Leveraging Robotics to Enhance Accessibility and Engagement in Mathematics Education for Vision-Impaired Students

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***Abstract*— There is potential to use robotics in education to revolutionize teaching and learning in mathematics. This is particularly relevant for vision-impaired students, who face different challenges when accessing mathematical content. Educational robotics can potentially enhance accessibility, motivation, and engagement in mathematics for students through enjoyable and novel interactions. Students commonly experience positive interactions with educational robots during learning activities, which influences their learning motivation. Recent studies show that students with disabilities face issues related to classroom participation, lack of collaborative learning, reduced social engagement, and potential for isolation. Digital-based learning technologies have transformed how vision-impaired students engage with and learn mathematics. Leveraging robotics in mathematics teaching and learning through personalised guidelines offers considerable benefits for vision-impaired students, including enhanced engagement, multimodal learning opportunities, and improved collaboration and communication skills, which enhances the opportunities for inclusive classroom experiences. This paper outlines the role of educational robotics in inclusive education. It examines the challenges and benefits of using educational robotics in mathematics for vision-impaired students. The importance of human-robot interaction (HRI) in steering the design and functionality of educational robots and their potential use within the classroom to facilitate learning is also highlighted.**

Keywords*— *Educational robotics, STEM education, vision-impaired, accessibility, inclusive education, Human-Robot-Interaction (HRI), Human-Computer Interaction (HCI).

I. Introduction and Background

Mathematics education is essential for developing critical thinking and problem-solving skills [1]. However, for vision-impaired students, accessing mathematical content can be challenging [2]. According to the social model of disability perspective, it is essential to eliminate systemic barriers that prevent disabled individuals from accessing the same academic benefits as their peers [3]. Traditional teaching methods rely heavily on visual representations, such as diagrams and graphs, which can be difficult for vision-impaired students to analyze [2]. This can lead to a lack of engagement, understanding and increased cognitive load, leading to exclusion and limited academic achievement [4, 5].

One of the main purposes of mathematics education is to develop an awareness of numbers and cope with different relations and dimensions [6]. Vision-impaired students in mathematics lessons use Braille mathematics notations or Nemeth Braille code which is a specialized form of Braille designed explicitly for mathematics and science notations [7], tactile pictures [8] and speech synthesizers [9] or multimodal systems that aim to aid blind and vision-impaired students while learning mathematics and that integrates complementary modalities to enhance their learning [10].

When vision-impaired students engage in mathematics lessons, they face several challenges related to using traditional assistive educational tools. For instance, Braille mathematics notations or Nemeth Braille code present limitations concerning the availability and access to materials [7]. Producing Braille versions of complex mathematical expressions and symbols requires specialized expertise, making it time-consuming [11]. Additionally, learning Braille mathematics notation requires proficiency in tactile perception and accurate interpretation of Braille notations [12]. Another tool used in classrooms is tactile pictures, which pose a challenge due to their limited ability to convey detailed information [7], making it difficult for vision-impaired students to learn the full scope of mathematical concepts.

The lack of knowledge among mathematics teachers about these specialized tools exacerbates the challenges faced by vision-impaired and blind students. Due to limited training and professional development opportunities [13], teachers may not have the necessary expertise to effectively integrate braille mathematics notations, tactile pictures, and speech synthesizers. The lack of knowledge among teachers creates a barrier to achieving inclusive education, as they encounter difficulties adapting their teaching approaches and resources to accommodate the specific requirements of vision-impaired and blind students in mathematics classrooms [14]. Hence, it is important to emphasize teaching and learning methodologies when engaging with blind or vision-impaired students to ensure they are afforded equal opportunities as their non-disabled peers [3].

Educational robotics has emerged as a promising tool for enhancing accessibility and engagement in mathematics education [15]. Educational robotics involves using robots to support teaching and learning. It effectively promotes science, technology, engineering, and mathematics (STEM) education [33], enabling students to actively participate in experiential learning and cultivate skills in problem-solving, critical thinking, and creativity [16]. The utilization of robotics focuses on promoting the active involvement and engagement of students with disabilities, who are frequently underrepresented in traditional STEM education environments [17].

II. Educational Robotics and Human-Robot Interaction Role in Inclusive Education

Inclusive education is an approach that seeks to ensure that all students have equal access to education, regardless of their individual needs and abilities [18]. Robotics can be essential in promoting inclusive education, particularly for students with disabilities [19] and provide a platform for students to engage in hands-on learning experiences that are accessible and engaging. Robots can be programmed to provide audio feedback, making them accessible to vision-impaired students. In addition, educational robotics can promote collaboration and teamwork, allowing students with different abilities to work together towards a common goal [15].

The approach of mainstream education for vision-impaired students instead of special schools [20] is accompanied by persistent issues in participation [21, 22] and limited chances for collaboration and social interaction [23, 24]. The design of assistive learning technologies usually concentrates exclusively on the needs of vision-impaired students, thereby disturbing inclusive learning experiences for their sighted peers [25].

Almost all robot tasks currently use Human-Robot Interaction (HRI), including manufacturing, space, aviation, surgery, rehabilitation, agriculture, education, package delivery, and military operations [26]. Both the security drone that makes thieves feel secure and the humanoid robot that makes students uncomfortable need to be improved. Considering user perceptions before a robot is constructed may avoid such design errors, saving time and money and optimizing a robot's use. (HRI) requires a comprehensive understanding of how people view robots. Understanding the social impact, the robot's design, motion, and behavior potentially give off is essential for creating a robot competent at the job role, especially one intended to interact with people [27].

The relationship between HRI and universal learning (UL) is essential in the context of utilizing educational robotics in the classroom. HRI emphasizes the importance of establishing meaningful and effective interactions between humans and robots, ensuring that educational robots are accessible and usable for all students, regardless of their abilities or backgrounds. By incorporating universal learning principles, such as creating inclusive and flexible learning environments, educational robotics can facilitate fair and engaging educational experiences for students with diverse needs. This promotes their active participation and enhances their learning outcomes.

HCI has great potential in developing technologies that cater to human requirements, and it is essential in enhancing user experiences and fostering user-centric design principles [28]. To ensure an inclusive learning experience for all students, it is essential to carefully evaluate robots' usability, responsiveness, adaptability, and user-friendliness. In this regard, HCI plays an essential role in shaping the design and functionality of robots [28]. By prioritizing educational robotics usability and accessibility, HCI [28] and HRI [29] encourage inclusive education, accommodating diverse learners, including those with learning or sensory disabilities. HCI also considers emotional affect and cognitive processing during user interactions [30].

Salas-Pilco [31] found that using robots in educational environments benefited learners. The study examined the influence of robots on students' physical, social-emotional, and intellectual learning outcomes, where each student displayed distinct learning trajectories.

Psychological research approaches on HRI have offered significant and novel perspectives on how individuals perceive robots. Existing research suggests that cognitive processes to how people experience can also be important to how robots and other non-human things are recognized [32]. As technology advances, the use of robots and artificial intelligence technologies also offers opportunities for ubiquitous learning in the classroom. The potential of robots to facilitate collaborative learning and their impact on student's educational experiences should be examined to ensure effective implementation and inclusive education practices.

III. Towards Using Educational Robotics in STEM Education

Robotics has been identified as a promising tool for promoting STEM education [33, 34]. Integrating robotics into educational environments has demonstrated its capability to foster immersive [35] and experiential learning encounters for students, catalyzing problem-solving skills, critical thinking abilities, and creativity [36]. Educational robotics presents a universal platform for interdisciplinary education, facilitating the integration of various subjects, including but not limited to mathematics, engineering, and computer science [37]. By bridging disciplinary boundaries, educational robotics creates opportunities for students to explore the interconnections between different fields of knowledge and develop a holistic understanding of real-world challenges [36, 37].

A. Enhancing HRI: Mobile Solutions and Sensor Technologies

(HRI) focuses on designing, comprehending, and assessing robotic systems that involve communication and interaction between humans and robots [38]. The advancements in mobile and wireless technologies provide a feasible mobile solution to education, enabling and enhancing student and teacher interaction within the classroom environment [39]. Using advanced sensor technologies and a wireless sensor network is essential for the efficient operation of the HRI [40]. That encourages students to interact with a multisensory robotic system, enabling touch, speech, and communication. Students can engage with a comprehensive system that promotes active learning and multimodal interactions and incorporates various embedded sensors [41]. As robotics advances, users, including teachers, may have varying levels of expertise in operating robotics systems. In this context, the role of mobile phone personalised applications as a tool for facilitating HRI becomes more significant [42].

B. Empowering Engagement and Accessibility: Robotics, VR/AR, and Inclusive STEM Education

Robotics has demonstrated its effectiveness in teaching multidisciplinary topics such as mathematics and physics [43]. While students with disabilities are not well-represented in STEM education in schools, robotics is one promising approach to stimulate their interest and engagement in STEM education [17]. Teaching mathematics to vision-impaired students presents challenges that require innovative approaches to enhance mathematical content accessibility in an inclusive environment [44]. Robots provides an immersive [35] and interactive method for students to engage with mathematical concepts through tactile and auditory feedback [45]. That can potentially enhance understanding of mathematical concepts and improve problem-solving skills for vision-impaired students. Neto et al. [46] argue that the opportunity to use robots in the classroom lies in their ability to utilize their physical attributes, multimodal feedback systems, customized social behaviors, and sensory functions.

By leveraging virtual reality and augmented reality (VR/AR) technologies into the classroom, teachers can control robots remotely using VR headsets and motion-based control, allowing a highly immersive interaction with their students [35]. Such integration improves the quality of feedback provided to the students. (VR/AR) and other artificial intelligence (AI) technologies can facilitate immersive and interactive learning experiences, aiding learners in developing a more comprehensive understanding of intricate concepts and applying their knowledge in practical, real-world situations [47].

C. *Addressing Challenges of Using Robotics In STEM Education For Vision-Impaired Students*

Despite the potential benefits of using robotics in mathematics education for vision-impaired students, technical and student engagement challenges still need to be addressed. The challenges include identifying and differentiating robot parts, teaching students how to assemble them, providing accessible building instructions, and addressing technical and engagement issues [48]. Additionally, the lack of resources and training for educators [49] and the high cost of robotics equipment [50] are other challenges that need to be considered.

When working with robots in the classroom, it is important to make building instructions accessible for vision-impaired students. This likely can be achieved through various methods:

- Providing clear and concise written instructions in accessible formats such as braille or large print.
- Creating audio instructions that describe each step sequentially.
- Developing tactile models or 3D-printed representations of robot parts allows students to explore and assemble them by touch.
- Utilizing assistive technology, such as screen readers, can enhance accessibility on digital platforms.
- Promoting peer support and student collaboration can facilitate information sharing and cooperative problem-solving.

Using robotics in mathematics education has great potential to increase accessibility and engagement for vision-impaired students. The challenges, such as lack of resources, training, and high cost, must be addressed to fully realize the benefits of using robotics in mathematics education for vision-impaired students. Educational robots in STEM education have been identified as practical tools for improving academic achievements [55]. Howard et al. [51] also pointed out that robots can serve as alternative interface modalities that help engage students with visual impairments in the classroom. Robots can take on various roles, such as peers, learning companions, tutors, or teachers, providing hands-on and interactive learning experiences [56, 57, 58].

D. *Affordable Robotics Tools: Fostering Inclusive STEM Education*

Robots such as LEGO Mindstorms EV3, NXT, WeDo [51, 52], and microcontrollers like Arduino [53] and Raspberry Pi [54] are affordable educational tools educators can use to teach STEM. These resources provide tactile and interactive learning experiences that actively engage students in hands-on exploration and problem-solving. LEGO allows students to construct and manipulate mathematical models, facilitating comprehension of concepts such as geometry and spatial relationships. Arduino and Raspberry Pi enable the development of personalised mathematical projects, including voice-based calculators. These technologies foster an inclusive learning environment where vision-impaired students can actively participate in mathematics, utilizing their senses of touch and hearing. By incorporating these tools, teachers can enhance the accessibility of mathematics education and cultivate a deeper understanding of mathematical concepts among vision-impaired students.

Robots are purposefully developed to engage with humans in a manner that replicates natural, interpersonal interactions to provide support and assistance through social engagement [59, 60]. By using robots as active participants in the classroom, educators aim to bridge the gap in STEM education and foster interdisciplinary learning [34]. However, the role of the teacher in such settings remains relatively unexplored, highlighting the need for further research to understand their involvement and experiences [36, 61, 62].

E. *Educational Robotics in Mathematics Education for Vision-Impaired Students: Benefits and Challenges*

Educational robotics can provide a multisensory approach to learning, incorporating auditory, tactile/haptic, and visual feedback. Robots can be programmed to provide audio descriptions of mathematical concepts, allowing vision-impaired students to access mathematical content that may have been previously inaccessible [63]. Students develop a comprehensive understanding of mathematical concepts through hands-on exploration, haptic feedback, and auditory cues, promoting their spatial reasoning and problem-solving skills. This multisensory approach ensures vision-impaired students can access and comprehend mathematical content effectively. Having multiple modalities in a user interface has the benefit of spreading the interaction across various senses or control abilities of the user. If one modality is not available or fully utilized, another can be employed to ensure successful interaction, especially for those with sensory or situational impairments [64].

In addition, educational robotics can promote engagement and motivation in education by providing a hands-on and interactive learning experience [65]. By physically manipulating robots and observing the real-time outcomes of their actions, students will potentially develop a better understanding of mathematical concepts and become more engaged in the learning process.

Robotic activities require collaboration and teamwork, facilitating effective communication and social interaction among vision-impaired students. Educational robotics encourages students to collaborate, share ideas, and engage in meaningful discussions. This collaborative environment promotes the development of critical interpersonal skills alongside mathematical knowledge, creating a well-rounded learning experience.

However, challenges are also associated with using educational robotics for vision-impaired students in mathematics education. One challenge is the need for specialized equipment and teacher training [66]. Providing adequate training and support for teachers to effectively integrate educational robotics into mathematics education for vision-impaired students. Teachers need to possess the knowledge and skills to adapt robotics activities to cater to the individual needs of vision-impaired students, including modifying programming interfaces, providing alternative feedback methods, and facilitating inclusive group work.

The cost of educational robotics can be a barrier to implementation in some schools [67, 68]. Another challenge is the need for accessible software and programming languages suitable for vision-impaired students. This poses a significant challenge in implementing educational robotics for vision-impaired students emphasize the importance of designing robotic platforms, programming interfaces, and instructional resources with accessibility features [69] to facilitate inclusive learning experiences, improve understanding, reduce stress [70] and cognitive load [71] to improve mathematical understanding and student confidence.

IV. Conclusion

Blind and vision-impaired students encounter considerable difficulties, especially in mathematics, as learning mathematics relies on solid visual capabilities. Unfortunately, the world has yet to provide adequate facilities and appropriate technical solutions to facilitate their learning curriculum and make it more accessible [72]. Incorporating educational robotics in mathematics education offers various benefits for vision-impaired students, including enhanced engagement, multisensory learning experiences, and improved collaboration and communication skills. However, challenges related to accessible materials, technologies, and teacher training must be addressed to ensure successful implementation. By overcoming these challenges, educational robotics can significantly empower vision-impaired students to excel in mathematics and foster their overall educational development. Robots introduce great opportunities to enhance inclusive education through their physical embodiment and integrate various sensors and multimodal feedback capabilities, facilitating the participation and collaboration of vision-impaired and sighted students in shared technological experience [46, 25, 73, 74]. Our future work aims to explore the potential implementation of robotics in teaching mathematics to vision-impaired students. We will focus on enhancing their learning experience by personalizing the human-robot interaction (HRI). We intend to explore the opportunities of (VR/AR) technologies to establish an immersive learning environment that allows students to visualize mathematical concepts and participate in interactive activities. By integrating robotics into mathematics education, we believe that students will discover the learning process to be more engaging and enjoyable, boosting their motivation and enthusiasm for learning.

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