The Balance Number Line: Incorporating Vestibular Activation into Math Instruction

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Abstract

Objective: To Investigate how the integration of vestibular-activating sensory tools into math instructional designs impacts a learner who is frequently vestibular-seeking.

Methodology**:** This is a pilot for a broader mixed methods design-based research project using the Balance Number Line (BNL), a balance board-based math design that incorporates a common sensory regulatory movement, rocking, into conceptual learning about absolute value and negative numbers. A semi-structured pedagogical interview was conducted consisting of a series of mathematical tasks on the BNL with a 13-year-old learner on the autism spectrum who self-reported frequent vestibular seeking behaviors (jumping and climbing). Qualitative data analysis was conducted on audio-video recording of sensory behavior type and function over the course of the interview.

Results: While completing mathematical tasks with the BNL, the participant fluidly engaged in vestibular sensory behavior in several ways: 1) leveraging mathematical artifacts to act upon rocking, as when using positions on the number line to rock the same degree to each side; 2) using rocking as feedback about mathematical quantities, as when comparing the degree of tilt associated with two positions on the number line; 3) self-regulating, engaging in rhythmic rocking between problem-solving episodes.

Discussion: This case shows that the sensory design of instructional materials shapes what sensory input may become a resource for conceptual learning. This suggests the importance of evaluating the forms of sensory engagement offered by dominant learning tools such as lectures and manipulatives.

Conclusion: In the sensory-enriched context of the BNL, sensory behaviors such as rocking entered into mathematical discourse and in parallel, supported spontaneous sensory regulation. New forms of multisensory (here, vestibular) learning engagement are possible that may be better suited to some learners' sensory profiles.

Background

- Cognitive science suggests that conceptual learning is rooted in sensorimotor experience (Varela et al., 1991). This suggests that the sensory composition of learning tasks stands to impact students' access to conceptual learning (Tancredi et al., 2020).
- Supporting learners' sensory needs (Dunn, 1997) is often approached by providing supports in parallel to or outside of academic activities. This project investigates how *integration* of enhanced sensory activation *into the learning design itself* affects learning and engagement.
- Design conjecture: The integration of vestibular-activating sensory tools with learning designs will improve their efficacy for learners with vestibular sensory-seeking tendencies.

Research Questions

1. How does sensory engagement and behavior partake in mathematical thought?
2. How do sensory task demands interact with learner-initiated sensory-regulatory behaviors during learning?

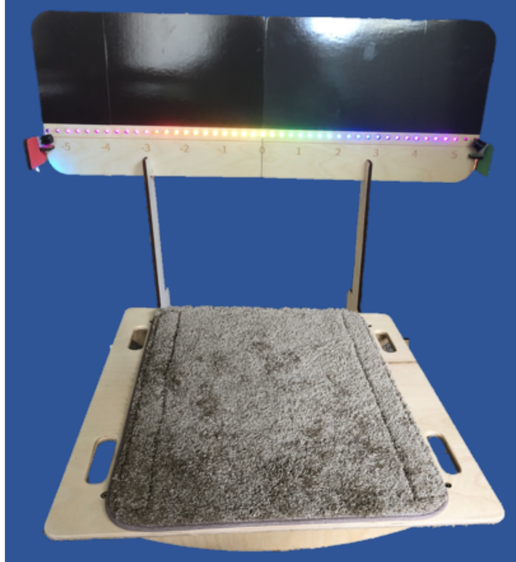
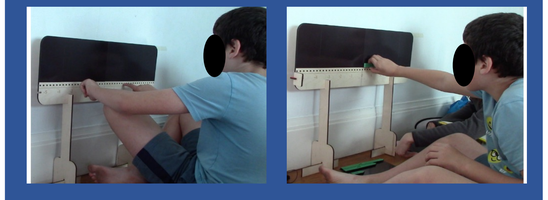


Figure 1. The Balance Number Line (BNL).

(a) The learner sits on the balance board and moves their hands along the illuminated number line. (b) Hand positions shifts yield shifts in the board's balance: for example, positioning hands at -2 and 2 results in a flat horizontal angle, while -3 and 2 yield a slight tilt to the left.(c) Magnetic arrows are used to discuss, plan, and document movements.



Methodology

- The BNL was developed using the iterative design-based research process (DiSessa & Cobb, 2004) to targets 6th grade math Common Core Standards for learning about **negative numbers and absolute value.**
- A pilot ~1.5-hour **semi-structured pedagogical interview** (Ginsburg, 1981) consisting of mathematical tasks was conducted with participant (13 y o male on the autism spectrum) who **frequently engaged in vestibular seeking behaviors** such as climbing and jumping according to self-report.
- Data sources included audio-video recording, participant debrief interview on the design, and a parent debrief interview on the participants' sensory and learning profile.

The following initial qualitative codes were set, drawing upon phenomenological perspectives on sensory behaviors (Nolan & McBride, 2015):

Theme	Code	Operational Definition	Example
Sensory behavior	Vestibular	Activity that stimulates the vestibular system in the inner ear through changes to head position and/or orientation.	rocking, balancing
	Proprioceptive	Activity that stimulates the proprioceptive system of muscles and joints through changes to body position.	bracing legs against wall, lifting heavy objects
	Tactile	Activity that stimulates the skin through dynamic contact.	Scratching skin with edge of magnetic arrow
Function	Communication	Sensory behavior is deployed as part of mathematical discourse.	Demonstrating the degree of tilt associated with a particular number line position while verbalizing a strategy.
	Regulation	Sensory behavior is used to maintain a calm and engaged state of arousal.	rhythmic rocking while waiting for the next problem.
	Exploration	Sensory behavior is engaged as part of mathematical problem-solving process for purpose of gaining information.	Checking whether the board is in balance when hands are at -3 and 3.

Results

Rocking vestibular sensory behaviors were selected as a focal behavior due to their relation to the specific affordances of the balance board. Three types of rocking movements manifested:

(1) **Rocking as target outcome**. The participant aimed to create a rocking pattern and used mathematical artifacts to do so, for example using number line positions to rock an equal amount to each side.

(2) **Rocking as mathematical feedback.** The participant used the position of the balance board to provide feedback for mathematical comparisons, as when checking if two points were "in balance" to compare their absolute value.

(3) **Rocking as regulation.** Rhythmic rocking emerged during moments of reflection, discourse, and waiting.

Discussion & Conclusion

- **Vestibular sensory information can be recruited as a resource for mathematical reasoning**, Here, negative numbers were conceptualized as the equilibrating counterpoint of their positive counterpart.
  - These preliminary findings resonate with phenomenological perspectives that **sensory behaviors can be exploratory, communicative, and regulatory** (Nolan & McBride, 2015) and show the impact of instructional designs' sensory features on learning.
- Sensory behaviors such as rocking **co-evolve with the mathematical task,** changing in response to sensorimotor demands.
  - The findings suggest the need to **reanalyze the efficacy of existing learning tools** such as lectures and manipulatives **according to the types of sensory engagement they offer** learners.
- Next steps in this project include running further participants and quantitative comparison of versions of the number line task with and without the balance board.

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