Inclusive Computational Thinking in Public Schools: A Case Study from Lisbon

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Insights

- Integrating inclusive computational thinking (CT) education into children's school curricula is essential for developing problem-solving, logical reasoning, and creativity skills.
- Implementing inclusive, multisensory robotic environments in schools can enhance learning, engagement, and collaboration between children with diverse abilities, promoting educational equity and reducing the risk of social exclusion.

AI is one of the most prominent examples of how technologies can affect society. Although it has benefits and could potentially make advanced resources and opportunities more accessible and affordable, it could also increase inequalities. Equipping young people with the skills and knowledge to navigate and harness technologies such as AI is pivotal for their success and for societal progress and democracies in general. It is crucial, then, to prepare the next generation to not only understand how technology works but also recognize both its advantages and potential drawbacks. In achieving this educational goal, no child should be left behind, especially those facing the risk of social exclusion due to their socioeconomic status or physical characteristics such as race, sex, and disability. These children frequently lack access to the necessary resources for developing digital literacy skills, making them disproportionately susceptible to the adverse effects of technology [1].

Fifteen years ago, a seminal paper by Jeannette Wing [2] emphasized the importance of integrating computational thinking (CT) into children's education for the upcoming digital age, touting its role in developing problem-solving abilities, logical reasoning, and creativity.

Children with visual impairments in a Lisbon public school engaged in commanding robots and building structures using Lego and other playful tools.

These skills are essential for children to interact effectively with technology, preparing them for a rapidly evolving technological landscape. In this article, we advocate for inclusive CT education, emphasizing that every child should have the opportunity to develop CT and digital literacy. We will present a case study from Lisbon, Portugal, where we have been collaborating with an inclusive public school.

The relevance of CT in preparing individuals for future professional success is undeniable. Many countries, including the U.K., Singapore, and Uruguay, have recognized its significance by incorporating CT into national educational curricula, ensuring that every child has the chance to develop these skills. And beyond their well-established problem-solving and logical-reasoning benefits, CT activities foster creativity and student collaboration. Providing these resources in a formal school setting is critical to ensure equitable learning opportunities and prevent further educational disparities. For instance, children at risk of social exclusion might not have access to necessary computing resources at home; therefore, having those resources at school becomes fundamental. But while the benefits of CT curricula are clear, public schools often encounter challenges in effectively implementing these innovations.

CHALLENGES FOR PUBLIC SCHOOLS

The challenges of integrating technology into public school curricula include a lack of economic resources, lack of technology appropriation, limited teacher technology expertise, a shortage of user-friendly materials for group instruction, and the absence of accessible materials tailored to students' varied abilities. These factors collectively contribute to the challenge of effectively integrating digital technologies into the public school curriculum, underscoring the need for more-tailored solutions and support.

One of the most effective tools for teaching CT is robots. They are highly engaging for children and have the potential to significantly motivate them to participate in CT activities, making learning interactive, playful, and enjoyable. One of the primary challenges we encounter is that robotic kits are typically designed for individual or paired use. Classrooms, however, present a unique context with distinct demands. Given large class sizes, educators need resources and activities designed to engage students collaboratively. Engaging each student individually is impractical, making it essential to focus on group-oriented educational approaches.

If the current situation is challenging for public schools in general, it becomes even more challenging when considering robotic kits specifically tailored to serve children with disabilities. The stark reality is that there is a profound scarcity of inclusive and accessible technology designed to facilitate the learning of CT for children with disabilities in educational settings. Additionally, the inclusive technologies that do exist not only fall short at providing materials at low cost and with high usability but also at providing support for teachers and children.

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INCLUSIVE DESIGN

Recent calls [3] for accessible and inclusive technology in education highlight that in addition to technically providing access to content, it is also essential to tailor user experiences to meet the diverse needs and preferences of students. Addressing this issue implies a shift toward inclusive design principles. These principles involve integrating the perspectives and needs of children with disabilities and educators throughout the development process and in alignment with pedagogical practices to ensure the relevance and effectiveness of these technologies in schools [4]. Creating technology for children with disabilities in public schools therefore requires a concerted effort to prioritize inclusive or participatory design approaches. By doing so, we can work toward a more inclusive educational environment where technology is a tool for empowerment rather than a barrier to learning.

We embrace inclusive design principles to uphold equity, ensuring that all children have access and can all participate fully and effectively. Our goal is to provide robotic environments that accommodate various sensory and motor skills, allowing the broadest range of children to play and learn together. To design such systems, we include stakeholders' and children's voices guided by the following principles [5]:

• Actively engaging with children and stakeholders through frequent sessions

• Employing a multidisciplinary approach aimed at a comprehensive understanding of children's development, needs, and abilities

• Recognizing and valuing children's unique characteristics and individuality

• Ensuring the practicality of integrating technology into children's everyday environments to significantly affect their lives, adhering to the principles of low cost and open source for sustainable use and scalable potential effects.

A CASE STUDY IN LISBON

We now share insights from our collaboration with public schools that accommodate children with and without visual impairments in Lisbon, Portugal. In 2019, we embarked on a long-term initiative to create inclusive CT coding kits for mainstream schools.

Motivated by the potential of tangible user interfaces and robotics, we approached information technology educators and those with specific training and expertise in working with children with visual impairments to assess their opinions and needs as well as what they perceived as barriers and opportunities in teaching CT to children with visual impairments. We demonstrated off-the-shelf robots and programming tools following recent advancements in robotics, from traditional graphical interfaces to tangible user interfaces, often supplemented with auditory feedback. Educators expressed that tangible interfaces present a unique opportunity to foster spatial cognition, a crucial skill for children that directly correlates with orientation and mobility capabilities. They acknowledged the significance of physical interaction with objects in comprehending spatial relationships, a fundamental part of developing spatial skills in children with visual impairments. The study highlighted the crucial role of robotics in spatial and CT training, and how tactile and auditory feedback can be effective alternatives for information typically conveyed through visual means, thereby creating an inclusive and equitable learning platform.

In the subsequent phase, drawing upon our findings from the study with educators, we developed five prototypes, each focused on giving children with visual impairments a tool to learn CT while facilitating collaboration and inclusive behaviors among children with mixed visual abilities. A critical component of our methodology was the active involvement of children with visual impairments and their families and educators in different moments of the design process and user studies.

Our inclusive and tangible robotic prototypes. The first prototype we designed was LEGOWorld, inspired by Lego blocks due to their widespread availability, association with play, and presence in children's environments. Additionally, their properties, such as graspability, modularity, and high-contrast colors, make them suitable for an accessible programming environment. We enhanced the *repurposability* of this familiar toy, making it more widely reproducible and available, which reduced costs and fabrication time. Besides using tangibles to command the robot, LEGOWorld also enables children to program sequences of the robot's movements with their voices.

The second prototype, Accembly, was a robotic environment composed of tangible blocks, a robot, foam tiles for building a map, and toy animals as characters. We deployed this prototype in the homes of children with visual impairments so that the whole family could engage in CT activities. This work was recognized by the European Patent Office, which awarded coauthor Filipa Rocha second place in the Young Inventors Prize (see https://www.epo.org/en/news-events/european-inventor-award/meet-the-finalists/filipa-de-sousa-rocha).

The third prototype was designed to enhance collaborative programming for children with mixed abilities, building on the Accembly framework. It focuses on leveraging asymmetric roles to boost collaboration in CT activities. In this setup, children work together on an initially empty play mat to guide a robot through a path, avoiding obstacles. Each child possesses unique information crucial for the task, encouraging them to share and collaborate to succeed in the activities. This design fosters an inclusive environment where children with different abilities can engage and learn together.

By assembling elements from previous work and focusing on the trade-offs between remote and colocated collaboration, we developed a Sokoban tangible programming environment with interdependent roles where children with mixed visual abilities had to solve a complex game while applying CT skills [6]. We ran a study in different schools in Portugal, where dyads of children with different visual abilities had to collaborate to solve levels of a tangible Sokoban game, programming a robot with tangible coding blocks.

Finally, we designed TACTOPI [7], a prototype that leverages multisensory tangibles in a playful, robot-centric environment for children with mixed visual abilities. By emphasizing storytelling and guided play, we facilitated social, cognitive, and inclusive play and CT learning in 10 dyads of children with mixed visual abilities.

Embedded research in schools. These studies addressed the creation of inclusive, interactive CT environments for children with visual impairments. They underscore the potential of leveraging low-cost, pervasive technologies with multisensory features. Drawing upon our findings and after making adjustments, we revisited one public school in 2022 and 2023 to implement robotic sessions with children with visual impairments. The study was structured to incorporate diverse elements, all aimed at contributing to the overarching goal of engagement, motivation, and collaboration in an inclusive educational context focused on CT learning. We iteratively employed elements from previous prototypes, selecting the features we considered more suitable to an iterative process, session after session, relying on researchers' observations, feedback from educators, and children's learning, engagement, and collaboration in the sessions.

Central to our approach was using tangibles with 3D-patterned reliefs that fit Lego blocks. The tangible blocks have different functions (e.g., right, left, forward, loop, play), allowing children to directly program the robot's behavior, a hands-on element crucial for accessibility and fostering an interactive and playful learning environment. Using a robot, a floor map made of sponge material, and a map using a Lego baseplate provided a physical and exploratory map for moving the robot and completing missions collaboratively and engagingly. Children could tactilely engage with the map, enhancing their spatial awareness and interaction with the robot. This aspect was also relevant to ensure that each child was aware of their peers' surroundings and actions. Awareness played a crucial role in facilitating balanced and equal collaboration among the children.

Our preliminary results indicate that educators appreciated the robotic activities, engaging students and enhancing their learning experiences. They highlighted the adaptability of these activities to individual needs that catered to diverse learning preferences and abilities. Educators observed increasing participation and interest in these activities among children, seeing the activities as positively influencing the children's spatial reasoning, problem-solving, collaboration, and overall school atmosphere. We also observed children enjoying the robotic sessions, collaborating, and applying CT to control the robot. In interviews, children described their learning experiences with robotics and expressed eagerness to continue participating in these sessions.

Challenges and lessons learned. Despite the positive outcomes, we encountered several challenges throughout the study that we would like to share, as well as the measures we took to mitigate them and insights for future research. This reflection sheds light on the complexities of integrating technology into education and can serve as a guide for others embarking on similar journeys.

One of the biggest challenges is maintaining children's motivation and engagement throughout long-term sessions. Although this is not new for educational stakeholders, we found it challenging to support children who were constantly seeking playful and meaningful experiences while avoiding boring them with repetitive activities. We explored different elements to keep them engaged throughout the sessions, such as tangible characters, coding blocks, storytelling, and gamified elements like sandbox activities. Storytelling, in particular, played a significant role in motivating children to solve CT activities and in setting the context for each session. We found that maintaining engagement was crucial for fostering collaboration among children and sustaining their attention and focus. Nevertheless, it was challenging to consistently engage every child, prompting the need for further research in this area.

Another challenge is facilitating collaboration among children, as children may find it easier to collaborate with friends than with peers with whom they are less familiar. This dynamic can potentially hinder effective collaboration in groups with mixed visual abilities. To foster teamwork and communication, we iteratively introduced various activities, objects, and stories. A key aspect was the design of interdependent, asymmetric roles such as Captain, Pilot, Engineer, and Explorer, where each child was responsible for specific tasks and handling unique tangibles. This design promoted teamwork and communication, with each role handling particular tasks and tangibles and, in some sessions, receiving secret instructions to foster collaborative problem-solving and engagement. Cooperative teamwork was further encouraged by teams sharing maps and audio feedback, promoting joint problem-solving. However, the role of Explorer, responsible for indicating the corresponding laterality concepts to the other players and essential for guiding the robot in the correct direction (right/left/forward), was perceived as the most monotonous role, primarily due to its high cognitive demand. Further research is needed to devise ways to make this role and task more engaging, even when it requires a high cognitive load.

We faced another challenge: to iteratively design and adapt our prototypes to suit children with varying degrees of visual impairments and differing cognitive development. To address this, we incorporated multisensory elements into our designs, allowing for greater adaptability to different degrees of visual impairments and cognitive development and to fit their preferences. Furthermore, we varied our storytelling techniques, assigned diverse roles, and introduced interactive elements. These strategies were aimed at diversifying the contexts in which the technology was used and tailoring it to the children's individual preferences and needs. By doing so, we strove to create an inclusive and engaging learning environment for most participants.

One of our most significant challenges has become sustaining robotic sessions in the schools. The educators expressed concerns when we asked them about the possibility of running the sessions with children without our presence. They indicated a lack of time and expertise in using technology, suggesting that technology integration could be a pain point, or even disruptive. The educators felt they must prioritize delivering ample curricular knowledge over incorporating new technological elements. Interestingly, when the possibility of external facilitation of robotic classes was

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proposed, the teachers responded positively. They recognized the potential benefits of involving us to scaffold children's CT learning, seeing it as a valuable addition to their current educational plans. This openness to external collaboration reflects a willingness to enhance student learning experiences despite the challenges of directly implementing technology-based sessions.

Our research shows benefits for the community in terms of collaboration and CT learning. However, we must continue researching how to make these technologies available and sustainable at schools to facilitate teachers' and children's appropriation of technology. We are actively exploring solutions to this challenge, and our preliminary insights may offer valuable contributions to the HCI community.

We must pursue a comprehensive approach to identify and mitigate the needs, flaws, and barriers in bringing innovative technology to the classroom. This involves understanding the educational strategies employed by teachers and tailoring technology-based solutions to complement their regular activities. These tools should be scalable for classroom use and enriched with multisensory features to engage a diverse range of students, ultimately bolstering their self-efficacy and equipping them with the skills needed for future success.

Furthermore, seamless integration of technology into the curriculum is vital. Teachers should be able to incorporate tech into their lesson plans without extensive training. Supporting educators with theoretical knowledge about CT and its application in education is essential.

DECREASE THE DIGITAL DIVIDE

As members of the HCI community, it's evident that we have yet to fully address the pressing educational challenges of our time, including the imperative to incorporate inclusive AI learning. Leveraging inclusive technology in support of national public education offers a substantial opportunity. As a community, should we take on the responsibility of constructing the essential infrastructure, systems, and expertise required to ensure that every child becomes a critical consumer and creator of technology in this technology-driven world?

We propose embarking on this journey through inclusive design and participatory approaches, engaging both children and stakeholders and recognizing that children are multifaceted beings shaped by their biological, social, and cultural contexts. Involving stakeholders and the community in our research endeavors is crucial, forging a deep commitment to inclusive, sustainable, and scalable solutions. Inclusive codesign and participatory design methodologies may facilitate and foster community building, cohesion, and collaboration among children and stakeholders.

In conclusion, although we might not have all the solutions at our disposal, we have offered insights to enhance inclusivity and learning through technology in public schools. Beyond CT, integrating AI into children's education is also crucial. Children have evolved from passive consumers to active technology users, capable of expressing themselves and influencing their environment. We should ensure that no child is excluded from the opportunity to learn about, utilize, and critically assess new technologies that will significantly affect their future. To bridge the educational gap, we must engage in collaborative efforts with children and stakeholders to develop inclusive technology. Our primary objective is to guarantee that no child is left behind, equipping them with the necessary tools and support to thrive in a technology-driven society.

Endnotes

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