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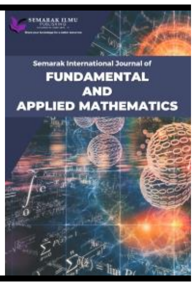

Crafting Mathematical Minds by Engaging Braille-Tangible 3in1 3D Printed Geoboards Module for Visually Impaired Children

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ABSTRACT

Worldwide, visual impairment and blindness stand as prevalent health challenges, exerting substantial effects on individuals and the communities they belong to. These conditions pose significant disabilities for visually impaired individuals and their immediate surroundings. Children with visual impairments encounter numerous challenges in their daily lives and learning, unlike their sighted counterparts. Nevertheless, despite these obstacles, they depend significantly on their tactile and auditory senses to glean information from their surroundings. Meanwhile, mathematics poses a unique challenge for students, as its abstract concepts can be difficult to visualize, potentially diminishing interest in the subject. Recognizing the potential of 3D printing technology to enhance visualization and interaction with three-dimensional models, this study aims to develop a module that combines mathematics in Braille with 3D printed models. The goal is to facilitate a more accessible and engaging learning experience for visually impaired children, fostering a deeper understanding of mathematical concepts. The module incorporates tactile games designed to improve focus and study habits, thereby addressing the specific needs of visually impaired learners. The module comprises 3 games as 3in1 Geoboard: Numerical Jumble, Pinpoint Placer and Geo Art. The game tools employed in this module underwent 3D design through computer-aided design (CAD) software, integrating Braille code within mathematical constructs tailored to the requirements of visually impaired children and their mathematics curriculum. Subsequently, the 3D model was transformed into a tangible object using a 3D printer. These printed objects served as educational tools within the development of an integrated module encompassing both 4IR elements and Braille components. Instructions for the game were seamlessly integrated to facilitate straightforward delivery of module content by educators. Therefore, adopting a game-based learning module approach not only proves effective for individuals who are blind but also provides visually impaired children with a practical avenue to learn Braille and enhance their understanding of mathematical concepts. This educational approach holds particular significance for visually impaired children in their daily lives while greatly revolutionize educator-

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coordinated learning of mathematics through engaging education for the framework of 10-10 MySTIE Socio-economic drivers.

1. Introduction

Today's world thrives on technology, driven by information, and propelled by knowledge. In this modern era, knowledge stands as the cornerstone of existence, and providing quality education becomes imperative, not merely a choice [1,2]. Over the past decades, problem-solving abilities have emerged as pivotal components of mathematics education. Indeed, problem-solving transcends into a fundamental competency within the spectrum of 21st-century skills [3,4]. Within mathematics education, problem-solving serves as the nucleus, giving birth to all mathematical concepts [5]. A curriculum centered on problem-solving not only facilitates comprehension of mathematical concepts but also nurtures a deeper understanding of the subject matter [3,6]. Consequently, problem-solving within mathematics learning accentuates three crucial facets: it serves as the primary objective, operates as an integral process, and embodies essential skills requisite for mastering mathematics [3].

In educational settings, the curriculum often assumes that students possess perfect eyesight, considering it a crucial factor in maximizing educational opportunities. However, individuals with visual impairments (VI) are present in virtually all societies globally. It's estimated that there are approximately 19 million blind children worldwide [1]. Meanwhile, in Malaysia, Associate Prof Dr. Mohd Zaki Awang Isa, the Director of the Center of Excellence for Vision and Eye Care (MSU-iCARE) at Management & Science University (MSU), highlighted findings indicating that one in ten children in Malaysia suffers from serious vision impairments or blindness, with various factors contributing to nine out of ten cases. Studies conducted in Asian and Southeast Asian countries further reveal that over 60 percent of children are highly susceptible to myopia (shortsightedness). A significant contributing factor to this trend is the prolonged exposure of children to various gadgets or smart devices. Therefore, it's vital to understand and recognize the challenges that students with visual impairments face in academic environments, along with the various strategies they utilize to overcome these obstacles. Each educator should have educational opportunities customized to their unique abilities [1].

Furthermore, the landscape of mathematical education is experiencing notable transformations propelled by technology and digital learning platforms. However, students with visual impairments (VI) may encounter distinct challenges in mathematical education due to the scarcity of accessible materials tailored to foster conceptual comprehension in mathematics. The shift towards greater reliance on digital learning resources poses particular challenges for both students with visual impairments (VI) and their educators [7,8]. Hence, it's relevant to acquire a deeper understanding of how students with vision loss can effectively engage with mathematics instruction and excel in mastering age-appropriate curricula [7,9,10].

Meanwhile, braille serves as a tactile writing system specifically designed for individuals with severe visual impairments [7,11]. However, the various mathematical braille codes pose challenges in developing universally compatible software and hardware. Traditionally, braille is embossed on paper, but it can also be presented through tactile sensory and kinaesthetic approaches [10,12].

Incorporating three-dimensional printing (3DP) technology into mathematics classes for visually impaired children offers an innovative approach to enhance teaching methods among educators [13, 14]. This distinctive method has the potential to captivate students' interest in learning mathematics despite their challenges, while also fostering an enhanced understanding of geometry. An alternative learning strategy involving 3DP entails integrating conceptual mathematical theories with tactile perception and interactive learning processes, promoting active engagement. Consequently, this approach can accelerate the learning progress of visually impaired students [12]. Furthermore, understanding the characteristic properties of geometric shapes and spatial relationships among objects is fundamental for visually impaired children, as these concepts underpin higher cognitive processes. By engaging with tactile models created through 3D printing, students can construct mental representations of space, which are crucial for daily tasks and serve as a foundation for comprehending advanced mathematical topics that demand spatial reasoning skills [14,15]. Hence, 3D printing emerges as a valuable educational tool for visually impaired students in the classroom. However, there remains a scarcity of features and a limited range of materials available to meet the demand, leading to uncertainties. This uncertainty stems from the lack of structure within the inclusive education framework and the failure to adapt materials adequately, resulting in challenges and the potential for visually impaired students to misconstrue certain points [15].

Therefore, the aim of this study is to develop a teaching aid, along with a corresponding module, specifically designed for visually impaired children to enhance their learning of mathematics through game-based approaches utilizing tangible kits. The objective is to facilitate the learning process among visually impaired children while also leveraging technological advancements, particularly through 3D printing technology. The focus is on utilizing the 3in1 3D printed geoboard as a teaching tool within a multisensory module to provide an inclusive and effective learning experience for visually impaired students.

2. Methodology

2.1 Digital Modelling and Fabrication

Digital modeling was employed to create 3D-printed models tailored for the mathematics learning needs of visually impaired children. Using computer-aided design (CAD) software, specifically TinkerCAD [17], a 3D digital model for the 3in1 geoboard was developed. Initially, the geoboard underwent a 2D sketching process to draft its design before transitioning to 3D modeling. This sketching phase entailed outlining the base of the geoboard, featuring four sides to accommodate braille geopins. Subsequently, the sketch was transformed into a 3D model using TinkerCAD. The dimensions of both the geoboard base and geopins are detailed in Table 1.

Table 1
Dimension of 3in1 geoboard

Geoboard	Dimension
Base	180 mm (l) x 180 mm (w) x 5 mm (h) x 4
Geopin	10 mm (l) x 10 mm (w) x 15 mm (h)
Geopin hole	12 mm (l) x 12 mm (w) x 3 mm (h)
Arrow	10 mm (l) x 14 mm (w) x 8 mm (h)

The 3D models for each object were exported in the standard triangle language (STL) file format. Subsequently, these files were sliced into multiple cross-sections and sent to the 3D printer. The STL format consists of a collection of connected triangular planar facets that depict the outer surface of an object. Each facet is characterized by its vertices and a unit surface normal vector indicating its direction away from the interior of the part [16,18]. As a result, the files undergo a slicing process using Pusar Slicer 2.7.1 software to generate a G-code file. This G-code file is derived from the STL model, which is sliced into cross-sections to form toolpaths. Subsequently, the G-code file is interpreted by the printer, instructing the extrusion of materials and movement of the print head to fabricate the intended model using a 3D printer, specifically the Mini Prusa model. During the material extrusion phase, a heated extrusion nozzle melts the plastic material, particularly polylactic acid (PLA) filament acting as ink [17,18]. Once melted, the material is extruded through the nozzle and then cooled to solidify, shaping the final geometry of the desired model [19]. The process flow is illustrated in Figure 1.

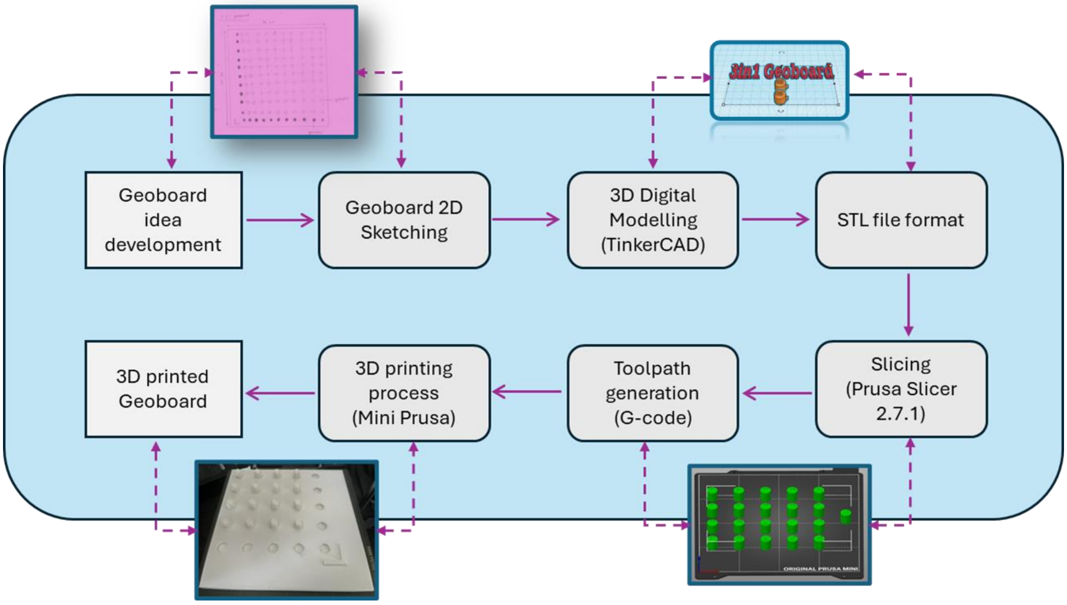


Fig. 1. Process flow on geoboard development

2.2 Crafting Module 3in1 3D Geoboard: A Multi-Sensory Math Adventure

A multisensory module designed for visually impaired children to enhance mathematics learning was developed, aiming to integrate tactile sensation with engaging mathematical activities to facilitate both braille literacy and mathematical skills. This comprehensive module encompasses various stages, including introduction, conceptualization, activities, learning outcomes, and participant feedback. Within this framework, a series of activities were devised, three of which utilize the 3D printed 3in1 geoboard. To assess the effectiveness of the module and gather feedback, an evaluation model was implemented upon completion. This model includes individual game assessments for each game station, an overall evaluation of the module, and feedback on participants' perceptions of the module, all aligned with the learning objectives. Figure 2 provides an overview of the game flow depicted in the developed module.

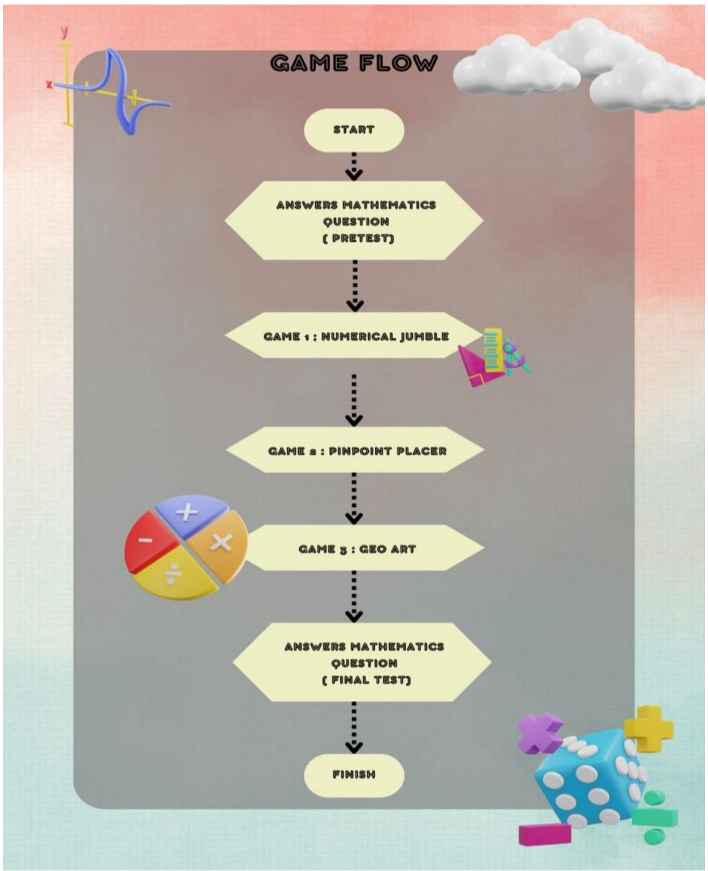


Fig. 2. Game flow in *3in1 3D Geoboard: A Multi-Sensory Math Adventure Module*

2.3 Development of Dynamic Assessments

A set of assessment questions was developed to investigate the performance and improvement of participants in learning mathematics using 3in1 3D Geoboard. The set of questions adopts an experimental approach to assess the performance and improvement of participants in learning mathematics utilizing the 3in1 3D Geoboard. The design incorporated pre- and post-test assessments to evaluate the effectiveness of the learning intervention.

3. Results

3.1 Digital Modelling and Toolpaths of 3in1 Geoboard Model

Figure 3 displays the digital modeling and toolpaths for each component of the 3in1 Geoboard model, including the geoboard base and Braille geopins. The dimensions of the geoboard base were 18 cm (L) x 18 cm (W) x 5 cm (H). The digital modeling process involved creating four distinct sides of the geoboard base, as illustrated in Figure 4(a), (b), (c), and (d). Each side differed in the number of geopins, reflecting the assembly required to form the complete geoboard base utilized in the developed game activities.

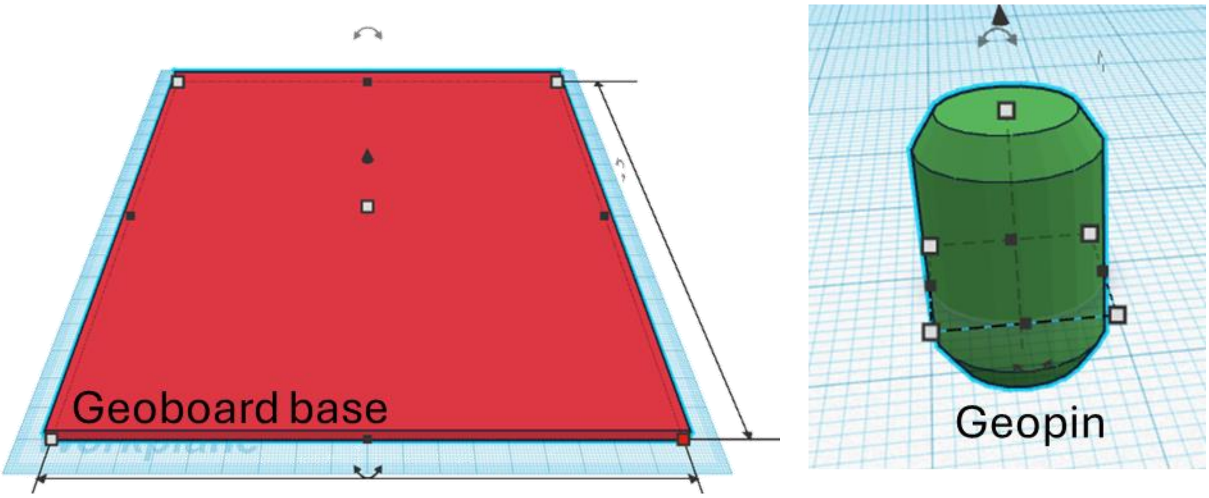
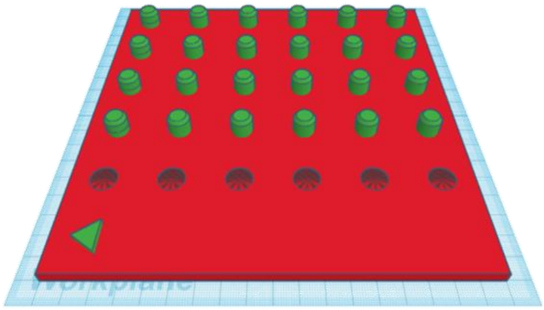
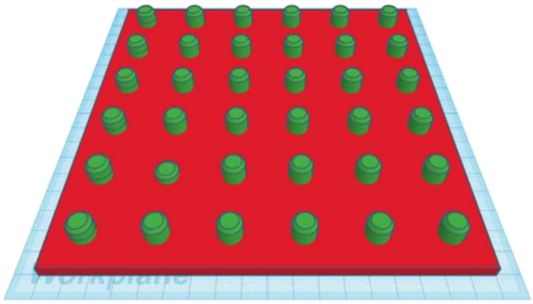


Fig. 3. Geoboard base and Braille Geopin



(a)



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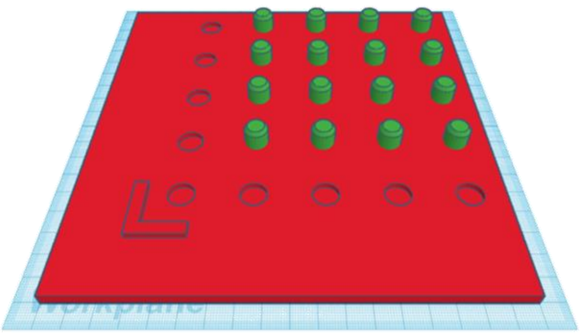
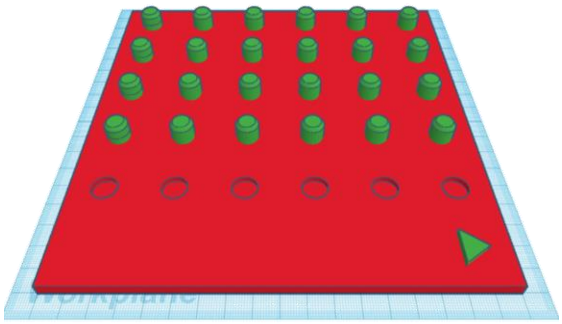


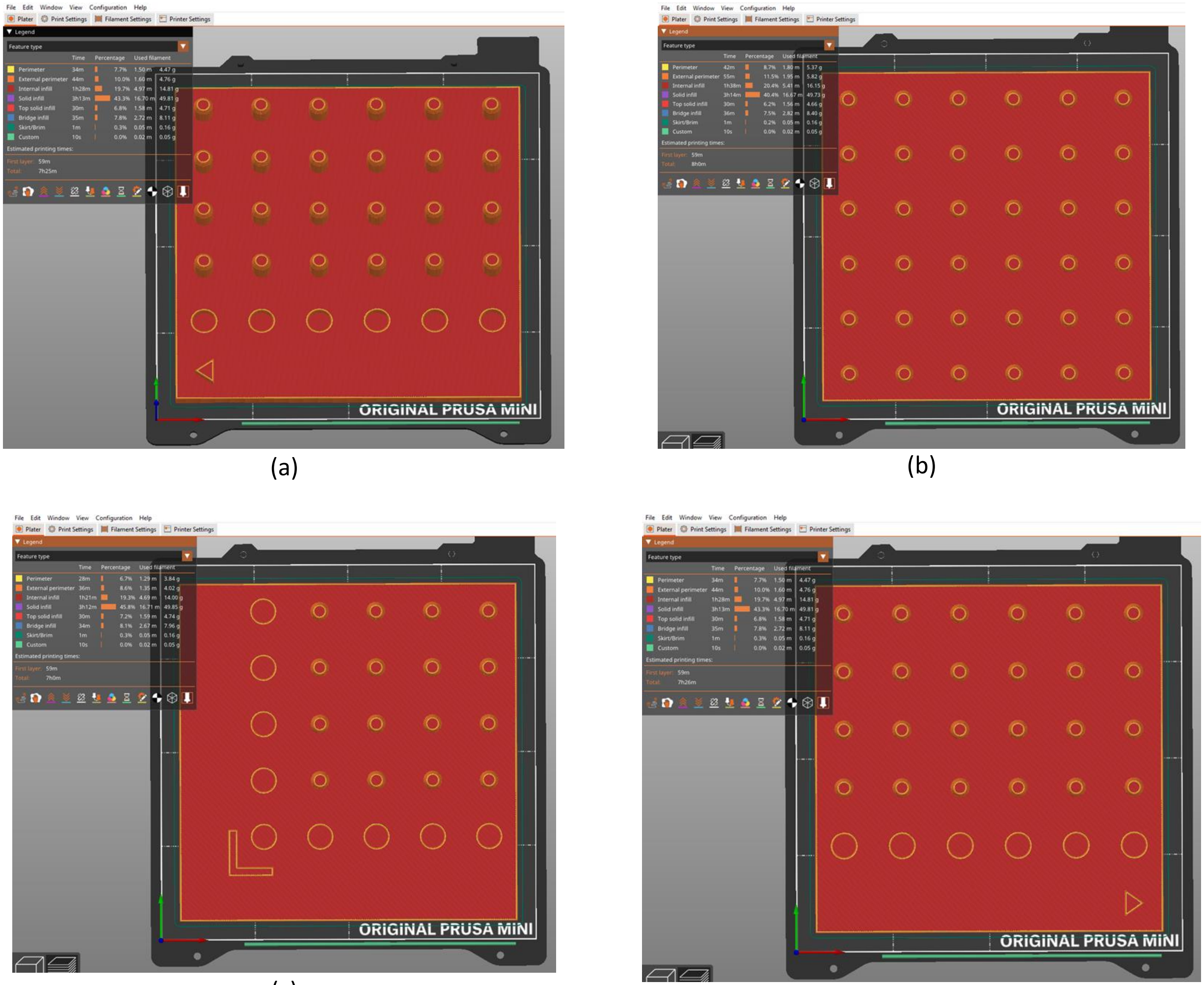
(c)



(d)

Fig. 4. Digital Modelling of (a) Geoboard 1, (b) Geoboard 2, (c) Geoboard 3 and (d) Geoboard 4

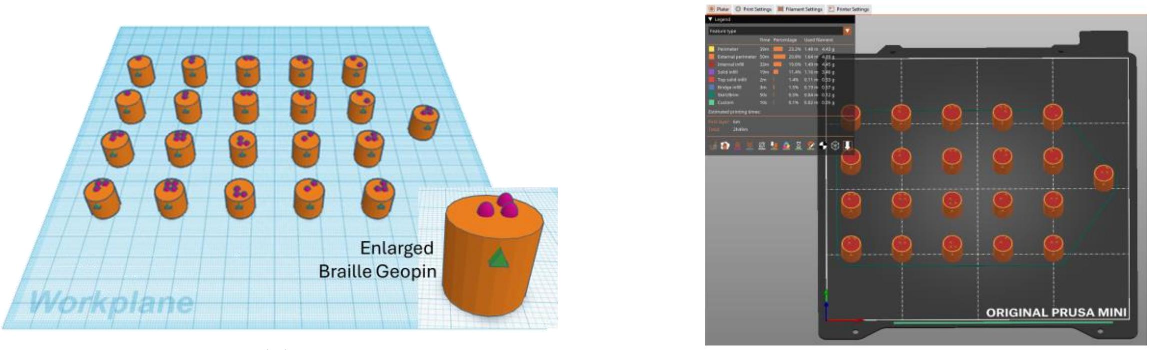
Meanwhile, Figures 5 (a), (b), (c), and (d) depict the sliced digital models of Geoboards 1, 2, 3, and 4. These models were sliced using Prusa Slicer (Version 2.7.2) with a 15% infill percentage, resulting in an estimated printing time of 6 hours for each geoboard. The slicing process generated g-code files, which were then used in the 3D printing process. Additionally, Figure 6 illustrates the digital modeling of the Braille Geopin in TinkerCAD software, followed by slicing using Prusa Slicer.



(a) (b)

(c) (d)

Fig. 5. Sliced geoboard of (a) Geoboard 1, (b) Geoboard 2, (c) Geoboard 3 and (d) Geoboard 4



(a) (b)

Fig. 6. (a) Digital Modelling and (b) Sliced of Braille Geopin

3.2 3D Printed Geoboard

The successful 3D printing of each component of the 3in1 Braille Geoboard following the slicing process marks a significant milestone in the development of accessible educational tools for visually impaired children. As depicted in Figure 7, the utilization of the MINIPrusa 3D printer enabled the fabrication of high-quality, tactile models of both the geoboard and the geopin. This tangible representation of geometric shapes and spatial concepts provides an invaluable resource for visually impaired students, allowing them to engage with mathematical concepts through touch and exploration [19,20].

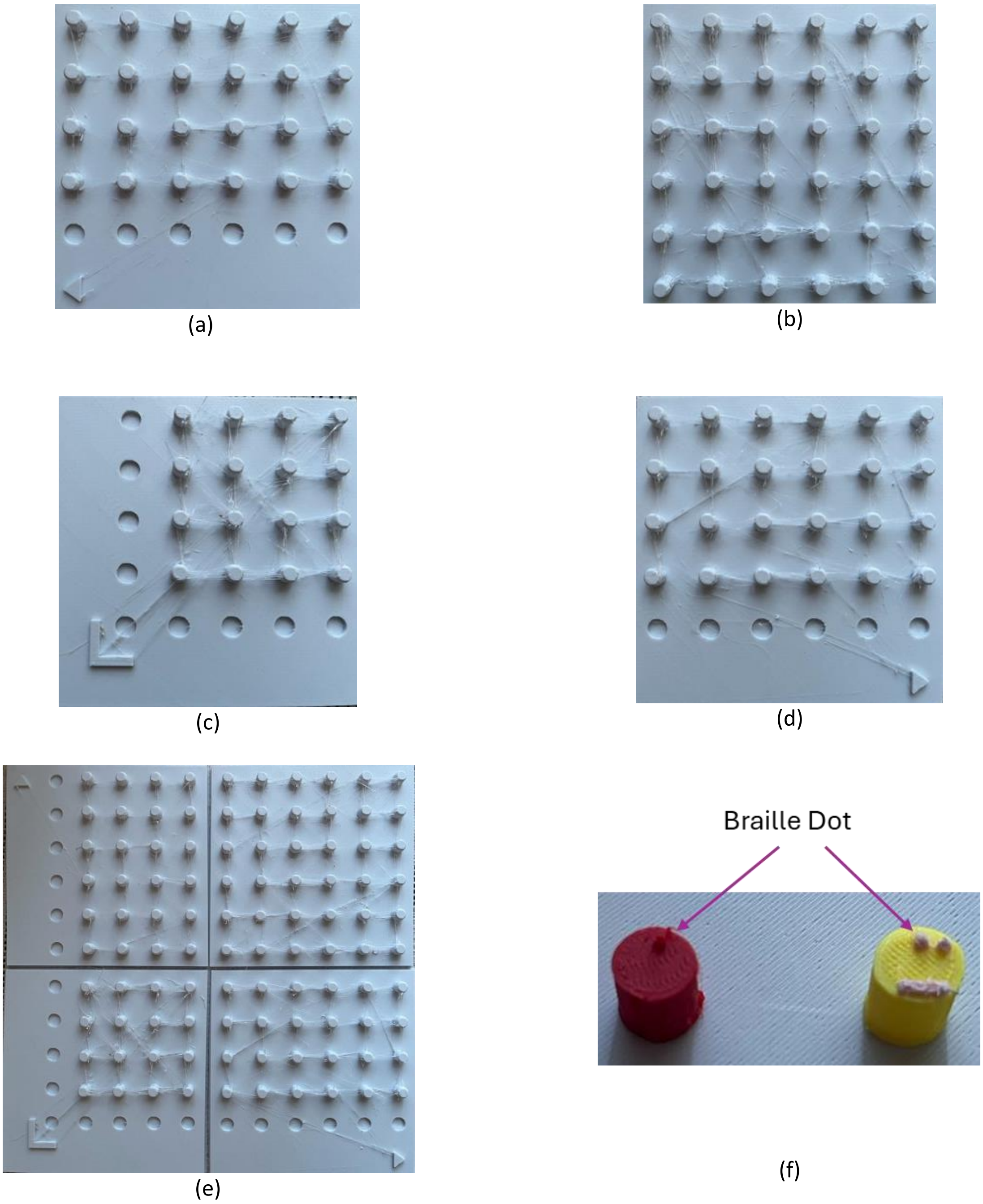


Fig. 7. 3D printed 3in1 Geoboard (a) Geoboard 1 (b) Geoboard 2, (c) Geoboard 3, (d) Geoboard 4, (e) assembled geoboard base and (f) geopin with braille dot

3.3 Developed Pre-test and Post-test

The activity and the 3in1 Geoboard were meticulously designed to complement the Coordinate Geometry topic in Mathematics. Consequently, the activity seamlessly integrates with the developed 3in1 Geoboard and its associated exercises. As depicted in Figure 8, participants will undergo a pre-test before engaging in the game segment of the activity. The pre-test comprises six questions focused on the principles of Coordinate Geometry. Serving as an evaluation administered prior to the commencement of learning activities, the pre-test aims to assess participants' initial competency and ascertain their existing knowledge of the learning material. The results derived from the pre-test hold considerable value for instructors, aiding in the selection of appropriate teaching methods tailored to the specific needs of the students. This initial assessment is particularly pivotal as it establishes a baseline from which subsequent learning experiences can progress, ensuring effective alignment with participants' skill levels [21].

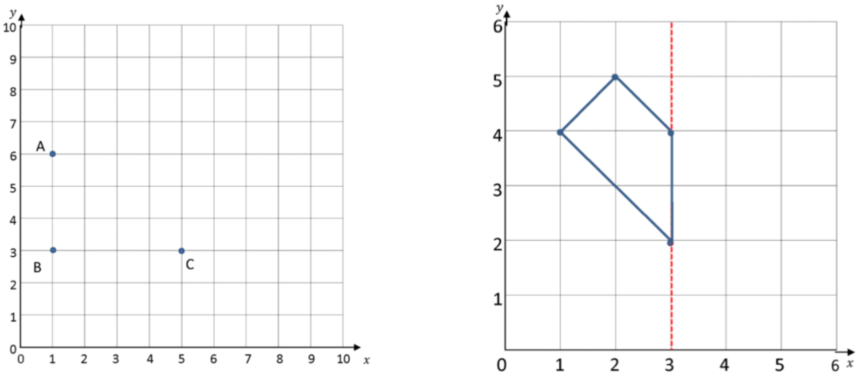


Fig. 8. Examples of Pre-test questions

Meanwhile, as for post-test, aims to collect and obtain information about participants' achievement levels or the content learned by each participant throughout the learning session and examples of post test questions as in Figure 9.

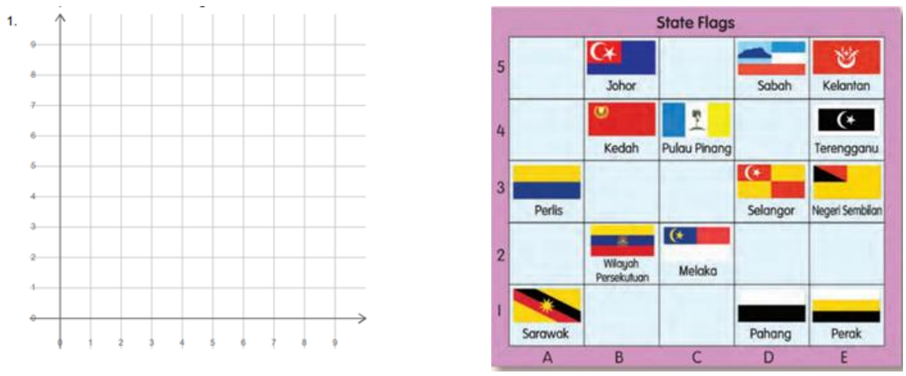


Fig. 9. Examples of Post-test questions

3.4 Developed 3in1 3D Geoboard: A Multi-Sensory Math Adventure Module

The module comprises three (3) game stations designed for all participants, with activities selected based on the Coordinate Geometry topic in Mathematics. The first activity, "Numerical Jumble," is tailored for visually impaired children who have learned basic braille numbers. Participants are tasked with guessing the numbers in braille based on the provided braille order, thereby enhancing their finger sensitivity to braille dots and improving braille recognition skills. The second activity, "Pinpoint Placer," involves each participant receiving a set of rubber bands to stretch, indirectly strengthening their hand muscles and increasing flexibility [22]. These rubber bands are used to create mathematical geometries on the geoboard, arranging braille geopins according to given mathematical questions. Lastly, the third game, "Geo Art," utilizes the 3in1 geoboard. Participants are provided with rubber bands and instructed to create their own geoboards using the geopins, placing them according to mathematical questions based on x and y directions. Instructions for each game station are summarized in Figure 10(a), (b), and (c), respectively.

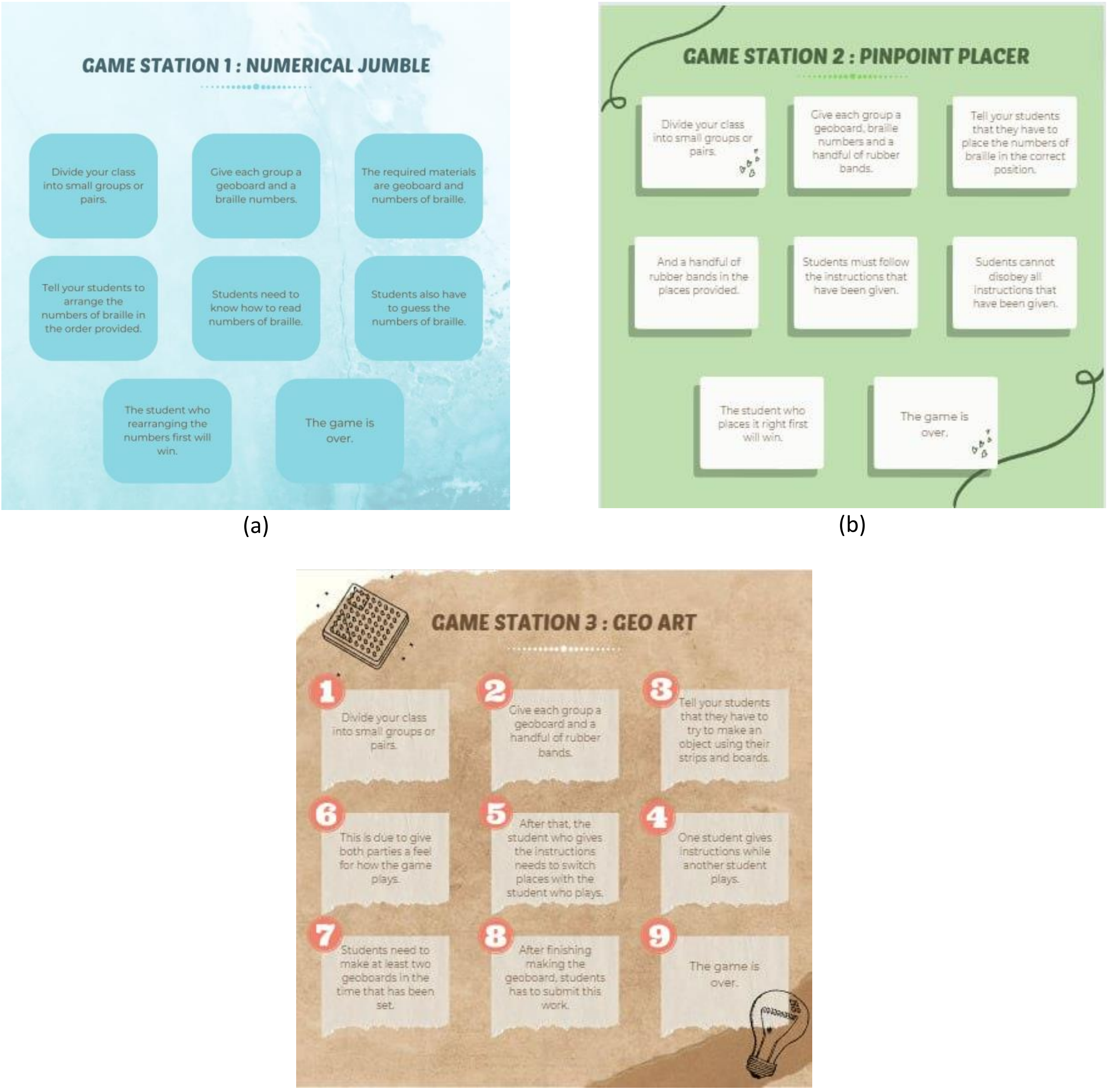


Fig. 10. Game instruction for (a) Numerical Jumble (b) Pinpoint Placer and (c) Geo Art in 3in1 3D Printed Geoboard module

4. Conclusions

In conclusion, this study marks a significant advancement in meeting the educational needs of visually impaired students in mathematics. Through the development of a multisensory module centered on the 3in1 Braille Geoboard, an interactive tool tailored was created to meet their unique learning needs. Innovative game-based activities like "Numerical Jumble," "Pinpoint Placer," and "Geo Art" have provided engaging hands-on experiences, enhancing mathematical skills and fostering tactile and spatial abilities. The successful integration of 3D printing, Braille notation, and game-based learning showcases the module's potential to transform mathematics education for visually impaired students. Continuing to refine and expand this approach, while researching its long-term impact, will further support academic achievement and inclusivity in education.

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