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# Arduino Advances in Web of Science. A Scientific Mapping of Literary Production

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**ABSTRACT** Technology and computer learning have acquired a great projection in the field of education. Arduino arises from current technological innovations with the intention of promoting a new approach to learning through machines. The objective of this research is to analyze the evolution of the Arduino concept in the scientific literature. To achieve this aim, a bibliometric methodology based on scientific mapping and an analysis of co-words has been used. The scientific production of Arduino indexed in Web of Science has been analyzed. We have worked with an analysis unit of 346 documents. The results of this research show that the scientific production on Arduino in the field of education starts in 2010 until today. The communications in the congresses to present the results of the investigations developed are the most used means of diffusion. The National University of Distance Education and the Lucian Blaga University of Sibiu are particularly noteworthy. The authors with more scientific production in this field of study are Bogdan, M. and Castro, M. It is significant that the collection of studies on this subject is carried out, above all, by EDULEARN Proceedings and INTED Proceedings. It can be concluded that the field of study on Arduino in the educational field is relatively recent, so that today, the basis for scientific research is still being established. However, the most relevant aspects in this field of study are physic experiments, computational thinking and computer-based learning.

**INDEX TERMS** Arduino, documentary analysis, educational innovation, educative technology, scientific mapping.

## I. INTRODUCTION

The current educational systems of developed countries strive to introduce and promote learning based on computational principles [1]–[3] and the maker movement [4]. Undoubtedly, the potential of computer learning and the possibilities of interacting with devices and creating low-cost robots, facilitate learning and promote collaborative work and problem solving attitudes that are much more effective [5]–[7]. In this way, these learning and contents can be considered a critical subject for education in order to develop a qualified job for and for the future.

These movements for the inclusion of computational thinking in the curricula, both in the Primary and Secondary education stages, and of robotic experiences in educational centers, are promoted by what is known as the Internet of Things (IoT). In relation to the concept of IoT, the International Telecommunication Union (ITU) (2012, p.1) defines it as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" [8]. Kevin Ashton, who conceived the phrase "Internet of things", describes the network connecting objects in the physical world to the Internet [9], [10]. The idea behind this concept is that, every day, physical devices in our homes, companies or educational centers [11], [12], connect through the Internet with virtual servers and carry out interactions generating an enormous amount of information. These devices, such as temperature probes, geolocators, cameras, motion sensors,

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pressure sensors, have the ability to be programmed and to interact with them from anywhere in the world, without requiring face-to-face management [13]. The combined use of these devices can allow much more complex applications, such as the development of smart appliances, smart vehicles and smart homes with automation systems, as well as facility management and security systems [14], all with high impact on areas such as medicine and health, transportation, construction, agriculture and in industrial applications [15].

Within this IoT evolutionary and developmental process is Arduino. Arduino is an open source electronic board based on low cost and easy to use hardware and software [16]. These boards are capable of reading inputs (light on a sensor, a finger on a button, or a Twitter message) and turning it into an output (lighting an LED, activating a motor, or posting something online). To do this, it uses its own programming language based on Wiring and the Arduino Software (IDE) based on Processing. In the educational field, Arduino has had an exponential impact due to its low cost, the potential and versatility of design and experimentation that it allows, the possibility of using it in various operating systems (Linux, Macintosh OSX and Windows) and being code open and extensible both software and hardware.

The review of the literature on Arduino in the field of education allows to contrast the existing movement and the diversity of applications that teachers, both in primary and secondary education [1], [6], [17]–[20], and in higher studies [16], [21]–[23], make it. It is also used in the field of Vocational Training, where students are trained in the field of home automation [24]. These studies reveal that direct experimentation provides students with the opportunity to apply and reinforce understanding of the concepts; promotes interest in design and free-manufacture activities by themselves; in addition, they practice the spirit of a creator, such as the autonomous collection of data and the disposition of the same with colleagues; This new approach improves the attention and the general performance of the students of the courses, reflecting in the increase of their grades [25] and improves the attitudes towards technology in the students themselves. On the other hand, these experiences conclude with high degrees of satisfaction for both the students and their teachers [26]. It is noteworthy that the use of Arduino in education promotes the use of robotics in education [27].

From a methodological point of view, the educational experiences proposed for the use of Arduino in classrooms opt for the implementation of pedagogical methods such as project-based learning [28], collaborative learning [19] or learning based on tasks [17]. These methods allow interaction between students, answer both explicit and implicit questions, develop inferential thinking, learn problem-solving processes, and reduce students' fear of using microcontroller boards [4].

Despite the need to use the IoT in education, there are many difficulties for its implementation in high school and university students. This technology is complex and diverse, since it manages both the physical and the virtual environment and covers all Information and Communication Technologies including hardware devices. Today, IoT education for students is how to use the tools without giving them real-world applicability due to the training tools themselves and the limited time there is for their training. For these reasons, student education must be more than just teaching how to use the tools of IoT systems. These should allow students to develop the ability to understand the general configuration of the IoT and to solve problems through the proper use of the tools [29]. In other words, tools for IoT education should be simple and easy to learn, support basic IoT functions, and at the same time ensure usability. In this sense, there are more and more attempts to improve the usefulness of the tools to solve the difficulties of the students [30], [31] and that these awaken their interests and inspire them [32] to develop an understanding of the general configuration of the IoT.

Faced with this situation, the appearance of the Arduino system in 2005 provides a versatility and adaptability not seen until then in other projects to approach robotics and programming to education [33]. The real interest comes from the people who do the projects themselves, document them, and offer them online by sharing information about how they built them. Furthermore, the maker and DIY (do it yourself) movements have adopted Arduino as a device to build and design their own projects. This encourages more and more young students to start and start technology, giving them the feeling that they, too, can understand how software and hardware combine to produce new technologies.

## II. JUSTIFICATION AND OBJECTIVES

This work tries to analyze the term "Arduino", found in the publications indexed in the Web of Science (WoS) database. This analysis will be carried out using a scientific mapping technique, taking into account the quantification of various bibliometric indicators and the structural and dynamic development of the defined concepts. For this, the research structure of previous studies published in impact journals has been followed, in order to follow an analysis model validated by experts [34].

The purpose of this research is to study both the trajectory and the significance of this concept in the expert literature reported from the main WoS collection. After a search phase in said database, no bibliometric study on the state of the matter has been found. Therefore, this research reaches an exploratory nuance to reduce the gap found in the scientific literature. In addition, another of the potentialities of this study is the novelty that it presents as there is no work of such characteristics in the impact databases, allowing to increase the interest of the members of the scientific community for new exploratory results on the state of the question.

Therefore, the objectives set in this study are:

-To determine the performance and scientific production of the literature concerning "Arduino".

-To concrete the scientific evolution of both related concepts.

-To define the most influential themes in the conceptual association.

-To discover the most outstanding authors in the field of study on both terms.

## III. MATERIAL

### A. RESEARCH DESIGN

The research methodology carried out to achieve the objectives has been based on bibliometrics, following the considerations of the experts [35]. The choice of this study methodology has been based on the potential revealed by scientometry to account for, analyze and predict the evolution of scientific documents [36].

Specifically, co-word analysis is used in this study [37], supported mainly by bibliometric indicators such as the h-index and the number of citations, as well as others (g, hg and q2) [38], [39]. This will allow the generation of node maps to study the performance and location of terminological subdomains to determine the evolution of the topics on the state of the question [40], [41].

Likewise, at all times, the analysis protocol of the PRISMA-P matrix has been followed and various techniques of measurement and recording of the literature with documentary variables have been used.

### B. PROCEDURE AND DATA ANALYSIS

The procedure to carry out this bibliometric study has focused on various actions [42]. First, WoS was chosen as the default database that houses large impact scientific output. Second, the keyword "Arduino" was specified to define the search process and extract the existing literature on the state of the matter. Third, this term was entered as [TOPIC] in the search field provided by WoS. In this way, works containing the selected term in the title, abstract and keywords are located. A scientific production of 5,332 documents was obtained. After its analysis, it was decided to narrow the search to the categories of "Education Scientific Disciplines" and "Education Educational Research" because many documents were not related to the field of education. This reduced the documentary volume to a unit of analysis of 346 scientific publications. In addition, a bibliographic time interval of 10 years was established, starting in 2010 with the first documents on the state of the art and closing the literary report in 2019 since the year 2020 was not selected for not having finished and therefore was not going to obtain a significant and real volume of work. The literature was purged to discard repeated documents or those with some indexing error. Also, various inclusion criteria established for this study were followed (table 1). Therefore, the final sample of documents was purified in 342 publications (figure 1).

As specific document analysis tools, Analyze Results and Creation Citation Report (WoS own) have been used to extract information regarding the year, authorship, country, type of document, institution, language, medium and most cited documents; and SciMAT, a software for longitudinal analysis of the structural and dynamic development of scientific production, following the guidance of experts in this type of study [43]. With SciMAT the following processes have been carried out for a relevant co-word analysis at the thematic level:

- Recognition: In this process, all the keywords of the recovered scientific volume (n = 1049) are analyzed and a map of co-occurrence nodes is generated. A normalized network of co-words is generated and the most significant keywords are reported (n = 924). The most attractive themes and concepts are represented with a clustering algorithm.
- Reproduction: In this process, a strategic diagram and a thematic network are prepared based on the principles of centrality and density. The generated graphs are articulated in four well differentiated areas: 1-Upper right = motor and relevant issues are located; 2-Upper left = the consolidated but isolated topics are found; 3-Bottom left = topics in development or in disappearance are located; 4-Lower right: there are cross-cutting themes with little evolution.
- Determination: In this process the evolution of the nodes in periods of time is analyzed. The strength of association is established with the number of common keywords of the different periods. In this study, three periods

**TABLE 1.** Production indicators and inclusion criteria.

| Indicators | Criteria |
|---|---|
| Year of publication | x ≥ 1995 |
| Language | x ≥ 10 |
| Publication Area | x ≥ 100 |
| Type of documents | x ≥ 20 |
| Organizations | x ≥ 20 |
| Authors | x ≥ 6 |
| Sources of Origin | x ≥ 35 |
| Countries | x ≥ 15 |
| Citation | The four most cited documents |

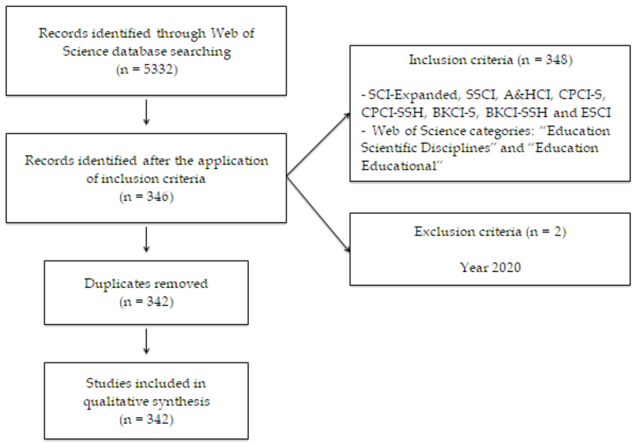


**FIGURE 1.** Flowchart according to the PRISMA Declaration.

have been configured to classify and analyze literary volume (P1 = 2010-2015; P2 = 2016-2017; P3 = 2018-2019). To analyze the authorship of the documents, only one period (PX = 2010-2019) has been established that encompasses all scientific production.

– Performance: Various indicators intervened in this process (table 2). The connections between the keywords and other latent aspects of the nodes were established by means of an analysis unit made up of the keywords determined by the authors, those established by WoS and those specified by the authors in other publications. In addition, a minimum frequency threshold was configured to enter the period (n = 2 for all intervals). With the network type, a co-occurrence network of keywords and authors (co-authors) was generated. The match union value was used to relate the configured periods (three periods for keywords and one for authoring the entire production volume). The normalization measure established the threshold of union, determining the minimum connection of the occurrence (Keywords = P1 ≥ 1; P2 ≥ 1; P3 ≥ 1; Authors = PX ≥ 1). The entire network was normalized by the equivalence index (eij = cij2 / Root (ci – cj)). The creation of thematic maps and connected subnets was carried out by means of a clustering algorithm with simple centers. The similarity measure was determined by the evolutionary measure with the Jaccard Index, generating an evolution map. Finally, the transition map was generated by the inclusion rate.

**TABLE 2.** SciMAT indicators and inclusion criteria.

| Configuration | Values |
|---|---|
| Analysis unit | Keywords authors, keywords WoS |
| Frequency threshold | Keywords: $P_1$ = (2), $P_2$ = (2), $P_3$ = (2)<br>Authors: $P_X$ = (2) |
| Network type | Co-occurrence |
| Co-occurrence union value threshold | Keywords: $P_1$ = (1), $P_2$ = (1), $P_3$ = (1)<br>Authors: $P_X$ = (1) |
| Normalization measure | Equivalence index |
| Clustering algorithm | Maximum size: 9; Minimum size: 3 |
| Evolutionary measure | Jaccard index |
| Overlapping measure | Inclusion Rate |

## IV. RESULTS

Below are the results obtained after applying the statistical analyses indicated above, showing firstly the most relevant elements of scientific performance and production, and secondly, the structural and thematic development of the field of knowledge.

### A. SCIENTIFIC PRODUCTION AND PERFORMANCE

The scientific production on Arduino in the field of education starts in 2010 until today, having a constant and increasing evolution in time, except in 2019, where there is a considerable decrease in production, reaching similar levels of 2016

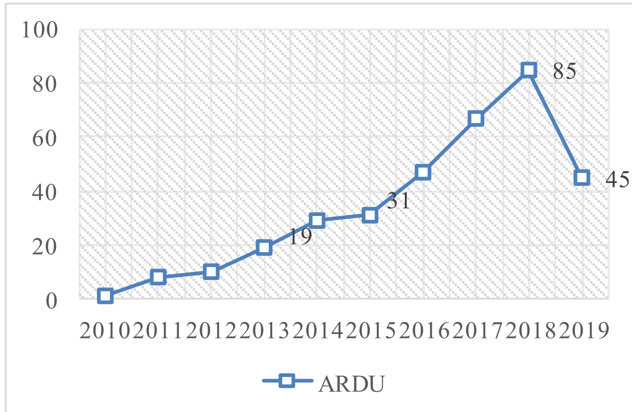


**FIGURE 2.** Evolution of scientific production.

(figure 2). The researchers in this field of study use the communications in the congresses to present the results of their investigations (n = 242; 70.76%), followed at a considerable distance by the articles (n = 96; 28.07%), which marks the recent interest on the part of the scientific community in this subject. The most prolific organizations in the study of Arduino are the National University of Distance Education (n = 10; 2.92%) and Lucian Blaga University of Sibiu (n = 9; 2.63%). The authors with most scientific production in this field of study are Bogdan, M. (n = 9; 2.63%) and Castro, M. (n = 7; 2.04%). The main sources that gather the studies on Arduino in the field of education are EDULEARN Proceedings and INTED Proceedings, both with the same production (n = 22; 6.43%). The countries most interested in this type of study are the United States (n = 76; 22.22%) and Spain (n = 38; 11.11%), with English (n = 319; 93.27%) being the majority language for the authors to present the studies, followed by Spanish (n = 14; 4.09%). The two most cited papers are [44], with 44 citations, and [45], with 33 citations.

### B. STRUCTURAL AND THEMATIC DEVELOPMENT

The evolution of keywords in the three established periods shows the data related to the keywords that appear in each established time interval, the keywords that stop being used from one period to another, the new keywords that appear in a certain period and those keywords that coincide between periods. According to the data offered in figure 3, there is only a low keyword match (<.22%). This fact shows that there is no established line of research on the subject.

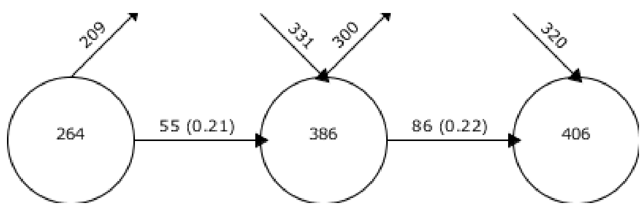


**FIGURE 3.** Continuity of keywords between contiguous intervals.

The academic performance presents the most relevant topics in the time intervals established in the research. As shown in table 3, in the first period, "Arduino" and "Labview" are the ones that present the highest bibliometric values. In the second period it is "computer-based-learning", "education" and "Arduino". In the last period it is "education".

**TABLE 3. Thematic performance by period.**

| Name | Works | Index-h | Index-g | Index-hg | Index-q2 | Citations |
|---|---|---|---|---|---|---|
| Period 2010-2015 | | | | | | |
| Labview | 5 | 4 | 4 | 4 | 9.59 | 77 |
| Arduino | 17 | 4 | 5 | 4.47 | 4.47 | 29 |
| Programing | 3 | 1 | 1 | 1 | 1 | 2 |
| Robotics | 4 | 1 | 2 | 1.41 | 2.24 | 6 |
| Education | 3 | 2 | 3 | 2.45 | 9.38 | 58 |
| Physics-Experiments | 2 | 1 | 1 | 1 | 2 | 4 |
| Period 2016-2017 | | | | | | |
| Name | Works | Index-h | Index-g | Index-hg | Index-q2 | Citations |
| Computer-based-learning | 3 | 3 | 3 | 3 | 4.24 | 35 |
| Engineering.Education | 4 | 2 | 2 | 2 | 5.1 | 20 |
| Computational-Thinking | 6 | 1 | 1 | 1 | 2.45 | 6 |
| Education | 8 | 3 | 3 | 3 | 3 | 9 |
| Arduino | 15 | 3 | 4 | 3.46 | 4.24 | 18 |
| Bluetooth | 3 | 1 | 1 | 1 | 1 | 1 |
| Hands-on-learning | 2 | 2 | 2 | 2 | 3.46 | 9 |
| Period 2018-2019 | | | | | | |
| Name | Works | Index-h | Index-g | Index-hg | Index-q2 | Citations |
| Potentiometry | 3 | 1 | 3 | 1.73 | 3.32 | 13 |
| Design | 4 | 0 | 0 | 0 | 0 | 0 |
| Arduino | 20 | 1 | 1 | 1 | 1.41 | 3 |
| Education | 9 | 3 | 3 | 3 | 3 | 14 |
| Laboratory-Computing | 3 | 1 | 1 | 1 | 1 | 2 |
| Free-Software | 3 | 1 | 1 | 1 | 1.73 | 3 |
| Learning-by-doing | 2 | 1 | 1 | 1 | 1 | 1 |
| MQ-Gas-Sensors | 2 | 1 | 1 | 1 | 1 | 1 |
| Computer-Science-Education | 2 | 0 | 0 | 0 | 0 | 0 |

The interval diagrams show information on the level of relevance of the topics that present the greatest bibliometric indicators in each of the periods analysed. According to the data provided by figure 4, in the first period the driving theme is "physics experiments". In this same period of time the themes "labview" and "Arduino", although they are of interest for the scientific community due to their high value of index h, are situated as highly developed-isolated and basic-transverse themes respectively. In the second period,

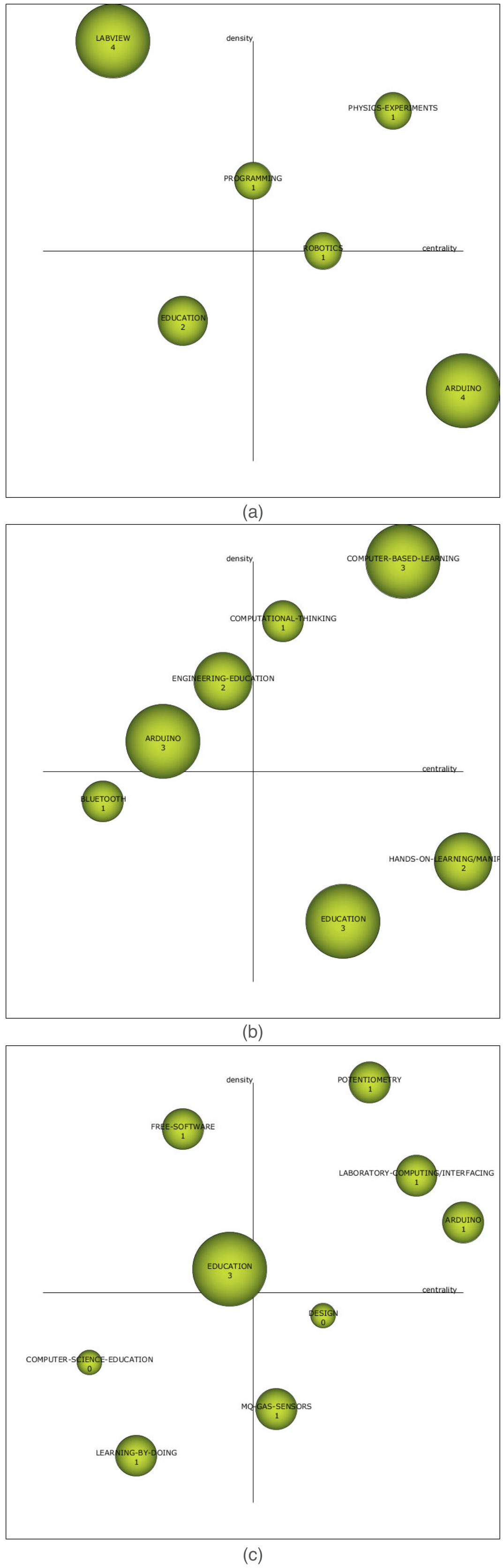


**FIGURE 4.** **Strategic diagram by ARDU h-index (a) Range 2010-2015; (b) Range 2016-2017; (c) Range 2018-2019.**

the driving themes are ''computational thinking'' and ''computer based learning''. As in the previous period, the themes with the highest h index, ''Arduino'' and ''education'', although of interest to researchers, are positioned as highly developed-isolated and basic-cross-cutting themes respectively. In the last period, the driving themes are ''potentiometry'', ''laboratory compunting/interfacing'' and ''Arduino'', while ''education'', which has the highest h index, is a highly developed, isolated theme. During this period, attention should be paid to the topics ''computer science education'' and ''learning by doing'', since their location in the diagram places them as unknown topics, since they may be the next driving topics, and therefore, the most relevant ones on the study of Arduino in education.

The thematic evolution shows the strength with which the different themes of each of the established periods are related. The indicator used to provide the information is the Jaccard index. Thematic evolution is developed when the theme of a given period shares themes or key words with previous or subsequent periods. The greater the number of themes or key words, the greater the relationship works. The two types of relationships that can be established are by key words, represented by discontinuous lines; or by themes, represented by continuous lines. The thickness of the line shows the strength of the relationship between themes.

According to figure 5, there is a conceptual continuity in the established field of study, with the ''Arduino'' theme being the basis of development in all the periods analyzed. Moreover, this connection is thematic. There is no coincidence of themes in the periods analyzed, which marks the continuous change of tendency on the part of the scientific community in research. In this case, it can be determined that the field of study is still settling. Furthermore, there are few relationships and connections between topics, there being equal relationships between topics and keywords.

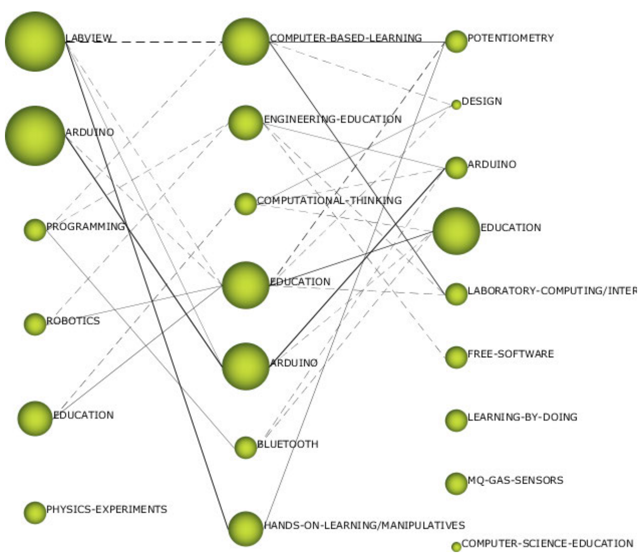


**FIGURE 5.** **Thematic evolution by h-index.**

According to the data provided by the authors (figure 6), Silva, M.P. and Morón, C., are the driving force behind all scientific production on Arduino in the educational field. Castro, M. should be kept in mind, as he is one of the authors with the highest h index, although his location in the diagram places him as an isolated author. On the other hand, Kafai, Y.B., being also one of the authors with the highest h index, is located in the diagram as an unknown author, so that in the future he can be a reference in this field of study.

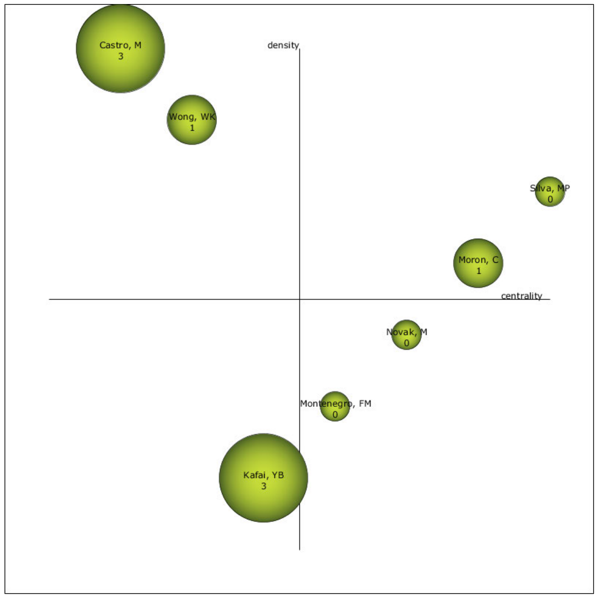


**FIGURE 6.** **Strategic diagram of authors of the entire productions.**

## V. DISCUSSION AND CONCLUSIONS

*Stricto sensu*, the new socio-educational needs force the introduction of innovation processes in didactic development. Fundamentally, curricular prescriptions at European and national level attach special importance to computer learning [1]–[3], and to the innovations derived from the movement maker [4]. With this, numerous doors are opened to learning with robot devices that, among its innumerable advantages, facilitates learning and fosters collaborative learning [5]–[7].

The inclusion of computational thinking in the field of primary and secondary education through the generation of robotic experiences, that is, the well-known IoT also offers numerous advantages since it allows establishing network connecting objects in the physical world to the Internet [9]. The emergence and expansion of these devices, in addition to the technical advantages that they offer [11]–[13], allow the use of innovative pedagogical methods to develop learning.

As it has been verified, Arduino is an excellent example of IoT [16]. Its success is above all due to the fact that, at a low cost, it offers students the possibility of applying and reinforcing the acquisition of learning, of concepts, promoting a creative spirit, the development of learning autonomy and collaborative learning [1], [17]–[23].

Teachers also make a very positive assessment of Arduino as a facilitating element of the teaching-learning processes [25], [26]. It is true that Arduino requires the execution of project-based learning [28], collaborative learning [19] or task-based learning [17]. Students need to be able to interact and be able to work with discovery learning in order to face problem solving [4].

This research has analyzed the term ''Arduino'' in the publications indexed in the Web of Science (WoS) database, using the scientific mapping technique. An attempt has been made to analyze the trajectory and significance of this concept in the reported expert literature from the main WoS collection. The assumed methodological option is bibliometrics [35], [36]. A word analysis was carried out [37], supported by bibliometric indicators such as the h-index and the number of citations, as well as others (g, hg and q2) [38]. The specific document analysis tools have been Analyze Results and Creation Citation Report (WoS own) and SciMAT.

The results of this research show that the scientific production on Arduino in the field of education begins in 2010 until today. Communications in congresses to present the results of their research (n = 242; 70.76%) are the most widely used means of dissemination. The National Distance Education University (n = 10; 2.92%) and the Lucian Blaga University of Sibiu (n = 9; 2.63%) stand out especially. The authors with the most scientific production in this field of study are Bogdan, M. (n = 9; 2.63%) and Castro, M. (n = 7; 2.04%). It is significant that the collection of studies on this subject is carried out, above all, by EDULEARN Proceedings and INTED Proceedings.

The fact that it is observed that the evolution of keywords takes place in the three established periods. These show the data related to the keywords that appear in each established time interval. In this case, there is a very low coincidence rate between periods. That is, there are major keyword changes used by scientists between established periods. This is an indicator of change and a solid research base is lacking.

On the other hand, academic performance presents the most relevant topics in the time intervals established in the research. The interval diagrams show information on the level of relevance of the topics that the highest bibliometric indicators present in each of the periods analyzed. By way of synthesis, recapitulating, in the first period the driving theme is ''physics experiments''. In the second period, the driving themes are ''computational thinking'' and ''computer based learning''. In the last period, the motor themes are ''potentiometry'', ''laboratory compunting / interfacing'' and ''Arduino'', while the theme ''education'', which is the one with the highest h index, is situated as a highly developed-isolated theme. However, attention should be paid to the topics ''computer science education'' and ''learning by doing''.

Thus, the thematic evolution indicates the strength with which the different themes of each of the established periods are related. Note that the indicator used to offer the information is the Jaccard index. It is significant that the thematic evolution develops when the theme of a certain period shares themes or keywords with the previous or subsequent periods. Thus, if the two types of relationships that can be established are analyzed, it is by keywords, represented by dashed lines; or by themes, represented by continuous lines.

The line of research in all established periods is based on the ''Arduino'' theme, although it is a field of study still unstable at a scientific level. This is because the field of study is not established, due to the lack of connections between the themes of the various time periods. Therefore, it can be determined that the scientific community does not have a strong and consistent line of research in this field of study, and is currently in training.

The results obtained promote a series of implications, both in theory and in practice. On a theoretical level, this study provides scientific literature with a concrete and specific analysis of Arduino's issues in the educational field, offering the most relevant lines of research in this field of study. In addition, it offers information about the lines of research that can be developed in this field in the future.

On a practical level, this study offers information to teachers about new resources in the educational field. It shows the most relevant research at a methodological level, and the implications it has in practice. In addition, this type of resource entails teacher training in digital competence, given that Arduino requires a minimum of computer literacy. Therefore, this study should serve as a guide on how to improve and update teacher training, what teaching methods are most suitable and what potential the use of Arduino offers us in the educational field.

It can be concluded that the field of study on Arduino in the educational field is relatively recent, so that today, the bases of scientific research are still being established. Still, the most relevant aspects in this field of study are experiments in physics, computational thinking, and computer-based learning.

The prospective of this research consists of offering researchers and other members of the educational community a sample of one of the most relevant applications of IoT. The state of the art constituting the starting point to develop key aspects based on how computational learning can help students to improve their learning and enhance their motivation, promoting at the same time the collaborative learning.

No doubt, there are some limitations in this research. First of all, we must be able to create a change in the basis of Didactics to implement Arduino. Teachers need to be updated to be able to offer students the best these technologies can provide us. The results show other comparisons can be made in the thematic evolution, relying our attention on previous periods. As future lines of research, it is proposed to develop practical applications and pedagogical actions in the educational field focused on education and IoT.

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