textual blocks [40] such as the *Scratch 3.0* programming environment [[41,42,43,44]]; robotics or programming boards such as *KeyStudio, Micro:BIT* [[45,46]] *or Lego* in its various versions and models (*NXT Mindstorm* and *EV3*) [[47,48,49]]; educational robotics simulators [[50,51]]; the combination of the Internet of Things (IoT) with AI technology called *AIoT* to create numerous smart applications [31]; the Python programming language [52]; the App Inventor programming environment, maintained by the Massachusetts Institute of Technology (MIT) and designed at developing applications for the Android operating system; *iArm* kit, a low-cost, programmable, open-source robotic arm [53]; *mBlock*, a graphical programming environment based on the *Scratch 2.0* editor for teaching simple programming of Arduino-based robots [54]; *Minecraft*, an "open world" construction video game enabling one to create and control the world as one wishes, stimulating creativity and curiosity [55]; the open source Arduino platform [[56,57,37,58]]; and the *BBC's* open source programmable board, *Micro:bit* [59].

For this work, we shall focus on the Arduino board, a low-cost and easy-to-program open-source electronic prototyping platform. This board allows students to become familiar with and acquire knowledge of the programming world and serves as a bridge to more advanced and highly effective resources in the field of computer science [60]. Due to its technical characteristics, this board is capable of reading inputs from devices or sensors and converting these into outputs, with the possibility of creating interactive projects, from robots to automatic control systems, by combining actuators, microcontrollers, or sensors. Its programming is performed through its own programming language based on Wiring and the Arduino software (IDE) based on Processing [[14,61]].

1.1. Justification and objectives

The results and conclusions of this study provide researchers and educational administrations with a basis and starting point for a resource that enables educational projects to develop computational thinking and its correlation to STEM jobs for the future of students. The use of Arduino in the education field has experienced a considerable increase due to its potential, the versatility of design and types that exist, the enormous possibilities for experimentation that it provides and the low cost thereof. Its software and hardware are open source and facilitate its programming from various operating systems and the extension thereof with more devices and sensors [62]. Nevertheless, the use of the Arduino controller board in education is a little studied topic [63]. For this reason, we have chosen to conduct a systematic review of the articles found in the scientific literature, given the fact that it is a tool of significant relevance which serves to inform and develop practice and invite discussion of the subject matter in question [64].

On the subject that concerns us, the use of Arduino in the educational field, and more specifically in the educational stage of secondary education, the literature consulted offers a very promising outlook. Just as studies are limited in primary education [14], the use of these devices for the development of computational thinking is more prolific in secondary education.

From the variety of studies and experiences that have been evidenced in the inclusion of robotics and programming in the curricula of non-university education systems, there is an underlying idea that for the adults of the future to be prepared for the evolutions, transformations and challenges of the 21st century, the youth of today must be empowered with a series of tools and strategies that equip them with the necessary skills and abilities which will make them competent for a constantly changing world. In this context, computational thinking brings together a series of skills that are aligned with the so-called 21st century competences. Boards and robotics skills are considered educational resources and are the basis for the development of computational thinking and access to STEM jobs increasingly common in our day-to-day life and work sectors [65].

For this reason, the objective of this paper is to analyse the implementation of Arduino, as well as the benefits and opportunities it brings to secondary school students.

The research questions that articulate this paper are the following.

RQ1. To what extent has the usage of Arduino in the formal framework of Secondary Education been documented in published works?

RQ2. How has Arduino been implemented and what resources have been used?

RQ3. For what purpose was the Arduino used and what were the results?

2. Methodology

2.1. Method

This study is framed within the framework of documentary research, with the objective to understand the reality and knowledge derived from analysing various types of scientific documents [66]. To this end, a systematic review has been applied, as it is a widely used research technique in the field of education [67]. Primarily as it provides an overview of the state of the art substantiated by empirical and reliable evidence [68].

To carry out a systematic review in an adequate manner, a protocol which adheres to a systematic approach is required. In this regard, there are different methodological frameworks, such as SALSA [69], PSALSAR [58,[70]], among others. In particular, for this study one of the most widespread frameworks in SR-based theoretical work, namely the PRISMA framework in its 2020 version was used [71].

The chosen framework outlines a three-stage process for creating the flowchart. The initial stage consists of identification, in which the selected descriptors are entered into the databases and then duplicate records, those flagged as ineligible by automation tools, and likewise papers eliminated for other reasons are removed.

The screening stage follows next, during which eligibility criteria are applied. These criteria, as suggested in various publications [[72,73]], include aspects such as time, language, type of paper and geographical area. For this research, in order to create a frame of reference to establish the exclusion criteria for the second screening stage, the PICoS strategy has been taken into account.

In this regard, it should be noted that for the screening stage there are different strategies, such as PICO, SPIDER [[74,75]]... are available. Nevertheless, for this research, PICoS strategy has been considered: population, phenomenon of interest, context and study design.

For the analysis of the qualitative information, the *Atlas.ti 9* software was used. The following process was applied: creation of the units of information (quotations), condensation/coding and creation of categories. Likewise, for the presentation of the results, both double-entry tables and semantic networks were used to present the different codes generated.

2.2. Stages of research

The use of the keywords and Boolean operators used enabled the identification of 316 relevant documents in Scopus and Web of Science (WoS) between the period 2016–2022. In particular, the search applied was Arduino AND ["high school" OR "secondary school" OR "middle school"].

The total number of extracted papers was reduced to 286 after eliminating 30 duplicate papers. This was subsequently followed by a screening stage as per the time frame, document type and language, which resulted in the exclusion of 78 papers.

Subsequently 11 further papers were likewise excluded as these lacked the entire text. Finally, the filters of the PICoS strategy were applied. First, the initial subject, which is the population and phenomenon of interest. In this case these are didactic proposals to develop computational thinking through Arduino.

The next criterion is the context. In particular, for this study are papers based on didactic proposals implemented at the Secondary Education level are specifically eligible, those works applied to the ages of the aforementioned level, but that have been developed in an informal or non-formal context, will not be considered.

Finally, the study design criterion. In this case, those papers whose nature is not theoretical (systematic reviews and meta-analyses) have been included.

Lastly, from this screening stage, a total of 160 papers were excluded and a sample of 37 papers was finally obtained.

Fig. 1 below shows a diagram of the different stages followed. For this purpose, the PRISMA 2020 flow chart [[76,71]] has been considered.

3. Results

The generated codebook is composed of a total of 109 codes, of which 9 are free codes and 425 citations. In particular: *Theoretical basis*, *subjects*, *objectives*, *resources,* and *results*. Table 1 below shows each free code with its corresponding density of associated codes.

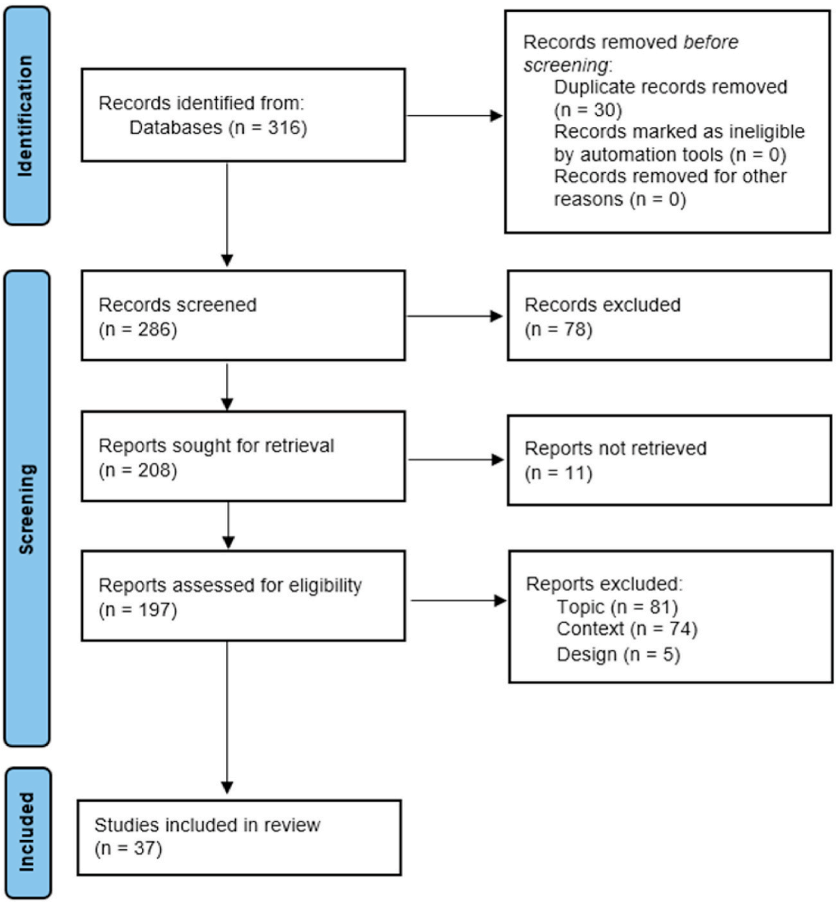

Fig. 1. Flowchart of the applied systematic review.

As can be seen, the code with the highest related density is resources, while the two with the lowest are *theoretical basis* and *subjects*.

3.1. Published papers

The following table provides a descriptive overview of the papers included in the analysis (Table 2). The year of publication, country and type of document are specified for each paper.

3.2. Implementing initiatives: methodologies and resources

To address the implementation of the didactic proposals supported by Arduino, the results extracted from each of the free codes generated are presented.

3.2.1. Theoretical basis for initiatives

Some of the papers that have been analysed specify the theoretical basis on which the practices developed in the classroom are justified. The framework of this work, theoretical bases are specifically defined as those methodological principles, psychological theories etc. and in conclusion, any conceptualisation under which didactic proposals are developed. Table 3 below shows the codified theoretical bases, as well as their grounding.

As can be seen, the most prevalent code in the documents analysed is *STEAM* (n = 10), followed by *Computational Thinking* (n = 8). Nevertheless, *constructivist theory* (n = 1) and maker movement (n = 1) are the least represented.

3.2.2. Subjects addressed by the initiatives

The focus of this study is in relation to the formal educational context, that is, considering the work carried out within the framework of subjects or interdisciplinary projects, but always taking into account the development of the educational curriculum. As in the previous case, the codes generated together with their grounding are listed in Table 4.

Arduino is primarily used in the *technology subject* (n = 13) and likewise in *physics* (n = 11). Furthermore, the development of interdisciplinary *STEAM projects* also stands out (n = 10). Chemistry is the only field where a singular experience can be developed.

3.2.3. Objectives of the initiatives

In relation to the objectives of the initiatives developed, two free codes have been created: didactic objectives and other objectives. The first of these is oriented towards particular content or competences specific to science or technology. While the code for *other objectives* is focused on more transversal or general objectives.

As can be seen in Fig. 2, the most frequent didactic objective is to *learn the basics of programming languages* (n = 18). This is followed by *conducting a science experiment* (n = 12).

Likewise, regarding other objectives, the most significant objective is to *develop general projects* (n = 11), thus learning to be competent in the development of the various stages of a project. And then, *to apply problem-solving strategies* (n = 10).

3.2.4. Resources used for the initiatives

The category with the highest density is that of the free code. In particular, 50 related codes. Therefore, these have been organised depending on whether these are software related codes (Fig. 3), Arduino board related components (Fig. 4) or other resources used in the initiatives developed (Fig. 5).

As shown in Fig. 3, the *software* most frequently used in the proposals analysed was *Scratch* (n = 5), followed by the *Linux operating system* (n = 4). Nevertheless, principally the wide diversity of codes generated stands out. This demonstrates that, depending on the nature and objective of each project, the corresponding software has been used.

There is a variety of software focused on block programming available, such as *Scratch* (n = 5), *Blockly* (n = 2) or *ArduBlock* (n = 2). Programming through C language, such as *Arduino IDE* (n = 2) or *LabView* (n = 1) is likewise available. There are also other more specialised examples, such as *Tinkercad* (n = 2) for 3D modelling, *MOVEit* (n = 1) for file transfers etc.

In relation to the programming-related components used (Fig. 4), unquestionably, the *Arduino board* code stands out (n = 35). Next, and in stark contrast to the remaining components, *LED* (n = 19) and *servomotors* (n = 12) are the most used components. These components are even more specifically mentioned than the *breadboard* (n = 11), even though the latter is a fundamental component when creating an electronic circuit connected to the Arduino.

And subsequently, in relation to other resources (Fig. 5), the devices used to interact with the circuits developed being the most

Table 1
Free codes according to density.

Code	Density
Theoretical basis	6
Subjects	6
Objectives	15
Resources	50
Results	14

Table 2
Papers selected for systematic review.

Title	Year	Country	Document type
Using an Arduino Seismograph to Raise Awareness of Earthquake Hazard Through a Multidisciplinary Approach	2016	Italy	Article
DidacTronic: A Low-cost and Portable Didactic Lab for Electronics	2016	Brazil	Conference paper
Computerisation of a telescope at secondary education	2016	Spain	Conference paper
Connecting hardware and software in a middle school engineering outreach effort-RTP	2016	US	Conference paper
Low-cost robot arms for the robotic operating system (ROS) and moveit	2016	US	Conference paper
A browser-based ide for the MUzECS platform	2016	US	Conference paper
The Study on Integrating the Design Thinking Model and STEM Activity Unit for Senior High School Living Technology Course	2017	Taiwan	Conference paper
From classroom Arduinos to missions on Mars: Making STEM education accessible and effective through remotely operated robotics	2017	US	Conference paper
Sustaining making in the era of accountability: STEM integration using E-textiles materials in a high school physics class	2017	US	Conference paper
Fundamental level measurement and control concepts demonstrated using microprocessor activities	2017	US	Article
The design focused engineering outreach to a middle school using Arduino projects	2017	US	Conference paper
Development and application of Arduino-based education program for high school students'	2017	Korea	Article
Educational Robotics: Algorithm Logic Learning Comparison	2017	Colombia	Article
Coding and computational thinking with Arduino	2018	Italy	Conference paper
Inclusive education on stem subjects with the Arduino platform	2018	Greece	Conference paper
The impact of an integrated robotics STEM course with a sailboat topic on high school students' perceptions of integrative STEM, interest, and career orientation	2018	Taiwan	Article
Experiences with the use of Snap Circuits and Arduino boards as tools for human development with students in an insular Colombian community	2018	Colombia	Conference paper
Low-cost programmable air quality sensor kits in science education	2018	Norway	Conference paper
Assessment of Computational Thinking in regular basic education: case IETP "Jose Obrero"	2019	Peru	Conference paper
Teaching Microcontrollers using Arduino Nano Based Quadcopter	2019	Indonesia	Conference paper
Measuring CO 2 with an Arduino: Creating a Low-Cost, Pocket-Sized Device with Flexible Applications That Yields Benefits for Students and Schools	2019	Spain	Article
Development of Arduino Assisted Microcontroller Instructional Devices in Vocational High Schools	2019	Indonesia	Conference paper
The effect of project-based Arduino educational robot applications on students' computational thinking skills and their perception of basic stem skill levels	2019	Turkey	Article
ArViz: An IoT Teaching Tool for High School Students	2019	Thailand	Conference paper
Analysis of Influencing Factors of Learning Engagement and Teaching Presence in Online Programming Classes	2020	Korea	Article
Use of sensors and automatic data collection equipment in the practical work of Physics and Chemistry of middle and high school: The Arduino platform	2020	Spain	Article
An environmental education project that measures particulate matter via an Arduino interface	2020	Greece	Article
Android based wireless measurement module for an educational tool in mechatronics	2020	Indonesia	Conference paper
Teaching CT through Internet of Things in High School: Possibilities and Reflections	2020	Brazil	Conference paper
Educational robotics: building and applying an App-controlled car to study newton's laws	2021	Brazil	Article
Arduino and LabVIEW-based remote data acquisition system for magnetic field of coils experiments	2021	Indonesia	Article
Computational thinking development through physical computing activities in STEAM education	2021	Lithuania	Article
Teaching Chemistry with Arduino Experiments in a Mixed Virtual-Physical Learning Environment	2021	Greece	Article
Arduino Platform as Learning Tool in High School and College Education	2021	Croatia	Conference paper
Physical computing strategy to support students' coding literacy: An educational experiment with Arduino boards	2021	Taiwan	Article
Using accelerometer smartphone sensor and phyphyox for friction experiment in high school	2021	Indonesia	Conference paper
Solving Ecological Problems through Physical Computing to Ensure Gender Balance in STEM Education	2022	Lithuania	Article

Table 3
Codes related to theoretical basis according to their grounding.

Code	Grounding
STEAM	10
Computational thinking	8
Problem/Project Based Learning (PBL)	5
Design thinking	3
Constructivist theory	1
Maker movement	1

Table 4
Codes related to subjects according to their grounding.

Code	Grounding
Technology	13
Physics	11
STEAM	10
Mathematics	5
Natural Sciences	2
Chemistry	1

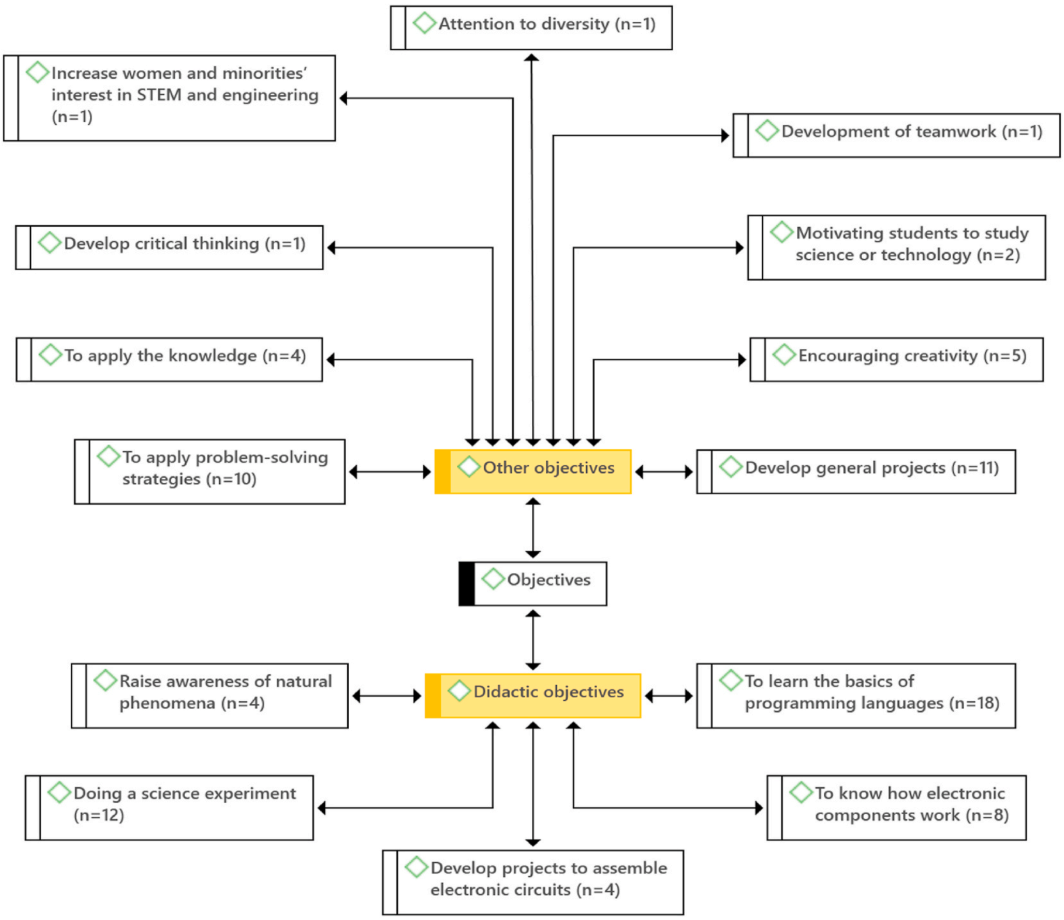

Fig. 2. Semantic network of target-related codes.

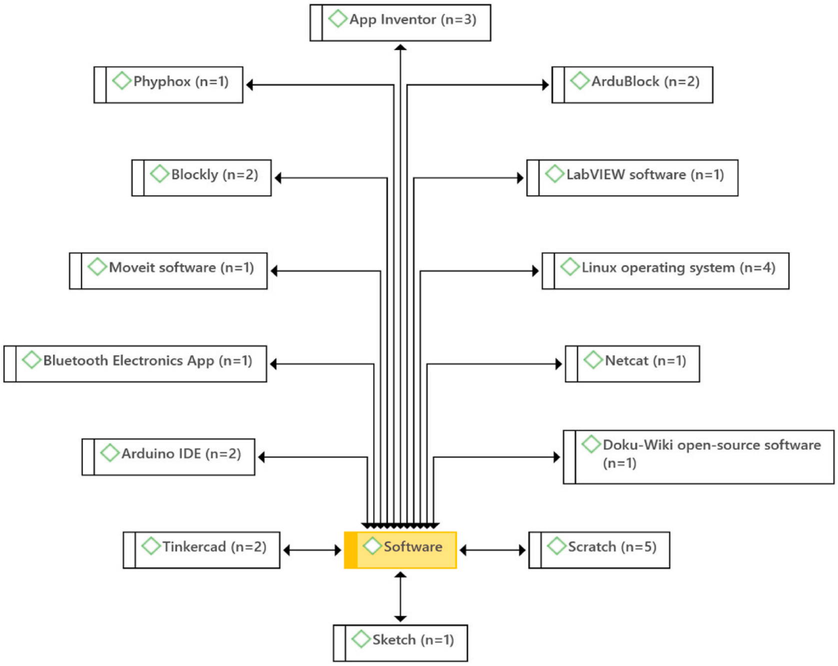

Fig. 3. Semantic network of software-related codes.

prevalent, that is, both *PCs* (n = 8) and *Smartphones or tablets* (n = 7). The *Bluetooth module* was also subsequently coded on six occasions.

3.3. Results of the initiatives

To analyse the results, two free codes have been created: negative perspective and positive perspective (Fig. 6). Among those results which provide a more critical perspective of the initiatives developed, *the projects were very difficult* (n = 3). Other specific results were *students demand more detail in the lab* (n = 1), *material was too expensive* (n = 1) and *creative problem solving did not improve* (n = 1).

Conversely, the most positive perspective is related to *the increase of motivation* (n = 9), *the development of problem solving* (n = 8) and, the *improvement of mechatronics-related knowledge* (n = 7).

4. Discussion

Based on the results of the study, the Arduino board is considered a technological educational resource in secondary education which fosters computational thinking and may be used to carry out transversal, interdisciplinary and multidisciplinary projects at various educational stages. Despite the potential of this educational resource described in the introduction, after analysing the review of the scientific literature in this study, the authors of this paper consider, based on the criteria used, Arduino is a resource that, that in the field of research, only thirty works have been found whose context of application is secondary education. This is despite the fact that the resources have been disseminated since 2005 [77] between 2016 and 2022.

Despite a high number of articles discarded as these did not fit the context or educational stage, the articles that were selected are closely related to the STEAM disciplines (Science, Technology, Engineering, Art and Mathematics), that is, at the secondary stage the word "Art" has a greater presence, which in the words of [5] is related to the creativity it fosters in students at the secondary stage and the possibility of knowing and experiencing the world made possible by art forms, practices or even specific pedagogies. Nevertheless, in other educational stages at earlier ages such as primary education, art or creativity is not a prevalent presence, and the STEM discipline is furthered [14] points out to foster computational thinking.

The theoretical underpinnings of this study likewise highlight the relationship between computational thinking and the STEAM field in education, this correlation is in line with the study by [[78,79]], which considers computational thinking an essential part of STEAM as it facilitates understanding how machines work and is a recent research subject matter popular among researchers although support, time and expertise is needed among teachers to translate these practices as a methodology in the classroom. Furthermore, the authors of this study agree with the research of [11] that implementing practices that foster computational thinking offers benefits for problem solving in light of the results of the theoretical underpinning and classroom practices developed in the results of this study (n = 8) of the Arduino board.

In relation to the areas found in this study, technology and physics are the most prevalent subject matters, in both cases the possibility of carrying out transversal and multidisciplinary projects as postulated by Ref. [22] offers new possibilities to bring students

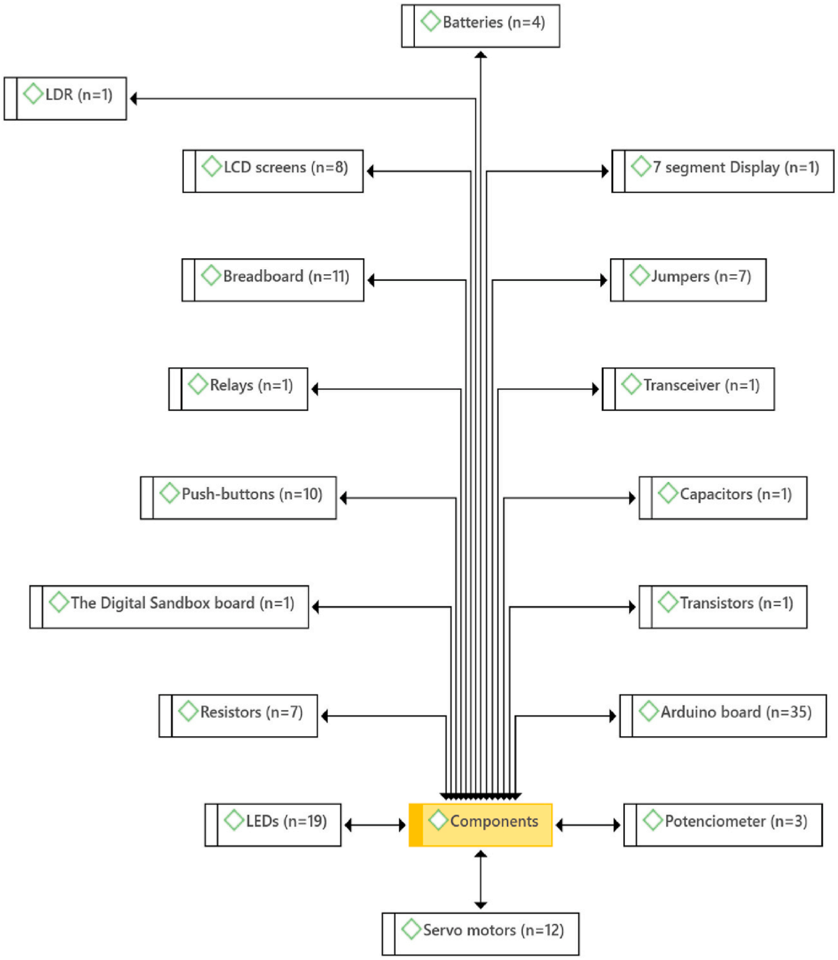

Fig. 4. Semantic network of component-related codes.

closer to the world around us by making use of technological and digital tools to learn other subjects of the curriculum through robotics, virtual programming and artificial intelligence in line with the studies of [27,30]. The world of physics requires manipulative practices and a maker culture to acquire more lasting knowledge over time, therefore, the authors agree with the research of [51] that considers the Arduino board as a resource and a possibility to learn physical phenomena of great difficulty due to its ease of use and can be replaced by expensive machines within the educational field and in relation to the learning of physics.

The objectives pursued by the papers analysed in this research demonstrate that knowing and knowing how to use basic programming languages (n = 18) is a fundamental objective at the secondary school stage in relation to the Arduino board for carrying out classroom projects. In this regard [19], considers that learning programming from an early age is an essential discipline to open new ~~paths~~ opportunities for pupils, such as visual programming language by blocks or textual programming. In this regard, Scratch software is considered in the studies of [[41,42,43]] to be a programming environment widely used in the secondary school stage to develop computational thinking. In line with Resnick's words, another objective that stands out in the results of this study is to conduct science experiments (n = 12), according to Ref. [13] which entail the application of computer science concepts and techniques to approach problems in a logical and methodical manner, breaking down complex problems into simpler and more manageable tasks.

This ability to learn to use programming languages is consistent with the results of this study in relation to the resources used, wherein Scratch software (n = 5) appears as the most commonly used among researchers. Therefore, the authors consider that the knowledge and skills acquired by carrying out projects using the Scratch programme can be extrapolated to other scientific fields, taking as a reference [54], robotics programmes with artificial intelligence can be carried out using the Arduino board as a resource, fostering the acquisition of problem solving, creativity skills and the development of a Maker culture, that is, learning by doing. Initiation into the world of robotics, according to the results of the study at secondary school level, coincides with the implementation of projects related to components such as LED lights (n = 19) and servomotors (n = 12), namely, it can be inferred that carrying out simple programmes such as a traffic light with LEDs or turning the wheels of a robot by means of servomotors is related to the implementation of projects with the Arduino board itself (n = 35), which is highlighted in the components section. These projects as pointed out by Ref. [50] can be undertaken through online simulators such as Tinkercad (n = 2) which appears in the results of this

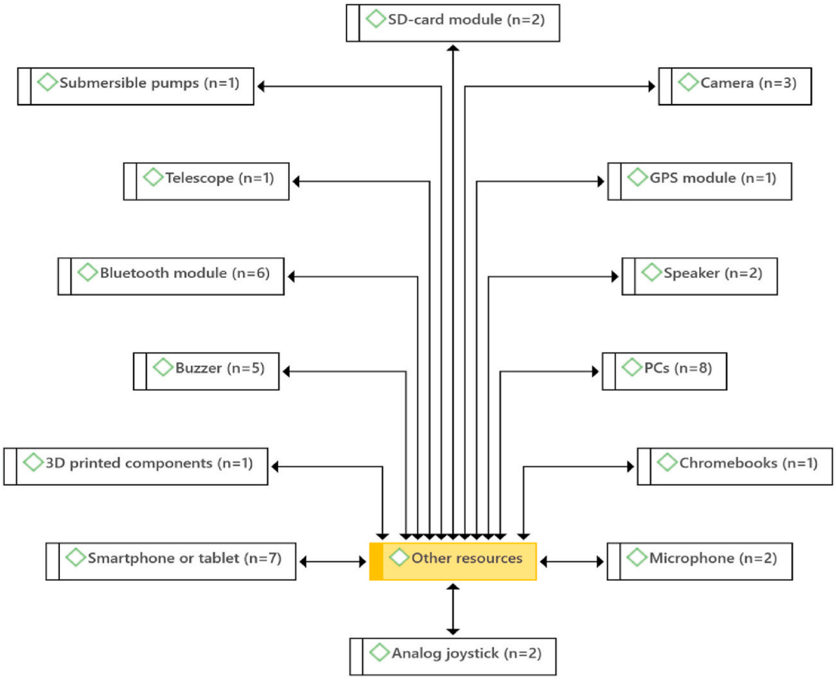

Fig. 5. Semantic network of codes related to other resources.

study and the authors agree with [31], that Arduino can be a basis for combining IoT with technology.

4.1. Implications for educational practice

Agriculture, livestock, home automation, security, healthcare etc. are examples of sectors that include technological tools for the automation of their tasks through machines and require STEM knowledge and skills. Learning how machines work in schools through practical competency tasks with Arduino develop computational and algorithmic thinking skills [80], moreover, these are important to adopt an interdisciplinary approach [81]. This approach, furthermore, develops in students the acquisition of mathematical knowledge by putting into practice the value of digits [82] such as negative numbers, decimals, learning multiplications through loops etc. through experiments or simulations of everyday life with tangible data that can be processed numerically [83].

Thus, it is evident how the use of this prototyping board is used for fostering creativity through problem solving [84]; the measurement of dynamic variables in physics experiments [[85,86,87,88]]; for use in environmental applications such as sensors for weather stations [89] or the creation of proprietary devices for measuring CO2 [90] or water hardness [91]; as a device for the inclusion of robotics in secondary school classrooms [92] and offering the possibility to perform pre-determined missions on real or simulated rovers [93]; it has similarly been used, with very satisfactory results in terms of the resulting benefits for learning and creativity, as an experience to introduce students to programming [94]; to bring abstract subject matters closer to students but that these can find in their daily lives closer to them, making these more understandable and meaningful, inspiring greater motivation through technology and fostering collaborative work [95]; in addition to the development of educational experiences that adhere to the spirit of STEAM learning situations [96].

Likewise, PISA highlights the use of computational thinking in high school as a discipline to foster creative thinking, cooperativity and moderate to high critical thinking [97,98]. Working with boards and programming allow to solve any problem by applying a computational strategy, that is, focusing the student first to apply the creation of an algorithm and then to the representation of the problem [99].

The use of Arduino in STEM project-based educational practices has the potential to address gender gaps and present opportunities for invention and enthusiasm for adolescent females to pursue various engineering careers [100]. Likewise, to bridge the digital divide, for example, particularly in rural areas by fostering among students in these areas the interest and motivation for enrolment in STEM university careers [79].

These hallmarks facilitate its inclusion in the educational field for students to develop skills and strategies of computational thinking and prepare and train them for the future, fostering creativity and critical thinking.

5. Conclusion

Every day we make use of technological systems that require the use of controller boards such as intelligent light sensors in the

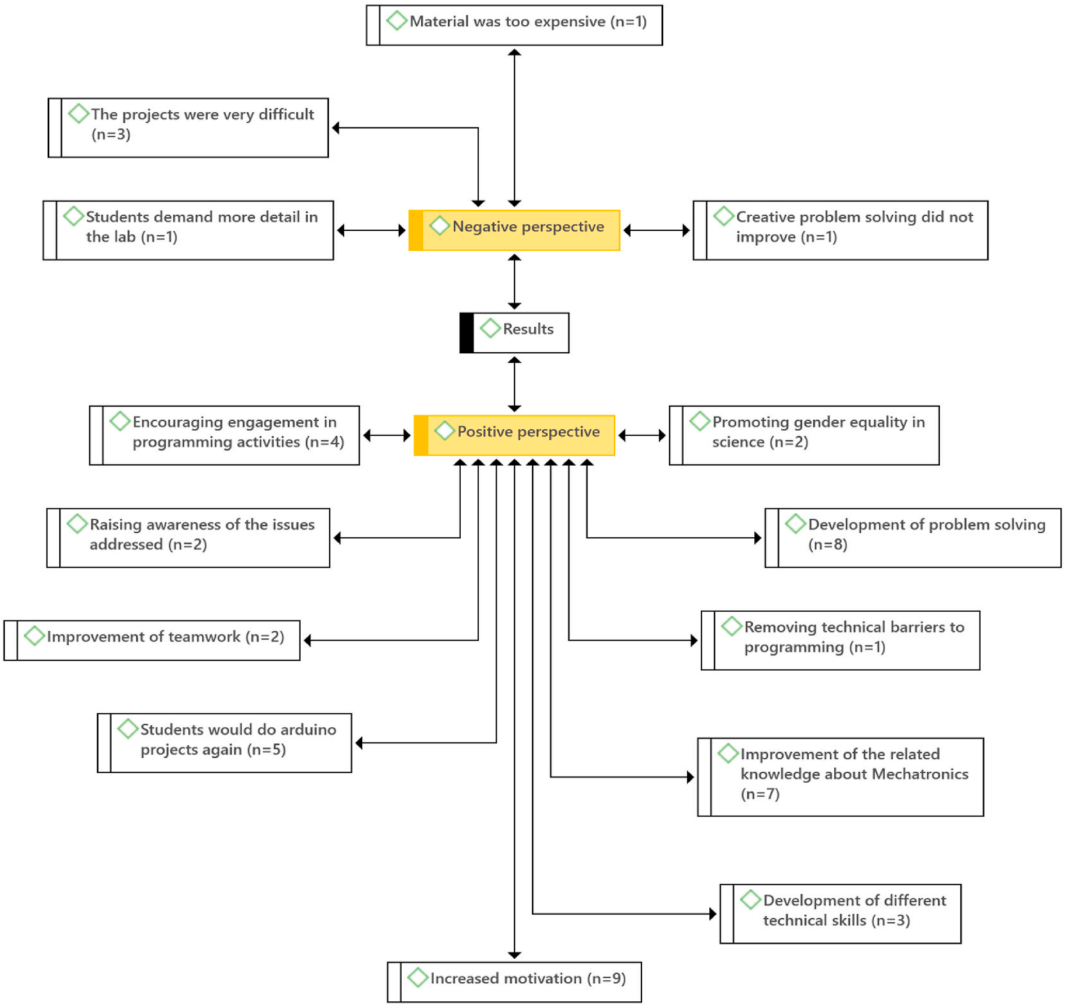

Fig. 6. Semantic network of initiative results.

home, automatic doors, parking or rain detectors in cars, kitchen or cleaning robots etc. Even these systems are connected to the Internet of Things (IoT) making people's lives and jobs easier. As a result, there are an increasing number of jobs that require qualified and trained people in this STEM field.

The main conclusions, taking as a reference the objectives set out in this article, are as follows: that since 2016 there have been 37 papers related to the Arduino board in the field of education, in particular in the Secondary Education stage. Moreover, the subject matters and field of work with Arduino are related to Technology and Physics, as well as to the development of interdisciplinary STEAM projects. The most often used resources with Arduino in the investigations are LED lights, servomotors and the breadboard. It is likewise related to the produced students' motivation factor and the development of problem solving skills during the learning process.

In conclusion and in relation to the main objective of the study "To analyse the implementation of Arduino, as well as the benefits and opportunities it brings to students of Secondary Education" the authors conclude that the Arduino board is a user friendly and easily accessible resource which can be used with simulators, generating motivation and facilitating transversal and multidisciplinary learning in students. The subject of technology is the most studied in the scientific field of this subject and, finally, learning to program enables students to learn other STEAM disciplines related to Computational Thinking, specifically with the world of robotics and Artificial Intelligence, preparing more critical and less manipulable students in this digital society and with skills and abilities to join the increasingly digitised labour market.

5.1. Limitations of the study and future lines of research

The limitations of this study lie in the fact that an educational board such as Arduino has been reviewed, nevertheless, currently more educational boards are emerging for the development of STEAM projects from the Primary and Secondary Education stage, such as the Makey-Makey, Micro:BIT, Echidna or KeyStudio boards that have not been included. Similarly, there are also online simulators and applications such as Tinkercad, Makecode or Mblock that can carry out projects with Arduino and have not been included in the study. Therefore, as future lines of research it would be necessary, to have a greater scope of the benefits and educational opportunities that educational projects offer, to conduct a general study of all physical boards and simulators in education.

Additional information

No additional information is available for this paper. Conflicts of Interest Statement. The authors declare that there are no undisclosed competing financial interests or personal relationships that could have appeared to influence the work presented in this paper.

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Data availability statement

The database used for this research is hosted in the repository of the University of Granada with access https://hdl.handle.net/10481/89681 and https://doi.org/10.30827/Digibug.89681.

CRediT authorship contribution statement

José-Antonio Marín-Marín: Methodology, Investigation, Conceptualization. **Pedro Antonio García-Tudela:** Software, Formal analysis, Data curation. **Pablo Duo-Terrón:** Writing – review & editing, Writing – original draft, Supervision, Investigation.

Declaration of competing interest

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References

[1] A. Goltsiou, C. Sofianiopoulou, Cultivating mathematical thinking with Scratch or approaching programming through geometry? in: E. Kallel, H.M. Kammoun, L. Hsairi (Eds.), Proceedings of the IEEE Global Engineering Education Conference (EDUCON 2022) IEEE, 2022, pp. 603–609, https://doi.org/10.1109/EDUCON52537.2022.9766689.
[2] M.P. Prendes, F. Cerdán, Tecnologías avanzadas para afrontar el reto de la innovación educativa, RIED. Rev. Iberoam. Educ. Distancia 24 (1) (2021) 35–53, https://doi.org/10.5944/ried.24.1.28415.
[3] D.S. Silva, S.L. Melo, J.R. Basto-Diniz, Developing a didactic sequence for introducing computational thinking in the early years of elementary school, in: Proceedings 2021 XVI Latin American Confrence on Learning Technologies, IEEE, 2021, pp. 526–529, https://doi.org/10.1109/LACLO54177.2021.00095.
[4] Real Decreto 217/2022, de 29 de marzo, por el que se establece la ordenación y las enseñanzas mínimas de la Educación Secundaria Obligatoria, Boletín Oficial del Estado 76 (2022) de 30 de marzo de, https://bit.ly/48zZssn.
[5] L. Colucci-Gray, P. Burnard, D. Gray, C. Cooke, A critical review of STEAM (science, technology, engineering, arts, and mathematics), in: P. Thomson (Ed.), Oxford Research Encyclopedia of Education, Oxford University Press, 2019, pp. 1–26, https://doi.org/10.1093/acrefore/9780190264093.013.398.
[6] J. Piedade, N. Dorotea, A. Pedro, J.F. Matos, On teaching programming fundamentals and computational thinking with educational robotics: a didactic experience with pre-service teachers, Educ. Sci. 10 (9) (2020) 214, https://doi.org/10.3390/educsci10090214.
[7] W.H. Stewart, Y. Baek, G. Kwid, K. Taylor, Exploring factors that influence computational thinking skills in elementary students' collaborative robotics, J. Educ. Comput. Res. 59 (6) (2021) 1208–1239, https://doi.org/10.1177/0735633121992479.
[8] A.A. DiSessa, Computational literacy and "The big picture" concerning computers in Mathematics Education, Math. Think. Learn. 20 (1) (2018) 3–31, https://doi.org/10.1080/10986065.2018.1403544.
[9] J.A. Marín-Marín, A.-J. Moreno-Guerrero, P. Dúo-Terrón, J. López-Belmonte, Steam in education: a bibliometric analysis of performance and co-words in web of science, International Journal of STEM Education 8 (1) (2021), https://doi.org/10.1186/s40594-021-00296-x.
[10] Ľ. Valovičová, J. Ondruška, Ľ. Zelenický, V. Chytrý, J. Medová, Enhancing computational thinking through interdisciplinary steam activities using tablets, Mathematics 8 (12) (2020) 2128, https://doi.org/10.3390/math8122128.
[11] J. Moreno, G. Robles, M. Román, J.D. Rodríguez, No es lo mismo: un análisis de red de texto sobre definiciones de pensamiento computacional para estudiar su relación con la programación informática, RiiTE Revista Interuniversitaria de Investigación en Tecnología Educativa 7 (2019), https://doi.org/10.6018/riite.397151.
[12] M.M. Sánchez-Vera, J. González, Pensamiento computacional, robótica y programación en educación, Revista Interuniversitaria de Investigación en Tecnología Educativa 7 (2019) 8–11, https://doi.org/10.6018/riite.407731.
[13] Y. Li, A.H. Schoenfeld, A.A. diSessa, A.C. Graesser, L.C. Benson, L.D. English, R.A. Duschl, Computational thinking is more about thinking than computing, Journal for STEM Education Research 3 (1) (2020) 1–18, https://doi.org/10.1007/s41979-020-00030-2.
[14] P.A. García-Tudela, J.-A. Marín-Marín, Use of arduino in primary education: a systematic review, Educ. Sci. 13 (2) (2023) 134, https://doi.org/10.3390/educsci13020134.
[15] J.M. García, La Expansión del Pensamiento computacional en Uruguay, Revista De Educación a Distancia (RED) 20 (63) (2020), https://doi.org/10.6018/red.410441.
[16] M. Lodi, S. Martini, Computational thinking, between Papert and wing, Sci. Educ. 30 (4) (2021) 883–908, https://doi.org/10.1007/s11191-021-00202-5.
[17] A. Csizmadia, B. Standl, J. Waite, Integrating the constructionist learning theory with computational thinking classroom activities, Inf. Educ. 18 (1) (2019) 41–67, https://doi.org/10.15388/infedu.2019.03.
[18] M.M. Sánchez-Vera, El Pensamiento computacional en Contextos Educativos: una aproximación desde la Tecnología Educativa, Research in Education and Learning Innovation Archives 23 (2019) 24–39, https://doi.org/10.7203/realia.23.15635.
[19] M. Resnick, Reviving papert's dream, Educ. Technol. 52 (4) (2012) 42–46. https://bit.ly/3t2u5q1.
[20] J.M. Wing, Computational thinking, Commun. ACM 49 (3) (2006) 33–35, https://doi.org/10.1145/1118178.1118215.

[21] J.M. Wing, Computational thinking's influence on research and education for all, Italian Journal of Educational Technology 25 (2) (2017) 7–14, https://doi.org/10.17471/2499-4324/922.
[22] P. Dúo, F.J. Hinojo, A.J. Moreno, J.A. López, STEAM in primary education. Impact on linguistic and mathematical competences in a disadvantaged context, Frontiers in Education 7 (2022), https://doi.org/10.3389/feduc.2022.792656.
[23] S.K. Nordby, A.H. Bjerke, L. Mifsud, Primary mathematics teachers' understanding of computational thinking, KI - Künstliche Intelligenz 36 (1) (2022) 35–46, https://doi.org/10.1007/s13218-021-00750-6.
[24] X. Basogain-Olabe, M.E. Olmedo-Parco, Integración de Pensamiento computacional en Educación Básica. Dos Experiencias Pedagógicas de Aprendizaje Colaborativo Online, Revista De Educación a Distancia (RED) 20 (63) (2020), https://doi.org/10.6018/red.409481.
[25] J. Bell, T. Bell, Integrating computational thinking with a music education context, Inf. Educ. 17 (2) (2018) 151–166, https://doi.org/10.15388/infedu.2018.09.
[26] S. Bocconi, A. Chioccariello, P. Kampylis, V. Dagienė, P. Wastiau, K. Engelhardt, J. Earp, M.A. Horvath, E. Jasutė, C. Malagoli, V. Masiulionytė-Dagienė, G. Stupurienė, in: A. Inamorato Dos Santos, R. Cachia, N. Giannoutsou, Y. Punie (Eds.), Reviewing Computational Thinking in Compulsory Education, Publications Office of the European Union, 2022, https://doi.org/10.2760/126955.
[27] E.N. Caeli, A. Yadav, Unplugged approaches to computational thinking: a historical perspective, TechTrends 64 (1) (2019) 29–36, https://doi.org/10.1007/s11528-019-00410-5.
[28] M. Chevalier, C. Giang, A. Piatti, F. Mondada, Fostering computational thinking through educational robotics: a model for creative computational problem solving, International Journal of STEM Education 7 (1) (2020), https://doi.org/10.1186/s40594-020-00238-z.
[29] A. Gerosa, V. Koleszar, G. Tejera, L. Gómez-Sena, A. Carboni, Educational robotics intervention to foster computational thinking in preschoolers: effects of children's Task Engagement, Front. Psychol. 13 (2022), https://doi.org/10.3389/fpsyg.2022.904761.
[30] D.N. Jawawi, N.N. Jamal, S. Abdul Halim, N.A. Sa'adon, R. Mamat, M.A. Isa, R. Mohamad, H.N. Abdull Hamed, Nurturing secondary school student computational thinking through educational robotics, International Journal of Emerging Technologies in Learning (IJET) 17 (3) (2022) 117–128, https://doi.org/10.3991/ijet.v17i03.27311.
[31] Y.-S. Lin, S.-Y. Chen, C.-W. Tsai, Y.-H. Lai, Exploring computational thinking skills training through augmented reality and AIoT learning, Front. Psychol. 12 (2021), https://doi.org/10.3389/fpsyg.2021.640115.
[32] R. Jocius, W.I. O'Byrne, J. Albert, D. Joshi, R. Robinson, A. Andrews, Infusing computational thinking into STEM teaching: from professional development to classroom practice, Educ. Technol. Soc. 24 (4) (2021) 166–179. https://bit.ly/3RtQMgS.
[33] Y.-K. Song, S.-H. Hwang, Relationship among pre-service early childhood teacher's perception on technology equipment use, computational thinking, and TPACK, Journal of Convergence for Information Technology 9 (9) (2019) 166–174, https://doi.org/10.22156/CS4SMB.2019.9.9.166.
[34] A. Valls, X. Canaleta, D. Fonseca, Computational thinking and educational robotics integrated into project-based learning, Sensors 22 (10) (2022) 3746, https://doi.org/10.3390/s22103746.
[35] R. Soler-Costa, A.-J. Moreno-Guerrero, J. López-Belmonte, J.-A. Marín-Marín, Co-word analysis and academic performance of the term TPACK in web of science, Sustainability 13 (3) (2021) 1481, https://doi.org/10.3390/su13031481.
[36] K. Takemata, A. Minamide, Poster: project based learning using digital storytelling: educational program for students before learning full-scale PBL practice, in: M.E. Auer, T. Rüütmann (Eds.), Educating Engineers for Future Industrial Revolutions, Springer, 2021, pp. 379–385, https://doi.org/10.1007/978-3-030-68198-2_35.
[37] M.-C. Hsieh, H.-C. Pan, S.-W. Hsieh, M.-J. Hsu, S.-W. Chou, Teaching the concept of computational thinking: a STEM-based program with tangible robots on project-based learning courses, Front. Psychol. 12 (2022), https://doi.org/10.3389/fpsyg.2021.828568.
[38] D. Muliyati, A.S. Tanmalaka, D. Ambarwulan, D. Kirana, H. Permana, Train the computational thinking skill using problem-based learning worksheet for undergraduate physics student in computational physics courses, J. Phys. Conf. 1521 (2020), https://doi.org/10.1088/1742-6596/1521/2/022024.
[39] F. Bertacchini, C. Scuro, P. Pantano, E. Bilotta, A project based learning approach for improving students' computational thinking skills, Frontiers in Robotics and AI 9 (2022), https://doi.org/10.3389/frobt.2022.720448.
[40] P. Dúo, Análisis del Software Scratch en la Producción Científica durante 20 Años: programación en Educación para Desarrollar Disciplinas de Pensamiento Computacional y STEAM, Ciencias de la Educación 13 (4) (2023) 404, https://doi.org/10.3390/educsci13040404.
[41] J. Estevez, G. Garate, M. Grana, Gentle introduction to artificial intelligence for high-school students using scratch, IEEE Access 7 (2019) 179027–179036, https://doi.org/10.1109/access.2019.2956136.
[42] H.J. Noh, S.H. Paik, Students' perception of scratch program using high school science class, J. Kor. Assoc. Res. Sci. Educ. 35 (1) (2015) 53–64, https://doi.org/10.14697/jkase.2015.35.1.0053.
[43] R. Silva, B. Fonseca, C. Costa, F. Martins, Fostering Computational Thinking Skills: a didactic proposal for elementary school grades, Educ. Sci. 11 (9) (2021) 518, https://doi.org/10.3390/educsci11090518.
[44] S. Zha, D.A. Morrow, J. Curtis, S. Mitchell, Learning culture and computational thinking in a Spanish course: a development model, J. Educ. Comput. Res. 59 (5) (2020) 844–869, https://doi.org/10.1177/0735633120978530.
[45] M. Perarnau, Introducció d'Arduino als centres escolars. Estratègies I Recursos, 2019 [Trabajo Fin de Máster, Universitat Politècnica de Catalunya]. UPCommons, http://hdl.handle.net/2117/167550.
[46] K. Seong-Yeol, A study on the effectiveness of IoT coding education using MicroBit, The Journal of the Korea institute of electronic communication sciences 15 (2) (2020) 363–370, https://doi.org/10.13067/JKIECS.2020.15.2.363.
[47] V. Grout, N. Houlden, Taking computer science and programming into schools: the glyndŵr/BCS turing project, Procedia - Social and Behavioral Sciences 141 (2014) 680–685, https://doi.org/10.1016/j.sbspro.2014.05.119.
[48] S.B. Kert, M.F. Erkoç, S. Yeni, The effect of robotics on six graders' academic achievement, Computational Thinking Skills and conceptual knowledge levels, Think. Skills Creativ. 38 (2020) 100714, https://doi.org/10.1016/j.tsc.2020.100714.
[49] I.M. Souza, W.L. Andrade, L.M. Sampaio, Educational robotics applied to computational thinking development: a systematic mapping study, in: 2021 IEEE Frontiers in Education Conference (FIE), 2021, https://doi.org/10.1109/fie49875.2021.9637185.
[50] C.M. Ángel-Díaz, E. Segredo, R. Arnay, C. León, Simulador de Robótica Educativa para la promoción del Pensamiento Computacional, Revista De Educación a Distancia (RED) 20 (63) (2020), https://doi.org/10.6018/red.410191.
[51] D. Higuera, J. Guzmán, Á. Rojas, Implementando las metodologías steam y abp en la enseñanza de la física mediante Arduino, in: V. Villareal, L. Muñoz (Eds.), Memorias del Congreso AmiTIC 2019, Universidad Tecnológica de Panamá, 2019, pp. 133–137. https://bit.ly/3Rp5ea1.
[52] J.C. García-Monsálvez, Python como primer lenguaje de programación textual en la Enseñanza Secundaria, Education in the Knowledge Society (EKS) 18 (2) (2017) 147–162, https://doi.org/10.14201/eks2017182147162.
[53] C. Zeng, H. Zhou, W. Ye, X. Gu, IARM: design an educational robotic arm kit for inspiring students' computational thinking, Sensors 22 (8) (2022) 2957, https://doi.org/10.3390/s22082957.
[54] W. Hong, J.-S. Choi, H. Lee, Effects of maker education for high-school students on attitude toward software education, creative problem solving, computational thinking, Journal of The Korean Association of Information Education 24 (6) (2020) 585–596, https://doi.org/10.14352/jkaie.2020.24.6.585.
[55] M. Cujdikova, Create minecraft fame, save the world, in: Proceedings of the 12th European Conference on Game Based Learning, 2019, pp. 182–191. ProQuest, https://bit.ly/3ru2v4i.
[56] H.-M. Chuang, C.-C. Lee, Effects of personal construal levels and Team Role Ambiguity on the group investigation of junior high school students' programming ability, Sustainability 13 (19) (2021) 10977, https://doi.org/10.3390/su131910977.
[57] D.A. Fields, D. Lui, Y.B. Kafai, Teaching computational thinking with electronic textiles: modeling iterative practices and supporting personal projects in exploring computer science, in: S.C. Kong, y H. Abelson (Eds.), Computational Thinking Education, Springer, 2019, pp. 279–294, https://doi.org/10.1007/978-981-13-6528-7_16.

[58] P. Martín-Ramos, M.J. Lopes, M.M. Lima da Silva, P.E.B. Gomes, P.S. Pereira da Silva, J.P.P. Domingues, M. Ramos Silva, Reprint of 'first exposure to Arduino through peer-coaching: impact on students' attitudes towards programming.', Comput. Hum. Behav. 80 (2018) 420–427, https://doi.org/10.1016/j.chb.2017.12.011.
[59] M. Shahin, C. Gonsalvez, J. Whittle, C. Chen, L. Li, X. Xia, How secondary school girls perceive computational thinking practices through collaborative programming with the micro:bit, J. Syst. Software 183 (2022) 111107, https://doi.org/10.1016/j.jss.2021.111107.
[60] F.M. Esteve-Mon, J. Adell-Segura, M.A. Llopis Nebot, G. Valdeolivas Novella, J. Pacheco Aparicio, The development of computational thinking in student teachers through and intervention with educational robotics, J. Inf. Technol. Educ. Innovat. Pract. 18 (2019) 139–152, https://doi.org/10.28945/4442.
[61] O.M. Kryvonos, Y.V. Kuzmenko, S.V. Kuzmenko, Survey and prospects of Arduino Nano 3.0 platform use in high school, Information Technologies and Learning Tools 56 (6) (2016) 77–87, https://doi.org/10.33407/itlt.v56i6.1506.
[62] J. López-Belmonte, J.-A. Marín-Marín, R. Soler-Costa, A.J. Moreno-Guerrero, Arduino advances in web of science. A scientific mapping of literary production, IEEE Access 8 (2020) 128674–128682, https://doi.org/10.1109/access.2020.3008572.
[63] D.A. Martínez-Cruz, *Robonoide bípedo autónomo realizado en plataforma Arduino* [Tesis doctoral, Universidad de Guayaquil], Repositorio Universidad de Guayaquil, 2018. http://repositorio.ug.edu.ec/handle/redug/36172.
[64] S. Guirao, Utilidad y tipos de revisión de literatura, Ene 9 (2) (2015), https://doi.org/10.4321/S1988-348X2015000200002.
[65] A. Peixoto, M. Castro, M. Blázquez, S. Martín, E. Sancristóbal, G. Carro, P. Plaza, Robotics tips and tricks for inclusion and integration of students, in: IEEE Global Engineering Education Conference (EDUCON), IEEE, 2018, pp. 2037–2041, https://doi.org/10.1109/EDUCON.2018.8363487.
[66] R.M. Luvezute, M. y Scheller, D.L. Bonotto, La investigación documental sobre la investigación cualitativa: conceptos y caracterización, Revista de investigaciones UNAD 14 (2) (2015), https://doi.org/10.22490/25391887.1455.
[67] V.I. Marín-Juarros, La revisión sistemática en la investigación en tecnología educativa: observaciones y consejos, RiiTE Revista Interuniversitaria de Investigación en Tecnología Educativa 13 (2022) 62–79, https://doi.org/10.6018/riite.533231.
[68] R.A. Arévalo, G. Ortuño, E. Arévalo, Revisiones sistemáticas [Systematic reviews], Revista médica La Paz 16 (2) (2010) 69–80. https://bit.ly/3UW6OPq.
[69] M.J. Grant, A. Booth, A typology of reviews: an analysis of 14 review types and associated methodologies, Health Inf. Libr. J. 26 (2) (2009) 91–108, https://doi.org/10.1111/j.1471-1842.2009.00848.x.
[70] W. Mengist, T. Soromessa, G. Legese, Method for conducting systematic literature review and meta-analysis for environmental science research, MethodsX 7 (2020), https://doi.org/10.1016/j.mex.2019.100777. Article 100777.
[71] M.J. Page, D. Moher, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E. Loder, E. Mayo-Wilson, S. Mcdonald, J.E. McKenzie, PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews, BMJ 372 (2021), https://doi.org/10.1136/bmj.n160. Article 160.
[72] S. Moss, X. Gu, Home and Community-Based interventions for Physical Activity and Early Child development: a systematic review of effective strategies, Int. J. Environ. Res. Publ. Health 19 (19) (2022), https://doi.org/10.3390/ijerph191911968. Article 11968.
[73] N. Tavares, The use and impact of game-based learning on the learning experience and knowledge retention of nursing undergraduate students: a systematic literature review, Nurse Educ. Today 117 (2022), https://doi.org/10.1016/j.nedt.2022.105484. Article 105484.
[74] M.A. Pertegal-Vega, A. Oliva-Delgado, A. Rodríguez-Meirinhos, Revisión sistemática del panorama de la investigación sobre redes sociales: taxonomía sobre experiencias de uso [Systematic review of the social networking research landscape: a taxonomy of use experiences], Comunicar 60 (37) (2019) 81–91, https://doi.org/10.3916/C60-2019-08.
[75] C. Stern, Z. Jordan, A. McArthur, Developing the review question and inclusion criteria, Am. J. Nurs. 114 (4) (2014) 53–56, https://doi.org/10.1097/01.NAJ.0000445689.67800.86.
[76] N.R. Haddaway, M.J. Page, C.C. Pritchard, L.A. McGuinness, PRISMA2020: an R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis, Campbell Systematic Reviews 18 (2022) e1230, https://doi.org/10.1002/cl2.1230.
[77] Arduino, *Getting started with arduino products*. Arduino.Cc. https://www.arduino.cc/en/Guide.
[78] A. Juškevičienė, G. Stupuriene, T. Jevsikova, Computational thinking development through physical computing activities in STEAM education, Comput. Appl. Eng. Educ. 29 (1) (2021) 175–190, https://doi.org/10.1002/cae.22365.
[79] G. Stupurienė, T. Jevsikova, A. Juškevičienė, Solving ecological problems through physical computing to ensure gender balance in STEM education, Sustainability 14 (2022) 2–16, https://doi.org/10.3390/su14094924.
[80] U. Sarı, H.M. Pektaş, Ö.F. Şen, H. Çelik, Algorithmic thinking development through physical computing activities with Arduino in STEM education, Educ. Inf. Technol. 27 (2022) 6669–6689, https://doi.org/10.1007/s10639-022-10893-0, 2022.
[81] U. Sari, H. Çelik, HM y Pektaş, S. Yalçın, Effects of STEM-focused Arduino practical activities on problem-solving and entrepreneurship skills, Australas. J. Educ. Technol. 38 (3) (2022) 140–154, https://doi.org/10.14742/ajet.7293.
[82] C. Morón, E. Yedra, D. Ferrández, P. Saiz, Application of Arduino for the teaching of mathematics in primary education, in: L. Gómez-Chova, A. López-Martínez, I. Candel-Torres (Eds.), ICERI2019 Proceedings, IATED Academy, 2019, pp. 6316–6321, https://doi.org/10.21125/iceri.2019.1524.
[83] D. Herceg, D. Herceg, Arduino and numerical mathematics, Inf. Educ. 19 (2) (2020) 239–256, https://doi.org/10.15388/infedu.2020.12.
[84] H.J. Kim, J.H. Seo, Y. Kim, The effect of scratch programming education using Arduino on middle school students' creative problem solving ability, Korean Association For Learner-Centered Curriculum And Instruction 16 (12) (2016) 707–724, https://doi.org/10.22251/jlcci.2016.16.12.707.
[85] J.M. Cardoso, M. Zannin, Proposta experimental para análise das Variáveis de Estado dos gases COM arduino, Rev. Bras. Ensino Física 41 (4) (2019), https://doi.org/10.1590/1806-9126-rbef-2019-0028.
[86] C.-C. Chung, S.-J. Lou, Physical computing strategy to support students' CODING LITERACY: an educational experiment with Arduino boards, Appl. Sci. 11 (4) (2021) 1830, https://doi.org/10.3390/app11041830.
[87] S. Silveira, M. Girardi, Desenvolvimento de um kit experimental com Arduino para o Ensino de Física Moderna no Ensino Médio, Rev. Bras. Ensino Física 39 (4) (2017), https://doi.org/10.1590/1806-9126-rbef-2016-0287.
[88] W.-K. Wong, T.-K. Chao, P.-R. Chen, Y.-W. Lien, C.-J. Wu, Mobile devices and a modelling tool for physics experiments in high school, in: G. Chen, V. Kumar, R. Huang, S. Kong (Eds.), Emerging Issues in Smart Learning, Springer, 2014, pp. 239–246, https://doi.org/10.1007/978-3-662-44188-6_33.
[89] J. Diz-Bugarin, R. Rodriguez-Paz, Arduino-compatible microcontroller module for electronics practices and Environmental Monitoring, in: 2020 XIV Technologies Applied to Electronics Teaching Conference (TAEE), 2020, https://doi.org/10.1109/taee46915.2020.9163728.
[90] H. Pino, V. Pastor, C. Grimalt-Álvaro, V. López, Measuring co2 with an Arduino: creating a low-cost, pocket-sized device with flexible applications that yields benefits for students and Schools, J. Chem. Educ. 96 (2) (2018) 377–381, https://doi.org/10.1021/acs.jchemed.8b00473.
[91] F. Zarantonello, F. Mancin, R. Bonomi, Working in a team: development of a device for water hardness sensing based on an Arduino–Nanoparticle System, J. Chem. Educ. 97 (7) (2020) 2025–2032, https://doi.org/10.1021/acs.jchemed.9b01156.
[92] F. Agatolio, M. Moro, A workshop to promote arduino-based robots as wide Spectrum learning support tools, in: M. Merdan, W. Lepuschitz, G. Koppensteiner, R. Balogh (Eds.), Robotics in Education. Advances in Intelligent Systems and Computing, Springer, 2016, pp. 113–125, https://doi.org/10.1007/978-3-319-42975-5_11.
[93] J. West, N. Vadiee, A. McMahon, K. Lake, B. Ray, T. Billie, From classroom Arduinos to missions on Mars: making STEM education accessible and effective through remotely operated robotics, in: Proceedings Of the 7th IEEE Integrated STEM Education Conference, IEEE, 2017, pp. 88–95, https://doi.org/10.1109/ISECon.2017.7910255.
[94] N. Gupta, N. Tejovanth, P. Murthy, Learning by creating: interactive programming for Indian high schools, in: 2012 IEEE International Conference on Technology Enhanced Education (ICTEE), 2012, https://doi.org/10.1109/ictee.2012.6208643.
[95] M.S. Alegre-Buj, M.J. Cuetos-Revuelta, Sensores y equipos de captación automática de datos en los trabajos prácticos de física y química de secundaria y bachillerato: el uso de arduino, Rev. Eureka sobre Enseñanza Divulg. Ciencias 18 (1) (2021) 1–16, https://doi.org/10.25267/rev_eureka_ensen_divulg_cienc.2021.v18.i1.1202.

[96] C.-C. Yu, J.-H. Hsu, Q.-H. Yang, W.-T. Hsieh, Wave experiment based on the arduino electronics and the mobile apps, in: L. Gómez-Chova, A. López-Martínez, I. CAndel-Torres (Eds.), INTED 2018 Conference Proceedings, IATED Academy, 2018, pp. 153–157, https://doi.org/10.21125/inted.2018.1022.
[97] J. Guggemos, On the predictors of computational thinking and its growth at the high-school level, Comput. Educ. 161 (2021), https://doi.org/10.1016/j.compedu.2020.104060.
[98] J. Guggemos, S. Seufert, M. Román-González, Computational thinking assessment-towards more vivid interpretations, Technol. Knowl. Learn. 28 (2022) 539–568, https://doi.org/10.1007/s10758-021-09587-2.
[99] B. Ortega-Ruipérez, M.M. Asensio, Robótica DIY: pensamiento computacional para mejorar la resolución de problemas, Revista Latinoamericana De Tecnología Educativa - RELATEC 17 (2) (2018) 129–143, https://doi.org/10.17398/1695-288X.17.2.129.
[100] L.M. Herger, M. Bodarky, Engaging students with open source technologies and Arduino, in: 2015 IEEE Integrated STEM Education Conference, IEEE, 2015, pp. 27–32, https://doi.org/10.1109/ISECon.2015.7119938.