Empowering Braille-based Mathematics: Early Findings from the MathPad Prototype (A Tactile Grid for Spatial Math Using Nemeth Braille Code)

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Abstract

This paper presents the design, development, and early-stage testing of the MathPad – a tactile grid-based tool to enable representation and solving of spatial math sums in the Nemeth Braille code, for learners with blindness. MathPad enables the learner to represent as they solve spatially aligned mathematical problems using tokens or tiles with Numerals, Signs of Operations, Signs of Comparison etc. in the Nemeth Braille code. The Nemeth Braille Code for Mathematical and Scientific Notations or the Braille Mathematical Code of India (as used in some states) enables blind learners to read, write, save, and submit mathematical work independently – just as sighted learners do with pen and paper. The learning of mathematics is a concurrent process of familiarisation with the mathematical symbols and quantitative reasoning. The MathPad mimics the Arithmetic exercise book, to further support this process by allowing students to seamlessly transition to Nemeth Braille skills, or support their existing Nemeth Braille skills, while allowing them to read, write, and store their work. The Mathpad may be used alongside traditional Braille writing tools like the slate and stylus or the Brailler.

The device bridges significant gaps left by conventional tools such as the Taylor Frame, providing a scalable and accessible solution for learning and practicing math through touch-based technologies.

1. Background and Motivation

1.1 Why Do Literacy Skills Matter in Learning Math? Isn't Oral Learning Enough?

It is long known that repeated practice of Mathematical sums – of the same type, with slight variations, and with increasing levels of difficulty – is the foundation of learning Mathematics. Practice builds fluency, deepens understanding of concepts, and strengthens application skills. Regular practice not only improves problem-solving abilities but also boosts students' confidence in learning Math concepts. Math skills are developed through practice and effort, not just innate ability.

The pedagogy for teaching of Mathematics worldwide relies of written practice and is structured around regular solving practice sums/problems—through worksheets, classwork, homework, online tools and assignments. **Even Math textbooks are designed with multiple "Exercises" in every chapter to ensure learners have adequate practice.** [1]

Practice problems or sums also help the teacher to monitor the student's progress. Additionally, practicing Math also often mandates the need for writing out of the working or steps followed to arrive at the answer.

These good pedagogical practices for teaching of Mathematics apply to learners with blindness as much as they do for sighted learners. **Thus, literacy skills or having a medium to read the sums or questions and solve them independently, becomes crucial for learners with blindness.**[2] Oral learning alone cannot substitute for the repeated written practice that learning Math demands.

Just as a sighted learner uses a textbook, notebook, and pen, a learner with blindness requires literacy skills (Braille/Computers) to work independently at the same level as their sighted peers.

1.2 What is Spatial Math?

Mathematical work can be broadly divided into two forms of representation:

1. **Linear Math** – where sums, equations, or statements are written in a continuous sequence.
2. **Spatial Math** – where the alignment of digits and symbols is critical for following the steps correctly.

Examples of **spatial math** include:

- Addition and subtraction of numbers (1-digit, 2-digit, 3-digit, etc.)
- Multiplication of multi-digit numbers
- Long division
- Factorization (e.g., finding factors, LCM, HCF, etc.)

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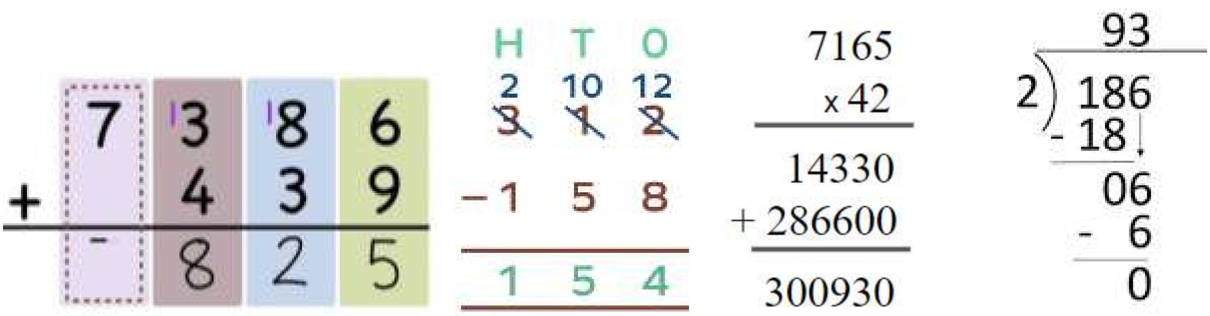
[1] Drawn upon the experience of one of the authors who is an experienced Nemeth Braille and Math teacher of students with visual impairment at XRCVC Mumbai.

[2] Drawn upon the experience of one of the authors who is an experienced Nemeth Braille and Math teacher of students with visual impairment at XRCVC Mumbai.

In all these cases, **place value alignment** is essential for following the steps to solve the sum.

Images of spatial math sums done in sighted-print can be found below:



1.3 Why Nemeth Braille?

The value of adequate practice, for all learners (blind or sighted), in the learning of Mathematics is highlighted above. However, **adequate practice cannot be achieved solely during school hours or in front of the teacher. A blind learner, like any student, must be able to practice independently, read the question, solve sums in writing, and submit their work for teacher evaluation.**[3] Thus, mastering an independent method for reading and writing becomes critical for blind learners.

Traditional tools like the Taylor Frame *do not* allow this. These methods do not allow a learner to keep a written record of their work or to solve *n* number of sums. Each sum solved in the slate has to be shown to the teacher, erased, and then replaced with the next one. This makes it impossible to practice adequate number of sums independently or to submit work for review—unlike sighted learners who can write freely in notebooks. Hence tools like the Taylor Frame when used as a standalone tool cannot be termed as a Literacy tool for Math i.e. a complete substitute for paper and pen used by sighted learners.

Note that mentioned above is the major limitation of the Taylor Frame, this is apart from the limitation that the Taylor Frame involves memorizing a completely new code to represent numbers and symbols that is different from standard Braille code, and will not be used anywhere else.

1.4 The Reason for the development of MathPad

[3] Drawn upon the experience of one of the authors who is an experienced Nemeth Braille and Math teacher of students with visual impairment at XRCVC Mumbai.

The Nemeth Braille Code (or The Braille Mathematical Code of India that is based on the Nemeth Braille code) enables blind learners to read, write, save, and submit mathematical work independently—just as sighted learners do with pen and paper.

MathPad, which is based on the Nemeth Braille system, further support this process by allowing students to seamlessly transition to or support their existing Nemeth Braille skills, while allowing them to read, write, and store their work using traditional Braille writing tools like the slate and stylus or the Brailler, alongside the use of the MathPad. This is the reason why the MathPad is designed to be used alongside traditional Braille writing systems.

Note: Reading and writing Math on the Computer is the other option that completely aids independent practice and meets all the objectives elaborated above. However, there are specific scenarios in which one selects Math-on-Computer or Nemeth Braille as the literacy format for doing Math. That is covered in a separate section below.

2. The Design of the MathPad

Mathpad is a tool designed by Touchétech Labs with inputs from Vision Empower to help students with visual impairment learn spatial Mathematics while learning Mathematical symbols just as their sighted peers do.

The MathPad kit includes a Grid board, Tokens or Tiles having four tactile faces; and a storage unit for storing the Tokens or Tiles in groups. Each face of the token or tile has the Braille code for a number or mathematical operation. Each token also has a unique tactile mark for quick orientation or finding.

The innovation lies in how each Tile serves as both a data storage unit (i.e. the Braille code on the faces) as well as a tactile mark to identify the Tiles.

2.1 The Grid Structure

The MathPad consists of a two-dimensional grid, functioning as an array of storage receptacles for the Tokens or Tiles with tactile Braille and markings on them. Each receptacle holds a single four-faced Token or Tile, with height to width dimensions of receptacle allowing for Tiles to be placed according to a predefined orientation convention. The grid is designed to maintain fixed spatial relationships between cells, preserving the relative positioning necessary for reading mathematical notation accurately.

2.2 The Four-Faced Tile Design

Each Tile features four distinct faces, each with a unique texture, orientation, or tactile marker. These faces correspond to four possible tactile representations that can be encoded on each Tile. For example group 1 would be 1,2,3,4 in Nemeth code on 4 adjacent faces of a Tile while rotating about a particular axis. The remaining two opposite faces on a perpendicular axis have one featureless face that orients the Tile to the left margin of the grid, while the right face oriented facing the right edge of the grid has a storage receptacle or storage drawer code. For instance one tactile line, to store Tiles in storage drawer 1, two lines on a Tile would indicate that Tile belongs to group 2 and is stored in storage drawer 2 etc.

The idea being explained is that Tiles with 4 faces allow for rapid selection of faces used for representation. However given that each Tile can be used to represent only 4 distinct characters of information, a system of grouping of Tiles using the line markers for group identification has been implemented. By providing distinct storage receptacles for Tile groups, rapid selection of Tiles and appropriate face identification is possible. Some systems use up to 16 different characters encoded per token. This has resulted in a need for a system of encoding that is unique and different from existing standard Braille and Nemeth codes.

The proposed MathPad uses Braille and Nemeth code. Tile variants to represent operands and symbols are made using 2 or more ganged Tile combinations

For example:

Tile 1 could represent 1,2,3,4

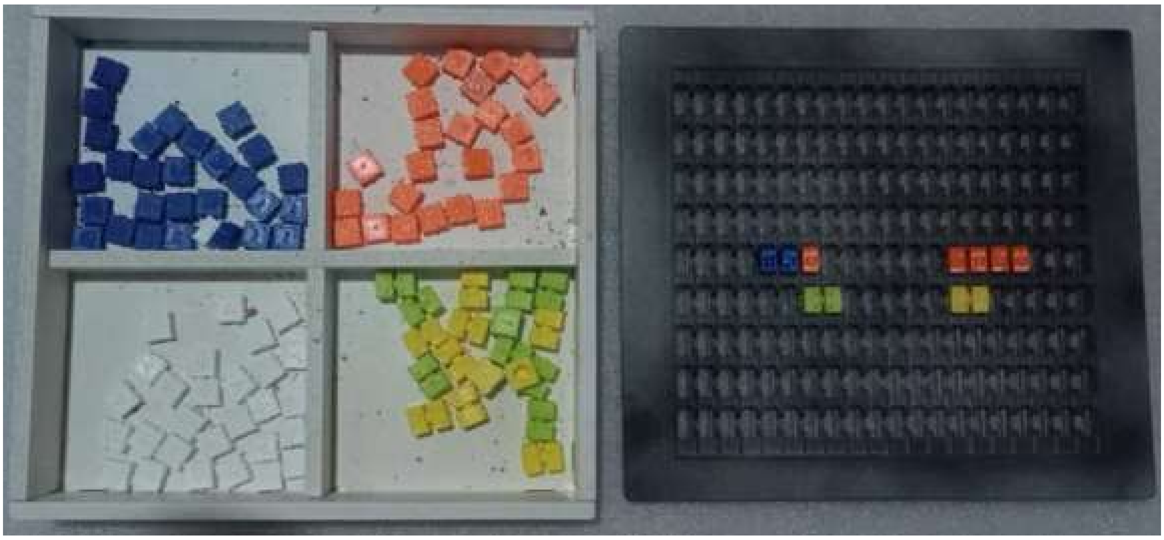
Tile 2 could represent 5,6,7,8

Tile 3 could represent 9,0,(.), - (decimal and negative numbers)

Tile 4 . +,-,*,/, (Ganged Tiles)

Ganged Tiles are 2 or more Tiles joined together used to represent operands and symbols as defined in Nemeth and other Braille based codes.

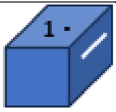
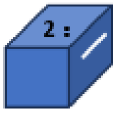
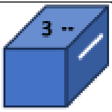
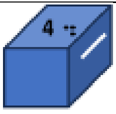
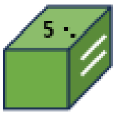
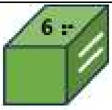
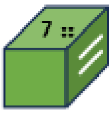
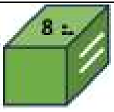
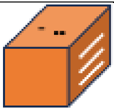
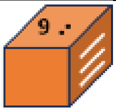
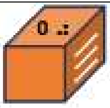
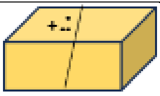
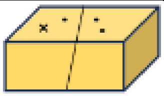
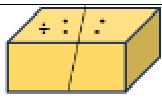
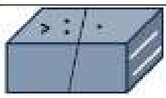
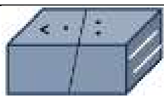
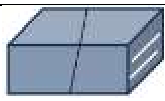
This hybrid system thus reduces tactile ambiguity while allowing users to build and manipulate numeric constructs spatially.



2.3 Storage and Retrieval Mechanism

Efficient Tile data representation and retrieval is central to the MathPad's design. Each Tile's orientation faces also encodes its storage location. This allows for organized storage and quick identification, as would happen while playing with 26 variants of Tiles stored in a bag as in a game of Scrabble.

By feeling the orientation and texture of a Tile, a user can immediately identify its data type and storage region, and face selection. greatly enhancing MathPad's Tile selection and placement efficiency.

Single Tile Set 1					*Rotation on 4 faces, representing numbers 1, 2, 3, 4*
Single Tile Set 2					*Rotation on 4 faces, representing numbers 5, 6, 7, 8*
Single Tile Set 3					*Rotation on 4 faces, representing numbers 0, 9, minus sign, decimal point*
Double Tile Set 4					*Rotation on 4 faces, representing numbers plus sign, minus sign, divided by sign and multiplication sign (Signs of Operations)*
Double Tile Set 5					*Rotation on 4 faces, representing numbers Equals to sign, Greater than sign, Lesser than sign and a blank face (Signs of Comparison)*

3. Prototype Testing and Feedback

Early testing focused on how blind students and their teachers interacted with MathPad for basic arithmetic, place-value alignment, and more complex problems such as multiplication, long division, and decimal operations.

Participant details:

Number of teachers: 4 math teachers (2 visually impaired teacher and 2 sighted teacher)

Number of students: 7

Prototyping sessions included:

- ✓ Practicing sums of various difficulty, monitoring alignment and correct working.
- ✓ Tracking student ability to independently set up, solve, and check problems.
- ✓ Collecting feedback on tactile recognition, usability, and fatigue.
- ✓ Recording challenges in quick symbol identification and maintaining orientation.
- ✓ Strong user appreciation for the spatial alignment features.
- ✓ Some challenges in recognizing isolated Nemeth numbers without numeric indicators, suggesting further refinement in tactile clues and orientation is needed.
- ✓ Teachers found MathPad valuable for reviewing students' steps, echoing the role of notebooks in sighted math practice and it has strong potential for integration into regular math lessons to strengthen spatial and numerical cognition in learners with visual impairment.


4. Limitations and Future Work

Our findings from the two rounds of field resting reveal that despite its innovative approach, the adoption of MathPad faces some limitations at the classroom level. A primary concern lies in the strong familiarity and comfort teachers have with traditional tactile tools such as the Taylor Frame. Many educators, especially those who have not learned the Nemeth Braille system, exhibit reluctance in transitioning to a new method. This resistance is often rooted in a lack of awareness regarding the value of reading and writing mathematics using a unified code. Teachers who are unacquainted with Nemeth may not fully recognize the necessity and benefits of representing mathematical content in a single, standardized Braille code. Consequently, without additional training and sensitization, widespread adoption among educators remains a challenge.

MathPad, while innovative, requires further research and iteration:

- Mapping standard Nemeth symbols to physical tokens demands ongoing refinement and possible customization per syllabus.
- User feedback highlights the need for even more distinctive tactile cues, especially for learners new to Nemeth or tactile math tools.
- Integration with electronic systems (e.g., for recording answers or auto-grading) is a promising area for future development.

Planned next steps include:

- Broader classroom pilots in partnership with schools.
- Iterative design based on teacher/student input and tech advancements.
- Exploration of hybrid tactile-electronic models for greater accessibility and data capture.

5. Conclusion

The development and pilot testing of MathPad demonstrate its strong potential to transform how learners with visual impairment engage with mathematical concepts. By combining tactile representation with the Nemeth Braille code, MathPad enables independent, spatially organized problem-solving and mirrors the experience of working on a traditional arithmetic notebook. Early classroom observations show that students quickly adapted to the tool and teachers recognized its value in reinforcing Braille-based math learning and conceptual understanding. While further refinement is needed to enhance tactile differentiation and align with diverse curricular needs, MathPad represents a significant step toward inclusive, accessible, and scalable math education. With continued research, co-design, and classroom integration, it can evolve into a comprehensive learning system that bridges tactile and digital modalities, empowering learners with blindness to explore mathematics with confidence and independence in STEM learning environments.

6. References

American Printing House for the Blind. (2018). *Nemeth code for mathematics and science notation: 1972 revision*. Louisville, KY: Author.