ALGORITHMIC THINKING IN EARLY CHILDHOOD EDUCATION: OPPORTUNITIES AND SUPPORTS IN THE PORTUGUESE CONTEXT

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Abstract

ALGO-LITTLE is an EU-funded project, with partners from Portugal, Italy, Turkey and Slovenia, searching for ways to integrate Algorithmic Thinking skills into preschool education for the purpose of preparing future code literates starting from an early age. Algorithmic Thinking stems from the concept of an algorithm, which refers to solving a problem by developing a set of steps taken in a sequence to achieve the desired outcome. The concept can be traced to the work of Papert and is connected to the seminal article by Wing that introduced Computational Thinking. Early Childhood Education algorithmic skills include abilities to learn and work according to the rules or models since children are capable of understanding, using, applying and developing simple algorithms. The paper analyses initiatives, studies, and projects that are connected to Algorithmic Thinking in Early Childhood Education in Portugal. In terms of curricular documents, it was found that code has been relevant for Portuguese Early Childhood Education (at least) since 1997. In 2016, the Portuguese Curricular Guidelines for Preschool Education (PCGPSE) were reviewed and this second version amplifies the mentions to technology. In terms of studies and projects, the “Kids Media Lab Project II” stood out as the only systematic initiative for promoting Computational Thinking in Preschool Education.

Keywords: Early childhood education, algorithmic thinking, curricular guidelines, computational thinking, Portugal.

1 INTRODUCTION

ALGO-LITTLE, or Algorithmic Thinking Skills through Play-Based Learning for Future’s Code Literates, is an EU-funded project, with partners from Portugal, Italy, Turkey and Slovenia. The purpose is to develop ways to integrate Algorithmic Thinking skills into preschool education for preparing future code literates from an early age. Algorithmic Thinking stems from the concept of an algorithm, which refers to solving a problem by developing a set of steps taken in a sequence to achieve the desired outcome [1]. The concept is associated with computational thinking which can be traced to the work of Papert [2]. The recent attention it has received is connected to the seminal article by Wing, in 2006, that highlighted the importance of computational thinking or “thinking like a computer scientist” [3]. The rationale is that computer science has produced not just technology that has transformed our lives but also an intellectual framework for thinking, named computational thinking [4]. Several other authors and entities have, since then, concluded about the need of having children and students begin to work with algorithmic problem solving and computational methods and tools in the educational system, from as early as Early Childhood Education [5]–[7]. In this call for including computational thinking and related concepts (like algorithmic thinking and coding) in schools, educational stakeholders have promoted them as skills that are as fundamental for all as numeracy and literacy [4], [6], [7]. This equates to developing in all citizens skills related to computational thinking in the same way all citizens are expected to know how to read and write. Computational thinking has been internationally acknowledged as a 21st century skill, needed to thrive in today’s world.

In several European countries, and internationally, there have been initiatives addressing computational thinking and coding: programming has been introduced into the curriculum, projects have been developed involving schools, continuing teacher education programmes have been implemented, international competitions occur. This high level of interest and developments has not been without issues and challenges [7]. The definition and framework for computational thinking, for example, is still in flux. This creates problems at the level of content knowledge for teachers, for example. Then, although most of the authors promote computational thinking as a cross-curricular or transversal skill, its

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connection to the several areas of the curriculum is still disputed. The purposes of introducing such skills in a complex world is also under discussion, as more critical components are suggested to accompany the problem-solving emphasis of the initial proposals. Finally, pedagogically, there is the need to develop methods and approaches that are aligned with the concepts themselves and with the aims for introducing them in the curriculum, as well as developing and systematising pedagogical content knowledge pertaining to computational thinking. Of particular relevance, and challenge, is the pedagogy for early years where adult-led activities do not exhaust teaching [8], [9].

ALGO-LITTLE based its approach to algorithmic thinking on a play-based pedagogy, coherent with international literature on the importance of play for early years learning and development [10]–[13]. The articulation between algorithmic thinking and play is still being studied, in a framework where play itself is being discussed as pedagogy [9]. The enormous, rich contribution of play for learning and development is under pressure from more oriented and adult-led approaches that look into achieving specific purposes from Early Childhood Education recognising its potential to make a difference in children's lives [14].

The paper analyses initiatives, studies, and projects connected to Algorithmic Thinking in Early Childhood Education in Portugal. A review of literature was developed, starting with curricular documents for Preschool Education (3 to 6 year-old) and other documents from the ICT Educational Policy in the country. The second step was a search about Algorithmic Thinking in Early Childhood Education in databases for studies and projects in Portugal. The analyses aim was to identify supports and opportunities for the development of the ALGO-LITTLE approach in Early Childhood Teacher Education in Portugal.

2 COMPUTATIONAL THINKING AND ALGORITHMIC THINKING

As with many important concepts, there is a lack of consensus on the definition of computational thinking. Wing's [3] idea of thinking like a computer scientist has been deepened, extended and connected with other ideas. On defining the limits and boundaries, it is useful to consider that several authors clearly distinguish it from digital literacy/competence, pointing out the distinctive characteristic of its focus on problem-solving processes and methods, and on creating computable solutions [7].

In its inception, in Seymour Papert's book *Mindstorms: Children, Computers, and Powerful Ideas* [2], computational thinking is referred to as the relationship between programming and thinking skills, as students' constructions with LOGO could facilitate their procedural thinking across multiple disciplines. The most recent definitions involve more concepts from computer science [15], but mostly maintain the idea of a way of thinking. It was reintroduced by Wing as "solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science" [3]. Expanding on this early definition, the author presented "Computational thinking is 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" [4]. From this definition, Wing highlights that people can learn computational thinking without a machine and that computational thinking is not just about problem-solving, but also about problem formulation, or creating a linguistic representation for the purpose of communicating a solution to others, people or machines [4].

Wing's version of computational thinking has reignited interest in the concept but it is not consensual or sufficient for the introduction of computational thinking in educational systems. Several versions and restructuring of the concept have emerged since. Based on the core concepts of computational thinking provided by computer scientists such as Wing, several definitions have been presented and refined [16]. From a review of studies, Zhang and Nouri [15] reinforced the list of most common skills connected to computational thinking: abstraction, algorithms, data, problem decomposition, parallelism, debugging and testing and control structure. Previously, another review had highlighted a different set of core concepts and skills including abstraction, algorithmic thinking, automation, decomposition, debugging, and generalization [7]. Some definitions have a broader scope considering computational thinking as comprehending the process of recognising aspects of computation in the world that surrounds us, and applying tools and techniques from Computer Science to understand and reason about both natural and artificial systems and processes [17]. Computational thinking can, therefore, be understood as an umbrella term that includes a subset of related skills that are involved in computational tasks and activities [18].

Together with the difficulty in establishing the concept of computational thinking, some contexts (literature, policy documents, contexts of use, national languages) opt for a variety of terms (for example, coding, programming, algorithmic thinking) to refer to computational thinking [7]. The interchangeable use of designations is one reason why algorithmic thinking is sometimes used to refer to computational thinking. The close articulation between the concepts also suggests such use of the terms. Other definitions consider algorithmic thinking as one of the skills of computational thinking [5], [18]. In this paper, algorithmic thinking is considerered from that perspective, as integrating computational thinking skills. The relationship between the concepts is much more complex [19], [20]. For example, algorithmic thinking has strong connections and meaning in Mathematics, outside a computational thinking framework [20]. In discussing the conceptualisation of algorithmic thinking in Early Childhood Education, it is useful to understand it as connected to computational thinking.

Algorithmic thinking is a key ability in Computer Science, but also in daily life. Therefore, it can be developed independently from learning programming and from any technology. Several definitions equate algorithmic thinking to a way of thinking oriented to solving problems and taking actions or steps to solve them [18]–[20]. Algorithmic thinking doesn't look for a specific answer, instead it entails building a replicable process, developing a set of steps taken in a sequence to achieve the desired outcome [1]; in other words, an algorithm. An algorithm is an abstraction of a process, a finite set of rules or/and instructions, necessary for achieving a desired goal; it takes inputs, guides the sequence of steps, and produces an output. Examples from daily life include various instructions like recipes, the route from home to school, the operation of the washing machine, etc. [20].

An interesting systematisation of skills involved in algorithmic thinking include a) analysing given problems, b) specifying a problem precisely, c) finding the basic actions that are adequate to the given problem, d) constructing a correct algorithm to a given problem using the basic actions, e) thinking about all possible special and normal cases of a problem, and f) improving the efficiency of an algorithm [19]. Creativity is seen as important for algorithmic thinking [19], [21], needed to find solutions for the problems and to improve existing algorithms. Developing an algorithm also requires expressing it in some language [22].

Considered a cornerstone in Computer Science, algorithmic thinking's importance is argued in many disciplines, and its gradual introduction already in early years has been gaining momentum [7], [22].

3 ALGORITHMIC THINKING IN EARLY CHILDHOOD EDUCATION

Teaching or supporting the development of algorithmic thinking is challenging and the subject of extensive discussions [1], [19], [21] and it is also important to find suitable support for students' self-learning. [23]. It has been introduced in several curricula for non-higher education. Most countries integrate computational and/or algorithmic thinking in secondary school and there is a growing trend towards primary school integration. For example, in 2016, Finland introduced algorithmic thinking and programming as a mandatory, cross-curricular activity from the first year of school (grade 1); and Hungary's National Core Curriculum includes algorithmic thinking as a competence for primary and secondary education inside Information Technology [7]. It is less common to consider algorithmic thinking in Early Childhood Education.

Research in early childhood education settings has shown the benefits of introducing technology and engineering for improving different learning areas for children [24], [25]. Bers [26] reminds us that there are no comprehensive longitudinal studies on the impact of teaching computer science in the early years, but that it is expected that results will be similarly positive. Existing experiences indicate that early childhood education algorithmic skills include abilities to learn and work according to the rules or models since children are able to organise themselves to perform a small set of tasks or to follow a sequence of tasks in an unspecified or moderately defined order in an efficient, non-redundant way [22]. Therefore, children are capable of understanding, using, applying, and developing simple algorithms. Children are also capable of analysing and correcting the sequence of actions to reach results, transferring known methods of actions to new situations, and describing their activities to others in a clear way [6], [22], [27].

By looking at an algorithm as a series of steps ordered in a specific sequence to achieve a goal, several sequencing tasks become visible in early childhood education: retelling a story in a logical way, ordering objects in a logical pattern, organising tasks of daily routines, such as washing their hands, or arranging their school bag or lunch box to go to school, which are tasks that can involve children in algorithmic thinking [6]. Through these, children begin to understand that they can achieve the same results with different algorithms, but they get better results with some of them.

An early study reported how children were able to discover simple algorithms without resorting to reading and writing, being able to design algorithms, express, and understand them [22]. It also showed the importance of finding problems that correspond to children's limited experience base, suggest solutions that are small enough to be kept in memory and that allow expressing themselves in other forms than writing [22]. Another important contribution from several studies is the relevance of oral communication for children's algorithmic thinking. It was observed that in the cognitive construction of an algorithm by the children, initially they verbalise the abstract conception of the algorithm, which some authors connect to Vygotsky's concept of language as "inner speech" [28]. Visual representations of steps and tasks were also considered important [22], [27], [28].

It is still needed to further study the way children develop algorithmic thinking and to explicitly conceptualize pedagogical approaches for teaching computer science in the early years that invite play and discovery, socialization, and creativity [26].

4 ALGORITHMIC THINKING IN PORTUGUESE EARLY CHILDHOOD EDUCATION

4.1 Analysis of the Curricular Guidelines for ECE

Early Childhood Education in Portugal includes 0-3 year-old children, outside the educational system, and 3-6 year-old children, also called "pre-school education" which is the first stage of the Portuguese basic education system, part of a lifelong learning process. There is no curriculum for ECE, only curricular guidelines that support the pedagogy. Teachers have a Master's Degree, equivalent to all teachers in the educational system.

Code has been relevant for Portuguese Early Childhood Education (at least) since 1997. In their first edition, the Portuguese Curricular Guidelines for Preschool Education [29] included computer code as one of the codes children should get acquainted with. This meant its inclusion under the domain "spoken language and introductory writing". It was stated that "code" was present and would be necessary in children's lives and could be used in arts, music, mathematic or writing (Portuguese). This approach is in line with Bers's [26] proposal that learning to programme involves learning how to use a new language (a symbolic system of representation) for communicative and expressive functions. The policies of the Portuguese educational system were positively singled out by the OECD report on Portugal that highlighted addressing the topic of ICT interconnected with other forms of communication and information learning [30].

In 2016, the Portuguese Curricular Guidelines for Pre-School Education (PCGPSE) were reviewed. The content areas in this version are Personal and Social Development, Expression and Communication (which includes Physical Education, Artistic Education, Mathematics and Oral and Written Language) and Knowledge of the World [31]. In this second version, there are more mentions to technology, particularly in the Knowledge of the World area under "Technological World and Use of Technologies". The document assumes children need to learn about, use and gain a critical understanding of the several technological resources that are now part of the life of all children, both for leisure (technological toys, computers, tablets, smartphones, television, etc.), as well as in their daily lives (electric mixer, heater, hairdryer, bar codes, flashlights, etc.). Besides playing with technology, it's suggested that access to a computer in the school, or elsewhere in the community, is important as a means of collecting information, communicating, organising, processing data, etc. There is no mention of code or coding in this new version that assumes a more holistic approach to technology as part of the daily and future life of children.

There are, however, several opportunities to connect the learning that is valued in the PCGPSE with algorithmic thinking. For example, in Oral and Written Language, the simplest activities, such as discovering words that start or end with the same sound or letter; identifying the number of syllables in a word by clapping hands, stomping, tapping the desk or speaking like a robot; games suppressing or replacing words in a sentence or following recipes to bake cakes, among so many other activities designed to explore and develop emergent literacy skills, imply algorithmic thinking, as there is data analysis, decomposition, recognition of pattern solution components and decision taking. The same holds true for Mathematics, since there is a strong emphasis on problem solving as one of the transversal skills of learning mathematics. In terms of Personal and Social Development, the attitudes of persistence and curiosity are very aligned with algorithmic thinking. Finally, the Knowledge of the World area aims "to lay the foundations for structuring scientific thinking" [31] as well as building an attitude of research that must be centred on the ability to observe and on the willingness to experiment with the hypotheses drawn. In a very close formulation to algorithmic thinking, it's expected that children "Ask about reality, define the problem, decide what they want to know and look for a solution" [31]. One study looked into curricular areas that were involved in children's activities with computational thinking, both unplugged and with robots [32], and registered concepts from Personal and Social development, Oral and Written Language and Knowledge of the World.

In terms of pedagogical approach, besides the ideas from Bers about play and discovery, socialization, and creativity [26], Resnick suggests creative educational contexts that focus on projects, passion, peers and play [33]. The PCGPSE [31] has play as one of its strong foundations, presenting a definition of play as a spontaneous activity of the child that corresponds to an intrinsic interest. While playing, the child will display pleasure, freedom of action, imagination and exploration. Play is promoted as a way of learning that supports the development of transcurricular competences. The PCGPSE also suggests how the teacher and other adults can organise for, support and engage with children's play. There are some studies that connect play with technology [34]–[38], but the connection to algorithmic and computational thinking is weak.

4.2 Projects and initiatives for ECE

There are several studies about technology in pedagogical practices in Early Childhood Education in Portugal (for example, [39]–[47]). But few experiences and studies particularly focused on algorithmic or computational thinking. Three initiatives are worth mentioning.

EduScratch is an initiative aimed at promoting the educational use of a programming language – Scratch – by supporting, training and sharing good practices among the Portuguese educational community. It has been successfully implemented in grades K-12, with a naturally increasing level of complexity. The initiative aims to contribute to the creation and development of a teachers' community of practice on the educational use of the intuitive programming tool. The studies suggest Scratch promotes the development of computational thinking and has proven to have huge potential in developing different types of skills (digital and subject-related) in students [48]. In Portugal, the initiative has been implemented through a partnership between the Directorate-General for Education of the Portuguese Ministry of Education and Science and its ICT Competence Centres. From an initial development based in the Setúbal ICT Competence Centre, in the Polytechnic of Setubal, there are other centres across Portugal (Minho, Coimbra, Santarém and Évora). *EduScratch* in the School of Education of the Polytechnic Institute of Setúbal presents proposals to work with *ScratchJr* with preschool children, and indicates references to other school levels. *EduScratch* held training workshops with ECE teachers, whose main objective was to promote the exploration, evaluation, construction and sharing of online educational resources for use in the school context. Associated with this project, there is also a national programming contest, *A Criar com Scratch!* (Creating with Scratch!), since 2016, that includes a strand for preschool (3 to 6 year-old), as well as Basic Education (6 to 12 year-old) (http://projectos.ese.ips.pt/acriarcomscratch). However, the impact at practice level has not yet been clearly studied. Project leaders have reflected on the impact of the initiative through levels of participation in national conferences and in EduScratch Day where students presented their projects and also from the growing number of student projects shared via the EduScratch online portal [48].

Part of the Portuguese strategy for implementing coding in Basic Education has been the involvement of the Municipalities which have some responsibilities over schools for Preschool and Primary Education. The project Smart City Lab for Kids grew from a partnership between the School of Education of Viseu and the Municipality of Viseu. The main goals were focused on working computational thinking and creative computing with primary school children from the city, anchored in the following guidelines: working as project-based and curriculum-based, exploring the potential of computational thinking to develop integrated and contextualised learning; collaborative work; creativity and diversity. Three hundred and forty-six students and twenty teachers used programming and robots to explore and present ideas to turn their city into a smart city. Students presented a diversity of proposals such as games to explore the rehabilitation of the river, programming robots to care for community gardens or to model an intelligent building [49]. There are other initiatives that involve local authorities and local schools. One example is the project *Robótica e Programação na Educação Pré-Escolar* (Robotics and Programming in Preschool Education), promoted by the Municipality of Santa Maria da Feira, a "project that aims to encourage school children to enjoy programming and to learn programming in a fun and playful way" (https://cm-feira.pt/robótica-e-programação-na-educação-pré-escolar. The project *Pensamento Computacional na Educação Pré-Escolar* (Computer Thinking in Preschool Education) was another initiative which was presented by the Municipalities of Leiria and Porto de Mós with the Competence Centre *Entre Mar e Serra*. This project included a training programme credited to teachers and involved 53 preschool education schools, in 2018, with the objective of developing computational thinking through the development of the ability to plan and execute activities and mental skills to solve problems. In addition, robot programming learning kits were offered to schools.

Finally, the "KML II - Programming technologies and learning laboratory for pre-school and elementary school in Portugal" should be highlighted as it is focused on the introduction of computational thinking, coding and robotics activities in both preschool and primary school with a cross-curricular approach [50], [51]. The project assumes technology teaching in initial years within a "globalizing dimension of education", in which technology constitutes an instrumental component in the support of learning goals across the curriculum, in line with Portuguese legislation. The connection is made between the aims of the educational system of universal access and inclusion for all students and equal opportunities with the way programming and robotics may offer hope for all children to achieve their full potential and effectively participate in a fully inclusive society. The authors consider that the several initiatives from the government together with the ICT Competence Centres have brought coding to school, but not primarily to classroom work since coding and robotics were mainly offered on a complementary basis [50].

In recent years, Portuguese educational policies have recognised the importance of developing digital skills from an early age. Information and Communication Technology (ICT) are assumed to be a cross-cutting area for the Early Years, both for Early Childhood Education, where there are several references in the different content areas, and for the 1st cycle of the Portuguese primary education system, whose Curriculum Guidelines explicitly state the crosscurricular nature of the approach. This allows the development of algorithmic and computational thinking in a multidisciplinary and curricula-based approach. Governmental initiatives to introduce programming and robotics in the Portuguese primary schools are close to the idea of development of computational thinking through project-based learning in a multidisciplinary approach. One important dimension is the connection between the activities and the curriculum. The Ministry of Education launched the project "Introduction to Programming in the 1st Cycle of Basic Education" (IP1CEB) aimed at developing Computational Thinking, digital literacy and transversal skills [52]. This pilot initiative ran from 2015/16 until 16/17, including primary school students from 3rd and 4th grades (9 to 10 years old). The initiative "Probótica - Programing and Robotics in Basic Education" followed in 2017/18, including primary education (up until 9th grade) [53]. However, in Portugal, work regarding the development of algorithmic or computational thinking in preschool education is less expressive and there is still the need to support teachers and researchers in developing the area.

5 CONCLUSIONS

For algorithmic and computational thinking to be integrated comprehensively across all levels of education, it is necessary to define a clear vision, conceive robust pedagogical approaches and involve several stakeholders. The international experiences are very relevant and positive. Many countries in Europe integrate coding into the curriculum at the national, regional, or local level, and countries such as Australia, Singapore, and Argentina have also established clear policies and frameworks for introducing technology and computer programming in K-12 education [6]. Many challenges are becoming more salient: the multi-disciplinary and inter-disciplinary contexts that are valued, how to organise teacher education, the delimitation of content knowledge and the construction of pedagogical content knowledge. For students to be engaged in opportunities to create projects, based on their passions, in collaboration with peers, in a playful spirit, a strong investment in pedagogy is necessary. Other wise, narrow ways of introducing computational thinking might become prevalent [54].

For early childhood education, the pedagogical challenges are enormous as experiences with adults or older children are not suitable. To have children encounter powerful ideas from computer science through low-tech games, singing, and dancing, but also through play, requires complex problem-solving skills. In Portugal, there are opportunities like the alignment between learning topics in the curriculum and algorithmic thinking, as well as the emphasis on play and active learning. There is also support coming from the priority that policies have placed on computational thinking and the widespread existence of projects and initiatives. Hopefully, the national and international research communities will continue the endeavour of researching together with teachers, parents and children.

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