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Graphing with Balance Board Math: Critical embodied design for regulation and learning

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Abstract: Some forms of movement, such as rocking, are common means of sensory self-regulation yet are discouraged in classroom contexts. We analyze the ableist underpinnings of this approach, and ask instead: could sensory-attractive activities such as rocking instead be solicited to serve content learning? Our design-based research project, Balance Board Math, fosters sensory–cognitive opportunities for the regulatory movement of rocking to serve as an intrinsic interaction resource for exploring mathematical graphical representations, with a focus on properties of sinusoidal functions such as frequency and amplitude. We analyze the role of balance/vestibular activation in pilot participants' exploration of graphing before, during, and after Balance Board Math activities.

Theoretical framework and design objective

Research on the relationship between bodily movement and learning flourishes in the learning sciences separately from fields such as psychology and occupational therapy (OT). While learning sciences researchers, inspired by the embodied turn in the cognitive sciences (e.g., Newen et al., 2018), are actively evaluating interactive designs that recruit bodily movement to enact concepts (Lee, 2015; Zhong et al., 2021), psychologists and occupational therapists advocate the maintenance of optimal alertness levels by engaging sensory stimuli that are of an adaptive intensity for one's neurological sensory processing profile (Dunn, 1997). As such, embodied cognition and sensory regulation paradigms currently offer distinct implications for understanding and fostering learning. Embodied cognition views of education construe movement as a means of exploring concepts (e.g., walking along a number line); sensory regulation construes movement as a means of regulating one's arousal state to sustain engagement (e.g., bouncing on an exercise ball). These two bodies of literature remain disparate due to the assumption that regulation and cognition are independent processes. We ask: might these siloed theoretical perspectives mutually inform each other towards a more holistic understanding of movement in learning? What if students' spontaneous regulatory activity, such as rocking or fidgeting, were resources for novel forms of instruction? We investigate these questions by creating a math instructional context where the sensory regulatory behavior of rocking is invited to participate in math conceptual exploration: Balance Board Math (BBM).

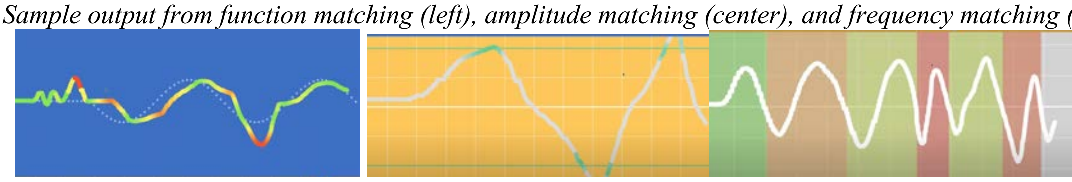
Self-initiated sensory-regulatory movements, such as pacing or rocking, are often read as disruptive, and such readings are compounded by the divergent sensory practices of many learners with disabilities (for example, learners on the autism spectrum; see Nolan & McBride, 2015) as well as racialized readings of students' bodies (Annamma et al., 2013). Situated within the Special Education Embodied Design (SpEED) design-based research framework (Tancredi et al., 2022), BBM sets out to deconstruct ableist norms of bodily engagement in schools, legitimizing learners' diverse sensory regulatory movements within the classroom. Inspired by the ubiquity of spontaneous vestibular-activating movement such as rocking and pacing, we imagine vestibular-driven mathematical conceptualizations that could offer new resources for inclusive instruction. Acknowledging the spectrum of sensory profiles (Dunn, 1997), BBM seeks to offer children the opportunity to engage their vestibular sense at an intensity adapted to their specific neurological thresholds and needs.

Design

Balance Board Math (BBM) (Figure 1) is a motion-graphing learning environment (Duijzer et al., 2019), where learners explicitly recruit and refine their capacity to attend through their vestibular sensory modality as their means of mathematical exploration. BBM establishes a whole-body relation to graphs, mirroring observations of skilled graphers "being the graph," not just "seeing the graph" (Gerofsky, 2011). In BBM, a sensor detects the board's angular shifts. As learners rock on the board, they draw a live graph representing properties of their rocking which is projected on a screen in front of them (Figure 1).The speed and sensitivity of the graph is calibrated at the onset to each student's comfort. Learners' left/back rocking correlates to an upwards trajectory and right/forward correlates to a downwards trajectory. BBM activities focus on sinusoids to solicit the rhythmic and repetitive rocking patterns that are characteristic of sensory regulation. BBM's discovery-based learning activities explore different aspects of a function: graphing, amplitude, and frequency (Figure 2). Learners are tasked with figuring out how to generate and maximize a focal color (here: green) within each activity. In Function Exploration, the user's line turns green if they trace a function displayed on the screen (Figure 2, left). In Amplitude Exploration, the graph turns green when they rock at a target amplitude (Figure 2, center). In Frequency Exploration, only periods of a focal length turn green (Figure 3, right). Users come to identify and control different parameters of their graphs. The specific focal amplitude, frequency, or function can be modified, serving primarily as a context to guide users to attend to different aspects of their rocking.

Figure 1
Rocking on a balance board (left) generates a graph (right)

Figure 2
Sample output from function matching (left), amplitude matching (center), and frequency matching (right)



Research questions

1. What roles do vestibular-stimulating movement play in learning when invited into math instruction?
2. Does BBM change children's perception of graphs, as expressed through their speech and gestures? If so, how?

Methods

BBM was piloted through semi-structured clinical interviews with six children grades 2-6 individually or in pairs in a lab or after-school learning center. Upon trying each activity, participants were prompted to ideate on what made green and offered to try again until they were satisfied with their explanation and outcome. Before and after the interviews, participants were prompted to describe three static images of sinusoidal graphs using gestures and words. We transcribed and coded video for rocking pattern, task strategy, and regulatory activity, and two raters blinded to pre/post order coded graph gestures quantitatively for the "seeing" vs. "being" the graph criteria in Gerofsky (2011). For a more in-depth description of methods and analysis, see (Tancredi et al., in press). Here, we draw examples from the case of one 6th-grade boy, Kyle, for whom we had the most complete data.

Results

Balance Graphing Interactions

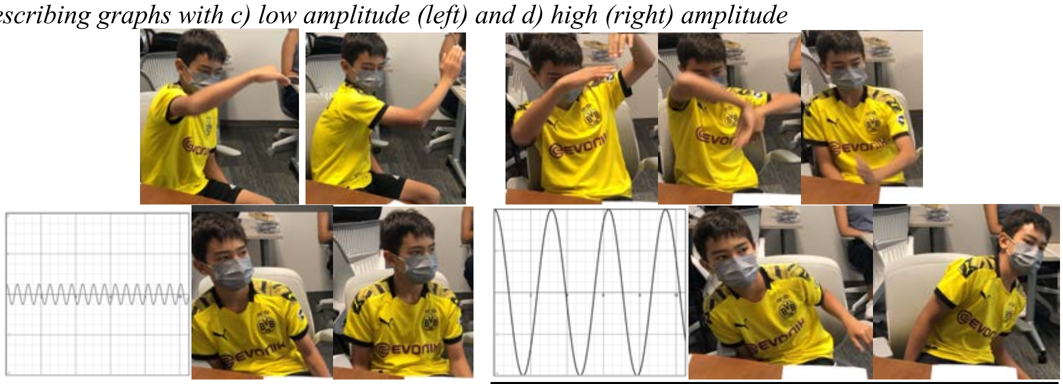
Participants rocked to explore each BBM activity. Participants expressed a range of vestibular sensory preferences during these activities, from gentle rocking with limited amplitude to intense rocking across the board's full range of movement. Our focal case student, Kyle, explored the three activities together with a peer, Cory, for several rounds, continuing after Cory departed. Kyle generally rocked with greater intensity than Cory. The pair were able to identify and control the focal parameter in each activity through cycles of graphing and reflection, and to communicate about their products across their different rocking styles.

Consistent with a sensory regulation perspective (e.g., Dunn, 1997), during activities like listening that entail less inherent vestibular stimulation, the children spontaneously rocked on the board. Children informally identified as highly sensory-seeking by their parents or instructors exhibited a higher frequency and intensity of such rocking. In one instance, Kyle was engaged in such rocking when the interviewer commented, "you mentioned earlier something about the distance between each hill." With the words "distance between each hill," Kyle's rocking suddenly shifted to slow, sweeping rocks, corresponding with how he would have created spaced out graphical features earlier. What would traditionally be interpreted as background movement-for-regulation fluidly transformed into movement-as-thinking as Kyle acted out the conjecture raised by his interlocutor. At times, such rocking seemed to participate directly in his thought process. For example, when asked, "what did you notice this time about green?" Kyle responded, "Maybe it's not how far it is, but… [rocks right, left, right, left, slows to a stop in the center]. I don't really know." Rocking was enfolded within his sense-making utterance, perhaps reanimating the actions that produced his graph, perhaps expressing a thought not yet verbalizable, as observed in gesture–speech mismatch (Church & Goldin-Meadow, 1986). What would traditionally be interpreted as sensory-regulatory behavior in this context fluidly interacted with the meaning-making process.

Pre and Post Graph Interviews

Across participants, there was a statistically significant increase in mean being-the-graph gesture index scores from pre to post ($t = -2.19$, d.f.=11, $p < 0.05$) (see Tancredi et al., in press), reflecting progress from "seeing" towards "being" the graph on Gerofsky's (2011) scale. For example, during all three pre-interview graphs, Kyle positioned his gestural graph's x-axis at roughly shoulder height and spanned from nose/forehead down to heart for the y-axis (Figure 3a). During the post-interview, his gestures covered a broader span, with the x-axis falling at heart level and the y-axis spanning from the top of his head to his waist (Figure 3b). Kyle also showed newfound core-muscle and spine engagement in the post interview. Furthermore, during the post-interview, Kyle exhibited rocking movements accompanying his speech descriptions: he he rocked his upper body left to right as he described one graph as "quicker," and another as "slower um but like rocking a lot farther" (Figure 3c, 3d). Kyle's rocking gestures also reflected graphs' relative amplitudes. When describing a low amplitude graph (Figure 3c), he rocked about 15 degrees from vertical, whereas for a high amplitude graph, (Figure 3d), he rocked about 25 degrees from vertical. Kyle's rocking motions during verbal descriptions suggest that applying the balance board instrument as a means of drawing graphs has shaped his *utilization scheme*: he perceived graphs as affording rocking (Vérillon & Rabardel, 1995).

Figure 3
a) Kyle gestures sin(x) (pre, upper left) and b) cos(x) (upper right); Kyle rocks while verbally describing graphs with c) low amplitude (left) and d) high (right) amplitude



Discussion

These preliminary findings suggest that dynamic/interactive/whole body experiences with BBM may residually affect how students perceive traditionally static graph displays even when off the balance board, enriching their enactive landscape (Kirsh, 2013). They also suggest that BBM could be a rich context to study the intersection of regulatory and mathematical movement. This design-based research project offers a prospective proof-of-concept for recruiting regulatory activity into mathematical discourse, as well as for the viability of vestibular experiences in conceptual learning. Future work will further evaluate the interaction between different sensory profiles and BBM activity and seek to evaluate BBM in inclusive education settings across profiles. To this end, BBM will expand into multi-user activities and other access modalities such as sonification.

Conclusion

BBM not only provides enhanced opportunity for vestibular sensory regulation, but also positions vestibular experience as integral to mathematical exploration. The project seeks to bridge previously disparate research on sensory regulation and math education and ultimately contribute evidence to elaborate upon embodied cognition theory through a sensory perspective. Embodied design (Abrahamson et al., 2020) calls for instructional design to embrace and build from learners' embodied resources. Grounding in these preliminary results, we propose that to do so, instructional design must 1) offer students access to a range of sensory stimulation to support regulation, and 2) think beyond the restrictive norms of classroom bodily engagement and the narrow focus on dominant instructional modalities like vision and audition. BBM focuses on rocking and the vestibular sense, but implications may carry over to other senses commonly engaged for sensory regulation such as the tactile and proprioceptive senses. Legitimizing sensory regulation within educational practice can help deconstruct ableist instructional norms that disadvantage sensorially minoritized learners and introduce new entry points into academic concepts for all learners.

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