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Coding as Literacy in Preschool: A Case Study

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Abstract: Coding is increasingly recognized as a new literacy that should be encouraged at a young age. This understanding has recontextualized computer science as a compulsory school subject and has informed several developmentally appropriate approaches to computation, including for preschool children. This study focuses on the introduction of three approaches to computation in preschool (3–6 years), specifically computational thinking, programming, and robotics, from a cross-curricular perspective. This paper presents preliminary findings from one of the case studies currently being developed as part of project KML II—Laboratory of Technologies and Learning of Programming and Robotics for Preschool and Elementary School. The purpose of the KML II project is to characterize how approaches to computation can be integrated into preschool and elementary education, across different knowledge domains. The conclusions point to "expression and communication" as an initial framework for computational approaches in preschool, but also to multidisciplinary and more creative methodological activities that offer greater scope for the development of digital and computational competences, as well as for personal and social development.

Keywords: coding as literacy; preschool; computational thinking; robotics

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1. Introduction

Coding refers to the use of languages that enable computing. As such, it is increasingly recognized as a new literacy [1,2]. This understanding has recontextualized computer science, with a focus on computational thinking, as a compulsory school subject and sustained several developmentally appropriate approaches to computation, including for preschoolers [2]. Over the past decade, a plethora of research and policy initiatives have focused not only on the conceptual and technical aspects of introducing coding to young children, but also on the cognitive and social facets that underlie this trend. This is true of work around the concepts of computational thinking [3,4] and computational participation [5] or computational making [6]. Meanwhile, new pedagogical approaches have prepared the ground for the introduction of coding in early education [2,7,8]. Similar to natural languages, children should be introduced to and familiarized with these new, artificial languages from an early age [8], thus fostering their perceptual, expressive, and creative skills and laying a strong foundation for the development of critical and functional competencies.

The project "KML II, within which this research takes place, emerged from a previous research project dedicated to preschool (Kids Media Lab, https://www.nonio.uminho.pt/kidsmedialab/ (accessed on 22 July 2020)). This research identified young children's involvement in computational activities as well as learning opportunities in a variety of curricular areas [7]. Although public interest in the introduction of computation in primary education and policy recommendations for ICT in primary education have increased since [9], more specific guidelines for the development of pedagogical practices that integrate computation into the curriculum are still lacking, especially for preschool. It is clear that, similar to ICT [9], a cross-curricular approach applies to both preschool and primary education. Nonetheless, the initiatives developed to date have brought computation into schools, but not primarily into classroom work. Rather, coding and robotics have been mainly complementary and always to the exclusion of preschool, despite research on their outcomes [7]. Furthermore, a consultation of the gray literature [10–12] shows that coding initiatives have been implemented in very different ways, most notably considering the different resources used.

This paper presents preliminary findings from one of two case studies [13] that are currently being developed, focusing on the preschool context sector. Its aim is to answer the following main question: How do preschool educators integrate approaches to computation into the curriculum? Specifically, it aims to identify curriculum areas, learning objectives, methods used, factors that promote children's participation and well-being [14], and necessary teaching skills. The findings will help to design a framework for undergraduate and in-service teacher training, and a competency profile for educators. In this context, the work outlined here will help to establish technology-integrated guidelines for pedagogical practice in preschool and primary education and evaluate existing practices.

The study of coding as literacy in preschool explores the development of personal and social skills that enable children to express, share, and create using computer science's languages, ways of thinking, and creating [2,15–17]. This study specifically examined how this new literacy can be integrated into the preschool curriculum. Its goal is to understand how to bring it into preschool practice. It considered three developmentally appropriate [18] approaches to computation: computational thinking, programming, and robotics. Within computational thinking, it distinguished between learning activities that incorporate non-programmable digital technologies (e.g., an interactive whiteboard, a digital camera, and a computer for non-programmable activities) and those that do not.

The work developed in this project embraces the idea of 'coding as literacy' in a broad sense, that is, not just as a technical skill or a set of technical skills, but as a social and cultural issue that cuts across different areas of knowledge. Despite different conceptual approaches, it can be said that the central underlying idea is that learning to think [16], create and collaborate [17] like a computer scientist, especially using its languages, is useful for everyone. Since computer science permeates and is permeated by social, cultural, and educational issues [19], its studies and developments need perspectives from these different areas. Going back to Papert [20], this is indeed a widely known idea that was apparently waiting for a broader implementation and access to technology to gain traction. Echoing his work, Bers describes this as an "encounter [with] powerful ideas from computer science" (p. 10, [2]). How educational research and practice translate this into adequate practices and outcomes is the challenge we face today.

Moreover, and without ignoring that this is a research direction that is still in its infancy, in Portugalthis work is expected to contribute through a practice-based approach. It is true that other countries have already developed relevant knowledge and experience [21]. Nevertheless, as Cohen and Ball put it, "the vision of a better education is complex" (p. 3, [22]), given the "challenges, uncertainties and complexity" (p. 30) of professional practice and practitioners. In today's rapidly changing world, the argument for teacher professional development to address this complexity could be seen as more important than ever. From this lifelong learning perspective, a shift from more traditional approaches to teacher education to practice-based professional learning [23] and the development of communities of practice in teacher education, including online communities, [24] is being considered.

2. Theoretical Framework

"Coding as literacy" sums up the idea that in digital societies learning to code is similar and as necessary and as learning to read and write [8,25]. Awareness of digital literacy as a lifelong learning skill and inclusion factor is an established need in digital societies [26]. Building on this momentum, research grounded on computer science has emerged as a major concern for compulsory education in a digital world [27]. In short, it calls for as a fundamental skill the ability to understand the "artificial languages" [2] used to build digital structures and transformations. In particular, recent research investigates how the underlying constructs overlap between written language and programming [28,29]. Jacob and colleagues [30] further discuss how computational thinking, defined as the ability to think using algorithms, multiple levels of abstraction, decomposition, and representation, is a new form of literacy, but also facilitates and is supported by the development of written language.

As formulated by Bers [2], this literacy framework is understood in different ways. Programming languages are defined "as symbolic systems for expression" (p. 72) and viewed as "tools for computational thinking" (p. 97). A focus on computational thinking, the author argues, leaves aside "the tools of the mind associated with language and expression" (p. 93). Taken by itself, or as a given set of skills and practices with no particular meaning, computational thinking is unable to connect to language and expression, that is, to constitute a literacy. Detached from social interaction, learning to think and solve problems like a computer scientist does not mean acquiring computational fluency. Expressing oneself and communicating requires the "tools [or programming languages] that enable the creation of an external artifact" (p. 94). "As literacy, coding involves doing, creating, and making, not just thinking. It involves the production of an "external, shareable artifact" (p. 63), the author writes. One might say that "powerful ideas from computer science" [20] are not so powerful when learned in a vacuum, without that connection to expression and communication or social interaction, without "[making] abstract ideas concrete" (p. 33).

Remarkably, this perspective is based on Papert's constructionism framework [20], as well as sociocultural [31,32] and critical [33] pedagogical perspectives (as cited in [2]). Engagement in collaborative and playful processes to create meaningful projects is the underlying pedagogy. To answer the question of what is the purpose of education, these pedagogical orientations would refer to the development of socially capable and engaged individuals rather than knowledgeable and skilled workers. Bers coined the phrase "coding as playground" to embrace this idea of children "learning by doing" what is meaningful to them, namely play. Recalling Papert's understanding that constructionism "boils down to the fact that everything be understood by being constructed," Bers presents four basic principles of constructionism: "1. Learning by designing personally meaningful projects in the community; 2. Using concrete objects to build and explore the world; 3. Identifying powerful ideas from the domain of study; 4. Engaging in self-reflection as part of the learning process." (p. 21, [2]).

Bers further developed the theory of positive technological development (PTD) [2] and provided tools to assess children's engagement with technology from this perspective. Aiming to extend the six-C model of positive youth development (PYD) [34] to technological experiences, PTD postulates a set of six positive behaviors that educational programs should target with new technologies: Content Creation, Creativity, Communication, Collaboration, Community Building, and Behavioral Choices. These behaviors are in turn linked to PYD developmental values, such as caring, connection, competence, or character. This theory emphasizes that, especially at younger ages, more important than achieving the thought processes in and of themselves is to ensure that technologies allow children to engage in these positive behaviors.

PTD theory parallels Laever's [35] perspective on involvement and well-being as quality indicators of learning. "Involvement is not the state of arousal easily obtained by the entertainer. The crucial point is that the satisfaction stems from one source: the exploratory drive, the need to get a better grip on reality, the intrinsic interest in how things and people are, the urge to experience and figure out. Only when we succeed in activating the exploratory drive do we get the intrinsic type of involvement and not just involvement of an emotional or functional kind" (p. 15), the author writes. In keeping with a constructivist tradition, Laevers shifts the focus away from educational products to processes. Regardless of age or other developmental indicators, learning is assumed to occur when children are highly involved. Involvement is recognized when the child is focused, persistent, motivated, and open to new stimuli while showing signs of well-being.

Laevers and colleagues' evaluation model has been specifically adapted to the Portuguese context, under the name 'Child Observation System' (SAC—free translation, SAC is the Portuguese acronym for 'Sistema de Acompanhamento de Crianças) [14]. SAC is described as "a more authentic, reliable and respectful approach of children's development and learning" that recognizes that "children's skills depend on the situation or context", which requires "continuous assessment and monitoring during the kindergarten experience" (p. 596, [36]). As further described by Portugal [36], a high level of involvement is closely related to Vygotsky's concept of the "zone of proximal development". This considers the "determination of the [child's] real and potential level of development, as well as the quality of the interactions that will allow the potential level to become real" (p. 597, [36]). The educator's role is to observe and acknowledge the acquired skills and encourage the child to use them to move on to higher levels of complexity. Rather than assuming a priori defined levels of development or competence and imposing tasks on the child that are too simple or too complex, the educator "builds scaffolds" (idem).

Also central to this understanding is the concept of deep-level learning, which "expresses the concern for a critical approach to educational evaluation" and "[challenges] superficial learning, learning that does not affect the basic competencies of the child and which has little transfer to real life situations" (p. 21, [35]). The focus is shifted from a "notional level" that takes into account knowledge, ideas, concepts, and theories to a "deeper level of intuition" that is "more interest[ed] in the competence that is evidenced in the way a person experiences, interprets (implicitly), and responds to reality" (p. 83, [37]). The developmental domains considered by Laevers are: emotional health, curiosity and exploratory drive, expression and communicative skills, imagination and creativity, competence of self-organization, understanding the world of objects and people, and values.

Two broader trends help us further distinguish the various concepts at play here, specifically coding, computational thinking, computational fluency, and computational participation. In a literature review conducted by the Joint Research Centre (JRC), the European Commission's science and knowledge service, Bocconi and colleagues [38] identify two main trends in terms of the rationale for including computation in compulsory education: "1. developing CT skills in children and young people to enable them to think in a different way, express themselves through a variety of media, solve real-world problems and analyze everyday issues from a different perspective; 2. fostering CT to boost economic growth, fill ICT vacancies and prepare for future employment" (p. 25).

While the broader concepts reflect the social aspects of developing children's participation and critical thinking skills, the technical concepts relate more to developmentally appropriate technical knowledge and skills. In a recent analysis, Resnick and Rusk [15] argue that programming, particularly Scratch, has made inroads into education, but not necessarily to develop appropriate skills for a digital world. The authors suggest that the development of computational concepts and skills should not override the development of "computational fluency" and emphasize the importance of learning to "use computational technologies to communicate ideas effectively and creatively" (p. 122).

Previously, Kafay and Burke [39] referred to a social turn in k-12 computer science education, suggesting computational thinking should be reframed as computational participation. Building on Wing's seminal work, in particular her conceptualization of computational thinking as a "universally applicable attitude and skill set" for everyone [40], this shift focused on social, creative, and shareable aspects, rather than the development of individual skills. In contrast to a focus on personal dimensions (building knowledge and developing skills) [17], perspectives on social and cultural aspects emphasize the role of computing in social inclusion, participation, and citizenship.

From this point of view, bringing computing into the education of young children is necessarily an effort that cuts across disciplines. Separating computing from other school subjects neglects its social and cultural branches and falls short of the goal of encouraging active and critical engagement with technology. As Resnick and Rusk [15] point out, promoting participation and inclusion rather than passive consumption of technology requires learning experiences that explore bridges rather than create artificial boundaries between disciplines. The authors also recall the "four P's of creative learning" (projects, passion, peers, play), as a framework for computational fluency [41]. Based on Papert's constructionism framework [20], engaging in collaborative and playful processes to create meaningful projects is the pedagogy behind it. Nevertheless, in this current discussion [15], the authors recognize the difficulties of formal learning in implementing creative perspectives, but also its possibilities. As mentioned earlier, this is in line with the Portuguese regulations for ICT in primary school [9] and the curriculum guidelines for preschool [42]. These assume a "globalizing dimension" of preschool and primary school learning, achieved through an articulated construction of knowledge across different domains.

A reference to regarding tangible dimensions is necessary [17]. Among the variety of learning approaches to computer science, a clear distinction can be made between plugged and unplugged practices, respectively with or without the need to learn programming or even use digital devices [43]. Unplugged approaches emerged as ways to learn "about great ideas in computer science" (p. 499, [38]) without the need for computers. Examples include real-life routines, board games, manipulative materials, treasure hunts, coloring by numbers, picture representations, and storytelling. This provided opportunities for those who did not have access to computer resources, as well as for younger or less experienced technology users.

Plugged activities, in turn, can be categorized into on–screen and off–screen activities [44]. While screen remains a tangible interface, this term currently refers more to robotics. Robots not only allow for more varied manipulation of physical objects, but also greater freedom of movement, interaction patterns, and responsiveness [45]. For younger children, these provide explorations not possible with non-computational manipulative materials as well as important developmental benefits, particularly fine motor skills, hand-eye coordination, and collaboration [3]. The use of robots for educational purposes brings us back to Papert, in particular his interest in providing children with "objects to think with" [46].

Since Logo turtles [20], there has been a surge of interest in educational robotics [47]. It has emerged as a multidisciplinary, hands-on learning approach that engages learners in both coding and non-coding aspects of computer science, such as engineering, mathematics, technology, and computational thinking [46,48]. As tangible coding interfaces, robots also support various expressions and integration with different curriculum areas [2,48].

3. Materials and Methods

Using a multiple case study approach [49], the KML II project works with 11 preschool educators and 17 primary school teachers in 8 different Portuguese districts to develop learning activities that integrate computation into the curriculum. Prior to their participation in the study, participants completed a 50 h in-service training course delivered in B-Learning. This training focused on three approaches to computation, namely: computational thinking (plugged and unplugged), coding, and robotics [13,50,51]. Computational thinking and unplugged computational thinking refer to activities that aim to have students develop and demonstrate the skills considered under this concept [16], which involve either no technologies or ICT from the user's perspective (without programming). Coding and robotics refer to activities that involve an educational programming language and/or robots. In this preschool project, these technologies are specifically: ScratchJr, two robots, one of which can be programmed with tangible blocks (https://www.clementoni.com/pt-en/67604-coko-o-meu-primeiro-robo/, accessed on 22 July 2020) and another with a built-in keyboard (https://www.clementoni.com/pt-en/67285-doc-robo-educativo-falante/, accessed on 22 July 2020) (no assembling kits were available for preschool).

Fieldwork took place during the 1st and 2nd terms of the 2019/2020 school year (October-February) and was interrupted in March 2020 due to the closure of school facilities caused by the SARS–CoV–2 pandemic. Participants experimented with both plugged and unplugged activities designed and developed by educators and teachers, depending on the educational project of each school and classroom. For this time period, data were collected through activity logs, field notes, photos, and video recordings. Descriptive data were collected primarily through an online activity log registered by educators and teachers.

An online form was provided that was divided into four sections: the introduction (introducing the form and its objectives), a description of the activity (requesting information describing the activity performed), an evaluation of the activity (requesting information about the results and evaluation), and sending files (photos, videos, and other supporting documents). The form was designed according to the learning framework underlying the national curriculum guidelines for preschool education and the corresponding lesson planning templates developed and used in the in-service training for in-service educators and elementary teachers conducted by KML II in 2019 [13].

Of the information asked in the four sections of the protocol, the following four were multiple-choice: how long the activity lasted (30, 60, 90, 120 min, other), educational level (preschool, 1st, 2nd, 3rd, or 4th grade), approach to computation, resources used (type of robot, tablet, computer, other). (Each participant was given a kit of robots and rotating access to tablets. Consistent with the training participants had previously completed, it was expected that preschool educators would work with ScratchJr. The robots were provided through sponsorship (the project is supported by the educational toy brand Clementoni, https://www.clementoni.com/en/ (accessed on 22 July 2020)) and the kits for preschoolers consisted of two units of a programmable robot based on tangible blocks (https://www.clementoni.com/pt-en/67604-coko-o-meu-primeiro-robo/ (accessed on 22 July 2020)) and two units of a robot that can be programmed using direction and action buttons (https://www.clementoni.com/pt-en/67285-doc-robo-educativo-falante/ (accessed on 22 July 2020)). The remaining fields were open-ended and concerned the adult(s) responsible for the activity, the number of children participating, other resources used, main knowledge area, curricular content, other areas/content, learning objectives, methodology, steps taken, children's reactions, positive and negative aspects, and additional information.

Alongside this protocol, social networking pages [52] and an online community were created to provide a space for participants to share and discuss their practices. A Moodle instance was provided by the learning environment set up for the training activity. This community was divided into the following areas: a news board, two generic forums (social and doubt), three thematic forums (computational thinking, coding and robotics), a resource repository and a moderator forum (exclusive for trainers, hidden for participants). However, after the first school term, it was supplemented by two instant messaging groups (WhatsApp, from WhatsApp Inc. of Mountain View, California, USA) as participants expressed the need for timely feedback in the course of preparing, developing and evaluating the activities.

Field observations were planned for the final school year of 2019–2020, but were postponed due to the interruption of school activities related to the pandemic COVID–19. The observation was postponed to 2020–2021. For each activity, researchers are expected to use the "PTD Engagement Checklist for Children" (PTD Engagement Checklist for Children is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. You can view a copy of this license at http://creativecommons.org/licenses/by-nc-nd/4.0/ (accessed on 22 July 2020)). Based on the PTD framework [53], this tool was developed for a variety of situations in which children interact with technology. It contains six sections, each devoted to a behavior described in the framework and measured using a 5–point Likert scale. It can be used to observe a group of children or an individual child interacting with technologies, multiple times during a lesson or on a single occasion. For implementation in this project, the checklist was translated into Portuguese and authorized by the author.

A database of information collected from the activity logs was created (the database was created using Microsoft Excel). As mentioned before, a concept-driven set of codes, based on the national curricular guidelines (http://www.dge.mec.pt/ocepe/ (accessed on 22 July 2020)) [42], informed the organization of the dataset into the following main categories: the approach to computation (computational thinking, unplugged computational thinking, coding and robotics), knowledge domains, curricular content, learning objectives, intervention methodology, children's responses, positive and negative aspects.

A summary table was prepared for each category and thematic analysis [54] was performed for the open categories (curricular content, learning objectives, intervention methodology, children's responses, positive and negative aspects). Inductive categorization was operationalized using word processing commentary tools (the software used was Microsoft Word Text Editor). Meaningful sections of data were selected and given a free code. A macro (ExtractCommentsToNewDoc) was run to export coded data to a new table. Subsequently, the free codes were exported to a spreadsheet and organized into topics and, in some cases, subtopics based on their relationship to each other. For each of the main categories, a table and, in some cases, a mindmap (app used: https://miro.com/app/dashboard/ (free version online, accessed on 22 July 2020)) were created.

Regarding the analysis procedures for curricular content and learning objectives, the categories related to the domain of knowledge and approach to computation were kept according to the categorization of the educators and teachers in protocols (Figure 1). Thus, while the bottom-up codes and categories may overlap with the framework for the activities as established by the educators and teachers, this analysis reflects that framework based on pedagogical practice. We offer an example: consider the "world knowledge" branch on the Learning Objectives unplugged computational thinking mind map (Figure S2). While the full mindmap itself includes a category for "expression and communication skills," our analysis shows that while most of the work was in the area of "world knowledge," "expression and communication skills" were also involved. The following figure illustrates this process:

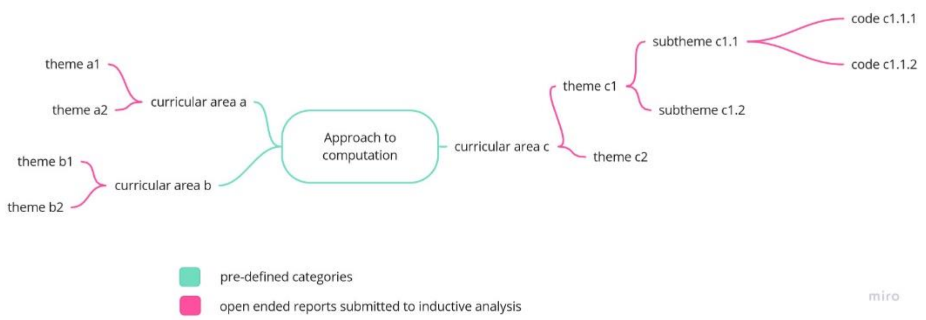

Figure 1. Data analysis procedure.

4. Results

The data presented here result from an analysis of preschool teacher logs. The preschool groups that participated in this case study (n 11) reported 47 activities distributed across the following approaches and knowledge domains (Table 1) (the knowledge domains are defined in curricular guidelines for Preschool Education (OCEPE) in Portugal [42] (http://www.dge.mec.pt/ocepe/ (accessed on 22 July 2020)). For an overview of Portuguese Pre-School Education and early childhood education and care, see https://eacea.ec.europa.eu/national-policies/eurydice/content/teaching-and-learning-programmes-children-over-3-years-8_en and https://eacea.ec.europa.eu/national-policies/eurydice/content/early-childhood-education-and-care-60_en. (accessed on 22 July 2020)):

Table 1. n learning activities per approach to computation and content area.

Approach to Computation/Content Area	Expression and Communication (EC)	World Knowledge (WK)	Personal and Social Development (PSD)	Multidisciplinary (M)	Total
Computational thinking (CT)	0	1	0	2	3
Unplugged computational thinking (UCT)	12	3	0	3	18
Coding (C)	1	1	0	4	6
Robotics (R)	8	2	0	5	15
Multiple approaches (MA)	0	0	0	5	5
Total	21	7	0	19	47

Multidisciplinary activities divide in the following content area combinations (Table 2):

Table 2. n multidisciplinary learning activities per content areas included.

Approach to Computation/Multidisciplinary Content Areas	EC + WK	PSD + CM	EC + PSD	PSD + EC + WK	Total
Computational thinking (CT)				2	2
Unplugged computational thinking (UCT)	1	1		1	3
Coding (C)	1			3	4
Robotics (R)	1		1	3	5
Multiple approaches (MA)			2	3	5
Total	3	1	3	12	19

Multidisciplinary approaches to computation divide in the following combinations (Table 3):

Table 3. n multidisciplinary learning activities per multiple approaches to computation.

Approach to Computation/Content Areas	EC + PSD	PSD + EC + WK	Total
UCT + R	2	0	2
CT + UCT + C	0	2	2
CT + UCT	0	1	1
Total	2	3	5

4.1. Methodologies

The following list summarizes methodological categories, ordered by computational approach (Table S1):

- Computational thinking: excursion/travel representation; storytelling; recipe;
- Unplugged computational thinking: play/challenges (floor activities, role play/ embodiment, chalkboard, construction, pixel art worksheet); concept map/diagram; drawing/representation; travel route representation; nursery rhymes/singing; recipe; role play/embodiment (child as robot); sequencing/patterns (visual, 3D art, worksheet); storytelling/visual storytelling; algorithm worksheets; free play;
- Coding: self-directed exploration; building random sequences (ScratchJr); storytelling; thematic project (Christmas card);
- Robotics: self-directed exploration; storytelling; challenges (storytelling, floor play, thematic, no theme);

- Multiple approaches: role-play/embodiment; visual storytelling; tangible pattern building (3D objects); itinerary planning/representation.

4.2. Curricular Content and Learning Objectives

As far as curriculum content is concerned, the following table presents the main categories by calculation approach and curriculum area. (Table 4 and Table S2):

Table 4. Curricular content per approach to computation and curricular area.

Approach to Computation/Content Area	Expression and Communication	World Knowledge	Multidisciplinary
Computational thinking (using ICT)		WK (local social settings) (n 1)	PSD (identity, self-esteem, motivation for learning, citizenship); EC (motor, oral, pre-writing, pre-reading, mathematical, artistic subjects); WK (technologic and natural) (n 2)
Unplugged computational thinking	EC (oral, pre-writing and reading, mathematics, drama, motor, arts, computational skills) (n 12)	Natural world and local social settings (n 3)	PSD (motivation for learning); EC (oral, mathematical, artistic subjects); WK (local settings) (n 3)
Coding	EC (oral skills—planning narrative sequence); PSD (reflect, collaborate) (n 1)	WK (technological world—ScratchJr) (n 1)	PSD (identity and self-esteem, motivation for learning, autonomy, citizenship); EC (oral skills); WK (natural, social and technological worlds) (n 4)
Robotics	EC (mathematics, arts, pre-writing, oral skills); WK (natural world) (n 8)	WK (technological world—robots) (n 2)	PSD (motivation to learn, identity and self-esteem, autonomy, citizenship, social belonging); EC (arts, oral, pre-writing, pre-reading, mathematics skills); WK (social world—local and foreign communities) (n 5)
Multiple approaches			PSD (motivation to learn); EC (arts, oral, mathematics, skills); WK (natural and technological worlds); others (other projects) (n 5)

In terms of learning objectives, the following patterns emerged from the data (Figures S1–S5, see Supplementary materials). Computation in preschool was mainly integrated with 'expression and communication' (n 21) and 'multidisciplinary' (n 19). This is directly reported by the preschool teachers (Table S2) and is visible through the thematic analysis (Figures S1–S5). In terms of learning objectives (Figures S1–S5), our analysis clearly highlights 'expression and communication' (EC) (yellow) and multidisciplinary (orange) code spots. This contrasts with the residual blocks of personal and social aspects (PS) (pink). Indeed, PS skills were reported exclusively within multidisciplinary activities and rarely stood alone in the thematic analysis. Moreover, EC is considered a major theme in most activities (n 40). "World knowledge" (WK) was the main topic of seven activities.

In the following, the individual computational approaches and knowledge domains of the conducted activities are considered in more detail. EC activities (n 21) covered a range of areas specified in the curriculum. Nevertheless, mathematics (geometry, numbers, operations, etc.) appears as the main theme in most activities (n 14), followed by language-related skills (oral communication, prewriting and reading) (n 11), artistic (n 3), motor (n 4), drama (n 1) and computation (n 1). Regarding computational approaches, unplugged activities and robotics appear hand in hand with different means of "expression and communication", while coding is exclusively associated with oral language.

The activities of WK focus on two main aspects: (i) social and natural local environments (n 4), addressed by unplugged activities; (ii) technological environments (n 3), in particular the functional and secure use of technological resources, addressed by coding and robotics activities. Robotics also included two activities that focused on aspects of the natural and social world (animals and traffic rules). Although not a major theme in many activities, WK is addressed in all computational approaches.Multidisciplinary activities present a more complex and somewhat different picture. There are two main differences: (i) a more even balance between the three different content areas; (ii) digital and computational skills are given greater visibility. At the outset, in several activities (n 9), educators deliberately state the aim of developing children's personal and social competences (e.g. cooperation, empathy, dialogue, self-esteem, participation, etc.) (Figures S1–S5). Among the 19 multidisciplinary activities, EC (n 10) and WK (14) show a greater balance. Looking at each of these areas, greater weight is given to language skills, which are intentionally addressed in 10 activities each. Mathematical and artistic expression (mostly related to visual communication) are addressed in 9 activities each. Social, natural, and technological worlds appear in five, five, and seven activities, respectively. This increase in technological world content reflects the relevance that digital and computational skills take on when working from a multidisciplinary perspective. Moreover, this theme goes hand in hand with work on EC in almost all activities. Finally, multidisciplinary activities have been developed in all the computational approaches, and exclusively in the case of multiple approaches (Figures S1–S5).

4.3. Children's Reactions

With regard to the children's reactions (Figure S6), the following two main categories emerged from the data: the children's enthusiasm and the difficulties encountered. Although mainly presented as a generic response, there was some evidence of specific sources of enthusiasm, in particular curiosity about new experiences, challenge and manipulation of technological devices; child-centered pedagogical approaches common in kindergarten, such as storytelling, role play, games, collaborative projects and art, encouraging confidence, educational mediation, sharing outcomes. Difficulties concerned managing children's anxiety to participate (especially when the ratio of resources per child was low), motivating younger children, and spatial awareness.

4.4. Positive and Negative Aspects

In terms of positive and negative aspects, our analysis took a closer look at each implemented computational approach (Figures S7–S12). Nonetheless, the following categories emerged as positive facets across the board (Figures S7–S11): children's involvement and motivation, skill development, and methodological features. Involvement was also described or associated with attractiveness, motivation, perseverance, achievement and self-esteem. Fine-grained analysis further reveals that opportunities to work towards the development of language and mathematical skills emerge across approaches. In the case of language, the focus is on oral and written expression and narrative skills. In the case of mathematics, it is mainly about spatial skills, but also numeracy, counting and geometric figures. Although not literally stated in all approaches, creativity also emerges as an overarching skill. Although not directly expressed in the learning objectives, 'personal and social' skills were also frequently mentioned. The following were present across the range of computational approaches: collaboration or mutual support and problem solving. Other frequently mentioned skills in this area include: autonomy, reflexivity, mutual respect and focus. Unexpectedly, digital skills are rarely mentioned directly.

Methodologically, approaches to computation appear to integrate seamlessly with the learning dynamics of preschools. The results presented regarding children's responses recurrently mention child-centered methodological approaches common in preschools, such as playfulness, flexibility, diversity, peer learning, drama or symbolic games (role-playing), interdisciplinarity, transversality between subjects, family involvement, choice of materials and progressive learning. In addition, computer-based approaches were generally welcomed for their innovation and immediate results/feedback.

Of the 47 activities reported, 25 were considered to present no negative aspects (unplugged computational thinking n 9, computational thinking n 1, robotics n 7, coding n 2, multiple approaches n 6) and tend to involve specific difficulties for children, such as plotting itineraries, manipulating paper folds, understanding equivalences (weight) and the impossibility of group work when there are insufficient resources. In these cases, particularly in relation to screen activities using ScratchJr, children's autonomy to engage in other activities and the help of an additional facilitator were presented as solutions. Nonetheless, time constraints remained as children required ongoing support.

A look at the remaining difficulties or negative aspects for the different types of activities (Figure S12), reveals three main challenges: classroom management, learning progress, children's participation. A common shortcoming was a low ratio of resources and/or facilitators per child, which took up more time, which in turn hindered children's ability to observe while waiting and disrupt participants. As mentioned earlier, solutions were found by taking turns in the activity and extending it in time. This was especially true for younger children who had difficulty engaging in more complex tasks and were more likely to explore freely or be guided to observe.

Given the generally low number of staff resources in Portuguese kindergarten classrooms, as well as the wide age range in the same group, activities that require close supervision by an adult and do not involve the group as a whole are associated with greater difficulties. Difficulties with learning progress were also associated with age diversity, with teachers struggling to manage the different learning rhythms. Nevertheless, specific difficulties were mentioned, in particular sequencing without visual support, spatial awareness (laterality), itinerary representation (drawing). Other negative aspects mentioned were malfunctions, logistics, children's difficulty in understanding the task and its goals (itinerary representation of the route), inappropriateness between the learning goal and the robot design, and barriers to social development (difficulties in promoting cooperation in coding activities).

5. Discussion

This analysis brings out and underpins important evidence for the introduction of curriculum-integrated approaches to computation in preschool. It supports previous findings on children's involvement [7], a key aspect when considering quality and educational outcomes in the preschool context, from a constructivist perspective [14]. Laevers understands involvement as "being intensely engaged in activities" and "a necessary condition for deep level learning and development (p. 3, [55]). Looking at this from the perspective of Resnick's [41] four Ps framework, this study suggests that passion played a role in at least some of the activities developed.

The computer also seems to appropriately provide playful learning opportunities that are integrated into the Portuguese preschool curriculum and pedagogical approaches. Playfulness, as a promoter of children's natural curiosity, is indeed a characteristic of the holistic pedagogical framework of Portuguese preschools [42]. This involves an articulated construction of knowledge and the development of transversal competences, leading to a globalizing approach to curricular knowledge areas. The fact that a significant number of activities in this study included multidisciplinary content and objectives, as well as the development of creative projects (e.g., visual storytelling, role-playing, artistic expression), reflects educators' efforts to implement this globalizing approach. This, in turn, is close to the promotion of creative and project-based learning as a foundation for lifelong learning skills [2,41]. The intention expressed by educators to develop children's self-expression and creative skills reinforces this view. As we mention below, this is an aspect that requires further research. Nevertheless, the methods used, especially visual storytelling, welcomed artistic expression.

On the other hand, the prevalence of activities focused on "expression and communication", including language skills, brings us close to a literacy framework [2,8]. Although "writing" code with an appropriate language (ScratchJr) occurred in only eight activities (two of them within multiple approaches), the use of these approaches for expression and communication purposes is prominent. The data do not contain many textual references to computational expression and participation [56], i.e., the use of computers as a language for self-expression, communication, and participation. Nevertheless, children's active participation in learning processes and personal and social skills such as self-expression, respect and collaboration are frequently mentioned. Finally, of the four implemented approaches to computation (Table 1), unplugged computational thinking and robotics were preferred by educators. Although this could be related to a low level of technological resources, especially computers and tablets, the results indicate a preference for tangible computational approaches. Portuguese public preschool classes are often composed of children aged 3 to 6 years. The results suggest that tangible approaches play a key role in engaging all children, especially younger children and children with special educational needs.

Methodologically, approaches to computation appear to integrate seamlessly with the play-based learning dynamics of preschool, particularly storytelling, games, artistic expression and more. This is reflected in the educators' evaluation of the positive aspects. Nevertheless, challenges were mentioned in terms of class management, learning progress and participation of young children, but not necessarily related to the activities, but rather to large groups of children in the same class and the low ratio of resources per child.

5.1. Limitations

This project was severely affected by the COVID -19 pandemic, so that field activities and observations were interrupted after half a school year. With a large number of children present in most classes, resources were also scarce. As part of an ongoing project, the work presented here is complemented by two other research activities: an investigation of educators' training needs, currently in its final stages; an observation of pedagogical activities, originally planned as fieldwork in the field but adapted to a remote data collection procedure in the pandemic context [50]. In this second phase, educators will also be asked to evaluate and provide feedback on the findings presented here. Further analysis will also look at data collected in videos, photos, and interactions in online communities.

Educators rated the children's response as particularly enthusiastic (Figures S6–S11). Nonetheless, as the aforementioned difficulties suggest, further research is needed to ensure that enthusiasm is not mainly related to novelty. Given the time constraints and the current stage of the project, particularly the ongoing data analysis, it is too early to confirm that children's enthusiasm provides any real educational value. Building on Laevers' [55] involvement approach, it is anticipated that further exploration of this aspect will shed light on levels of engagement and specific opportunities to develop learning.

Another important aspect to consider in more detail is how activities build on and foster creativity. As Resnick and Rusk point out [15], the introduction of computational concepts does not necessarily imply the development of creative skills. Although present in the data, this was not very clear in this first phase of data collection and is an aspect we intend to explore in more depth in subsequent research activities. Our second phase of fieldwork involves collecting data using the Positive Technological Development (PTD) Engagement Checklist for children (https://sites.tufts.edu/devtech/ptd/, accessed on 3 January 2020) [57]. This work will provide insight into how these activities may or may not promote the six positive behaviors (six Cs) suggested by the PTD theorizing framework: content creation, creativity, communication, collaboration, community building, and behavioral decision-making.

Moreover, the results presented here are not necessarily transferable to activities with other resources. In fact, the diversity of commercial and non-commercial resources available presents a significant challenge to this area of research and practice. Further research is needed to navigate this plethora of offerings and, more importantly, the features that clearly represent educational benefits.

5.2. Directions for Future Research

This work represents an important step in the development of the intended training framework and competency profile. Actual pedagogical practice is an essential basis for reflection and professional learning. The data collected to date provides an important benchmark for learning practice. However, further reflection is needed in terms of fundamental principles and competencies. We expect to conduct this reflection based on a transversal analysis of the results regarding training needs evaluation which is currently in its final stages, our earlier evaluation of the implemented teacher training program [51,58], the analysis of data collected in videos of activities, and the remote observation conducted in the second school year of fieldwork [50]. We further expect to validate this analysis with participants by organizing a series of focus groups.

6. Conclusions

The results presented here propose a map of contents, methods and learning objectives through which these approaches to computation can be integrated into the Portuguese preschool curriculum. Moreover, it addresses the cross-curricular knowledge and competences that can be promoted through them. In this regard, this work proposes that "expression and communication" can provide an initial framework for preschool learning activities to integrate computation, but multidisciplinary and diverse methodological approaches can provide greater scope for the development of digital and computational skills, as well as personal and social development.

This work forms the basis for the development of a framework for undergraduate and in-service teacher education and training and a competency profile for educators. Referring to this experience, as well as to the results of the training needs analysis which is currently in its final stages, and to our earlier evaluation of the implemented teacher education program [51,58], a reflection will be carried out with the participants on the principles and competences needed to integrate approaches to computation with the curriculum.

Supplementary Materials: The following materials are available online at https://www.mdpi.com/article/10.3390/educsci11050198/s1, Table S1: learning methodologies per approach to computation and content area, Table S2: curriculum content per approach to computation and content area, Figure S1: learning goals: computational thinking with ICT, Figure S2: learning goals: unplugged computational thinking, Figure S3: learning goals: coding, Figure S4: learning goals: robotics, Figure S5: learning goals: multiple approaches, Figure S6: children's reactions, Figure S7: positive aspects: computational thinking with ICT, Figure S8: positive aspects: unplugged computational thinking, Figure S9: positive aspects: coding, Figure S10: positive aspects: robotics, Figure S11: positive aspects: multiple approaches, Figure S12: negative aspects.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Ethics Committee for Research in Social and Human Sciences (CEICSH) of the University of Minho and approved according to the regulations of the Ministry of Education by each school where the study took place.

Informed Consent Statement: Informed consent was obtained from school administrators and families of children enrolled in classes participating in the study.

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