Movement Matters

How Embodied Cognition Informs Teaching and Learning

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13 The Need for SpEED: Reimagining Accessibility through Special Education Embodied Design

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Making learning media accessible to learners with non-majority sensory profiles is often conceptualized as presenting information in an alternate format, such as providing auditory descriptions of visual images. This definition presupposes that information remains fundamentally the same regardless of how media are used. A blind learner[1] might use a tactile version of a visual diagram, or a Deaf learner might access a spoken lecture through a sign language interpreter; at first glance, these students may be thought to access identical educational content to their peers. They benefit from state-of-the-art accessibility solutions, yet we propose that these students are not yet being granted fully equitable access to content. Emerging evidence from the embodiment turn in the cognitive sciences suggests that our bodily engagements with the world shape our cognitive structures (Fincher-Kiefer, 2019). What you see may be what you get, but what you hear, touch, or move might get you something else.

Educational design frameworks implicitly or explicitly take up extant theories of cognition and learning. As embodied cognition theory garners traction, we propose that it is necessary to rethink accessibility for students with sensory differences from this new theoretical perspective. The result of this reimagining is a new framework for design and design-based research that we term *Special Education Embodied Design* (SpEED). In many ways, SpEED is complementary to current accessibility frameworks and provides a means to develop more specific tools for accessibility. At the same time, SpEED's different theoretical foundations take accessibility in new directions.

In this chapter, we present SpEED as a new design-based research framework. We begin by describing the Universal Design for Learning (UDL) framework and its theoretical underpinnings. We then discuss how embodied cognition and its derivative design framework, embodied design (Abrahamson, 2014; Abrahamson et al., 2020), can provide a productive rethinking of these theoretical underpinnings, drawing upon each framework to form SpEED.

We introduce the core principles of SpEED and illustrate them with four SpEED projects, each developed for a different student population currently served within special education. Setting forth from the precedent of the UDL framework, we show how SpEED illuminates a new perspective on accessibility. We conclude with a discussion of where SpEED might go next.

The UDL Framework and Cognitive Neuroscience

Universal design began in architecture as a paradigm for providing equitable access to physical spaces (Mace et al., 1991; see also Goldsmith, 1997). UDL took up this mantle in education to guide educators in embracing individual differences in students' learning needs, abilities, styles, and preferences (CAST, 2018; Rose & Meyer, 2002; Meyer et al. 2014). The educational framework uses a variety of teaching methods to remove any barriers to learning and to give all students equal opportunities to succeed. In UDL, differences are flexibly accommodated through proactively offering students diverse representations, modes of expression and action, and means of engagement.

UDL takes up a view of learning rooted in cognitive neuroscience. The design principles of UDL are defined according to the three primary sets of brain networks activated during learning: recognition networks, strategic networks, and affective networks (e.g., Kandel et al., 2000; Damasio, 1994, as cited in Rose & Meyer, 2002, chapter 2). The recognition networks, including the visual and auditory cortexes, categorize information. These gave rise to the UDL principle of *multiple means of representation.* The strategic networks, including the frontal lobes of the brain, organize and express thoughts and ideas. These yielded the principle of *multiple means of action/expression.* The affective networks, including the limbic system, drive a learner's excitement and motivation. This final set gave rise to the principle of *multiple means of engagement.* We suggest that the use of neural networks as organizing principles for UDL reflects dominant views at the time of UDL's inception that mind and body are separable and that cognition is strictly the domain of the brain (Thagard, 2019).

The Embodied Design Framework and Embodied Cognition

Distinct from the implicit neural theoretical foundations of UDL, embodied cognition shifts from understanding cognition as based primarily in the brain to understanding it as including and emerging from the body and bodily activity (Newen et al., 2018; Shapiro, 2014). In this chapter, we will limit our scope to one lineage of embodied cognition of broad relevance in education: enactivism.

Enactivism posits that the material body-in-action forms the foundation of the mind (Hutto & Myin, 2012). Perception consists of perceptually guided action (Varela et al., 1991): we make sense of sensation through our actions in the world. Rather than a sequential process where sensation triggers processing and consequently action, perception and action mutually inform one another moment to moment in a *perception-action loop.* With repetition, the sensorimotor patterns supporting action give rise to cognitive structures.

Such an understanding of thinking and learning frames the ways we design in qualitatively different ways: the body itself becomes a primary instructional resource. Embodied cognition has inspired educational designs that use the body in new ways (e.g., Kelton & Ma, 2018; Nathan, 2014; Sinclair & Heyd-Metzuyanim, 2014; Vogelstein et al., 2019). The embodied design framework (Abrahamson et al., 2020; Abrahamson, 2014) codifies implications of enactivism for educational design. Embodied design aims to create the conditions for new sensorimotor schemes to emerge. Designers start from learners' existing resources, including their sensorimotor capabilities and innate capacity for certain perceptual judgements. Designers then render target concepts as a phenomenon that learners can explore using their existing resources. Disciplinary forms such as symbolic artifacts and measurement instruments are then introduced as potential tools to enhance the regulation, evaluation, or explanation of learners' initial responses.

Embodied perspectives are yielding meaningful reanalyses of disability (de Freitas & Sinclair, 2014; Lambert, 2019; Toro et al. 2020; Yeh et al., 2020) and UDL (Abrahamson et al., 2019). Building upon Abrahamson and colleagues (2019) prior efforts to enrich UDL through enactivism, we aim to crystalize embodied cognition into a framework for accessibility-focused design-based research.

SpEED Principles

SpEED reimagines accessibility from an embodied cognition perspective. It shares both UDL's commitment to proactive, adaptive education and embodied design's commitment to grounding in students' specific embodied resources.

SpEED sets forth from the following theoretical and ideological commitments.

1. *Learning happens through the body's sensorimotor engagement with the world.* SpEED roots in embodied theories of cognition and learning, which posit that the nature of sensorimotor engagement fundamentally shapes the learning that takes place.

2. *Learning begins from learners' existing embodied resources.* Embodied resources include prior sensorimotor experiences, practices, processes, and abilities.

3. *Instruction must flexibly adapt to learners' sensorimotor diversities.* This principle takes up disability studies' commitments to embrace human variation, challenge notions of normalcy, and recognize the social nature of disability (Ferguson & Nusbaum, 2012). SpEED actively centers learners whose educational potential could be further targeted in the general education classroom. It requires attention to how learners vary in their sensorimotor experience and how such diversities give rise to different cognitive architectures.

SpEED is a design-based research framework with a strong commitment to bridging theory and practice (Tancredi et al., 2020; Tancredi et al., 2021). The design-based research approach allows SpEED to both develop new useful practices (Odom et al., 2005) and create new contexts within which to empirically test embodied cognition theory (Cobb et al., 2003).

SpEED Parameters

Drawing on literature around multimodality and embodiment, we define three physical factors as key parameters of SpEED: media, modalities, and semiotic modes. *Medium/media* denotes cultural and natural material substrates such as pen and paper, a tablet interface, or the body (Kress, 2001). *Modality* delineates the sensorimotor systems recruited by a task. We include sensory systems such as the visual, auditory, tactile, body in space (proprioceptive), and balance (vestibular) systems, as well as kinesthetic forms of engagement such as manual, oral, or whole body (Edwards & Robutti, 2014). *Semiotic mode* refers to a system of meaning-making (Kress, 2001). These may include spoken or signed language, gesture, or mathematical symbols. Media, modalities, and semiotic modes act as interdependent constraints on the perception-action loop (figure 13.1). In turn, these factors mold what cognitive structures can take shape.

SpEED in Action: Introducing Four Designs

We present four SpEED examples that illustrate how SpEED reimagines accessibility. These four design-based research projects have convergently evolved through research on specific design problems affecting students in special education. In each case, embodied cognition theory has generated new possibilities by offering a new lens on long-standing problems of practice. Each SpEED project has a target population and specific learning design objectives; per SpEED principles, each begins from learners' existing embodied resources to design media that fosters sensorimotor engagement to cultivate

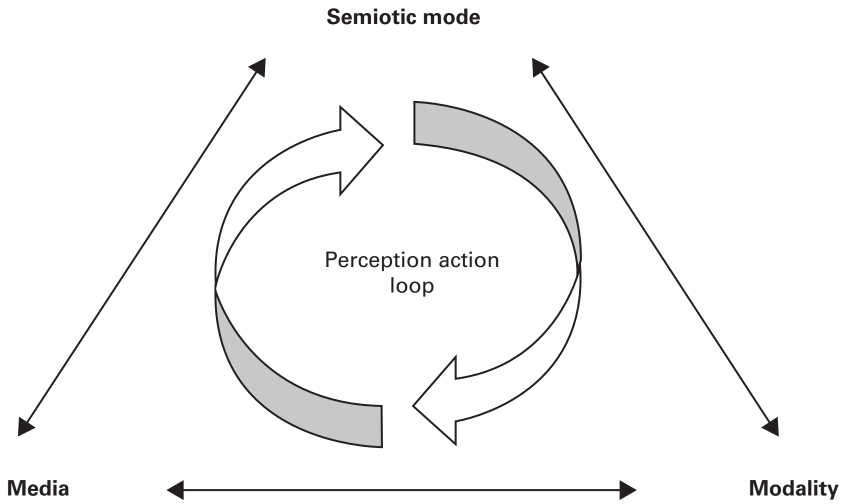

Figure 13.1
Key parameters of SpEED: media, modality, and semiotic modes. Media, modality, semiotic modes, and the reciprocal relations among them constrain possibilities for perceptually guided action.

learning (table 13.1). Three of the four SpEED projects deal explicitly with mathematical concepts; the fourth targets peer interaction. Triangulating across these four distinct populations and contexts demonstrates SpEED's widespread utility to research on accessibility and diversity.

The Balance Number Line

The Balance Number Line[2] (BNL, figure 13.2) re-envisions instruction on absolute value and negative numbers for vestibular-seeking learners. Extant theories in psychology and occupational therapy literature purport that sensory stimulation within an optimal range plays a key role in attention and self-regulation, with the optimal range varying by individual (e.g., Dunn, 1997). Stimulation levels that are comfortable for the sensory majority may be excessive or insufficient for some learners. A number of disabilities including attention deficit hyperactivity disorder (ADHD) and autism[3] (Little et al., 2018) are frequently associated with differences in sensory modulation, so learners in special education are especially vulnerable to sensory mismatch with their learning environment.

Evidence suggests that sensory experience impacts academic outcomes: sensory differences predict academic learning for children on the autism spectrum (Ashburner, Ziviani, & Rodger, 2008), and self-directed movement such as fidgeting positively correlates with performance for children with ADHD (Sarver et al. 2015). Additionally, phenomenological autistic perspectives

Table 13.1
Overview of SpEED projects

	Balance Number Line	Magical Musical Mat	SignEd|Math	Audio-Haptic MIT-P
Target population	Learners who are vestibular sensory-seeking	Nonspeaking learners on the autism spectrum	Deaf (and hard-of-hearing) learners*	Blind and low-vision learners
Design objective	Support learning of negative numbers and absolute value concepts	Facilitate participatory sense-making and spontaneous interaction	Enhance learning of proportionality and fraction concepts	Establish collaboration between students with different sensory access needs in learning proportionality
Embodied resource	Sensory regulatory movement (rocking)	Shared modality of touch	Signs' potential to be iconic and grounded in action/experience	Coordinated movement with multimodal feedback

*Although this design centers Deaf learners, it is also intended to extend to learners who are hard of hearing. Use of American Sign Language as the primary means of communication is the central characteristic of the population the presented design is aligned to.

suggest that sensory stimulatory movements like rocking can be not only regulatory but also expressive and exploratory (Nolan & McBride, 2015). Despite these findings, traditional mathematics classrooms provide limited stimulation opportunities for several sensory systems, notably the vestibular system in the inner ear, which governs balance and orientation. The vestibular system has been implicated in cognitive development (Hitier et al. 2014; Wiener-Vacher et al. 2013) and even abstract conceptual reasoning (Antle et al., 2013). Not only is vestibular engagement neglected in the majority of math activities, but also students' spontaneous vestibular-activating movements such as pacing or rocking can be read as disruptive in the classroom. Thus, vestibular-seeking learners are forced to learn in a suboptimal state of sensory regulation.

The BNL aims to directly incorporate vestibular stimulation into learning activity. It does so by making rocking on a balance board central to a series of exploratory and goal-oriented mathematics learning tasks. Learners sit on a balance board and slide their hands along a number line in front of them. Their movements cause shifts in the board's balance, providing stimulation to the vestibular system that serves as informative feedback about the placement of their hands (for example, −3 and 3 are experienced as being in balance, while −3 and 4 would be experienced as a slight lean to the right). BNL activities include finding a solution for how to move one's hands in balance (the solution involves moving both hands equidistantly from the origin), and later expressing this solution numerically, as well as planning using magnetic arrows and exe-

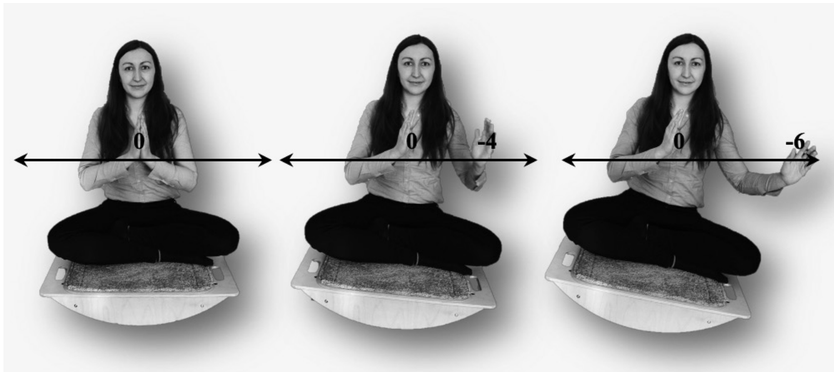

Figure 13.2
The Balance Number Line (Tancredi). Changes in hand position shift the angle of the board as shown. Students sit on the balance board facing a wall and move their hands along a number line on the wall (not shown) such that their vestibular (balance) system provides feedback about their hands' relative distances from zero. Here, the learner's left hand moves toward their left into negative numbers.

cuting arithmetic equations using sliding movements of both hands pressed together, resulting in shifts in the board's tilt.

The design builds upon learners' natural engagement with vestibular stimulatory behavior and uses this as a resource for conceptual learning and understanding. In a pilot study, a vestibular-seeking sixth-grade learner on the autism spectrum engaged the board in hybrid ways: sometimes rocking rhythmically for regulation as during waiting periods, other times acting upon the rocking to achieve matching degrees of tilt to either side, and still other times perceiving mathematical qualities through rocking, as when comparing the absolute value of two numbers by attending to the degree of board tilt for each. The BNL is designed not only to offer respite from vestibular understimulation, but also to use vestibular stimulation as perceptually salient learning-relevant feedback for conceptual learning.

The Magical Musical Mat

The Magical Musical Mat (MMM, figure 13.3) is a domain-general environment that allows people to interact with one another through the nonspeech modalities of touch and sound. Although social interaction is an essential component of any learning context (Vygotsky, 1934/1962), many Autistic learners, especially those who are minimally/nonspeaking, are unable to participate in interaction. Nonspeaking individuals often have to accommodate to their interlocutors' dominant communicative modality—speech—before being

Figure 13.3
The Magical Musical Mat (Chen). Two people have their feet on Magical Musical Mats and touch hands, resulting in dynamically changing sounds as they haptically interact.

deemed a relevant participant within social interaction (Light et al., 2019). The overriding focus on verbal speech is most visible in the design of aided augmentative and alternative communication (AAC) systems and interventions, which are geared toward serving as an alternative to or augmentation of an individual's speech (Beukelman & Mirenda, 2013). Although AAC can support the practical needs of Autistic individuals, their exclusive focus on speech has neglected the body's significant role in joint action (Chen, 2021), thus neglecting the developmental antecedents of communication: reciprocal, affective, and embodied attunement to others (Trevarthen, 2011).

A growing body of testimonials from Autistic individuals (Conn, 2015; Kapp, 2019), supported by scientific research (Behrends, 2012; Dickerson, 2007; Chen, 2016), suggests that Autistic individuals participate in interaction through nondominant modalities. Specifically, another characteristic of Autism—the production of repetitive, rhythmic behavior—has been identified a valuable resource for self-regulation, self-expression, and social interaction (Bascom, 2012, Nolan & McBride, 2015).

The MMM surfaces interpersonal touch as a modality through which musical co-exploration, and as a result, joint rhythmical action, can take place (see also

Chen, 2021). When participants step onto the mat and explore different types of touch interactions together, capacitive sensors in the mat detect their haptic, touch-based interactions, triggering musical sounds. Different types of touch—such as holding hands, high-fives, or gentle taps—offer distinct auditory qualities, resulting in a rich diversity of sound-touch expression. The Autistic students who used this mat in a pilot study explored a variety of touch-based gestures and sounds with their hands and feet, invented rhythmical hand games, and collaborated in pretend play. The practitioners who facilitated the session also noted a behavioral change in some students, for whom play on the mat had a lasting calming effect (Chen et al., 2020). This design project provides a medium for improvisational, creative co-engagement and communication that forms a basis for participatory sense-making (De Jaegher, 2013) in the learning context.

The Mathematical Imagery Trainer for Proportion

The remaining two SpEED projects each reimagine a specific embodied design, the *Mathematics Imagery Trainer for Proportion* (MIT-Proportion) (Abrahamson, 2014). The pedagogical purpose of this design is to support students' learning of the concept of proportional equivalence. Learners encounter an interaction problem wherein they control the vertical position of two cursors on a screen by moving their hands up and down. Whenever the heights of the two cursors correspond to a predefined ratio not known to the student—for example, the right hand being twice as high as the left hand for the ratio 1:2—the screen turns green. Otherwise, the screen is red. The students are first asked to make the screen green, then to do so in another way, and eventually to move their hands continuously in green. Using this feedback, students discover how to move such that the gap between their hands increases as their hand positions rise. This way of moving constitutes a new sensorimotor scheme that grounds proportional reasoning. Disciplinary forms such as a grid and numbers are then overlaid on the screen as means to better control, evaluate, and explain their movements. (See chapter 12 for further discussion of this design.)

SignEd|Math

SignEd|Math redesigns the MIT-Proportion with attention to Deaf learners' experience. The project's central assumption is that learning math through the medium of sign language changes the structure of learning content from both an individual-embodied and a social-constructivist perspective (e.g., Grote et al., 2018; Krause, 2017). There are concerns in Deaf education that Deaf students are often still treated as "hearing students that cannot hear" (Marschark et al., 2011, p. 4) without considering their specific ways of thinking and making sense of the world. At the same time, research in psycholinguistics reports that using sign languages influences conceptual understanding, specifically how concepts and knowledge become structured for the signer (see, e.g., Grote et al., 2018). This raises the question of whether traditional instructional approaches are actually appropriate to best accommodate Deaf students' way of thinking and learning mathematics. SignEd|Math starts to reimagine mathematical instructional approaches starting from the strengths of Deaf students and integrating sign language as a natural resource of Deaf learners.

The SignEd|Math redesign of the MIT-Proportion bridges from action to signed mathematical discourse to carry conceptual meaning from individual sensorimotor experience to social negotiation of meaning. It adopts the original idea of proportional movement and implements it on a touchscreen. Here, learners manipulate the lengths of two bars each spanned by the thumb and index finger of one hand (see figure 13.4). As in the original design, the screen turns green when the lengths of the two bars fulfill a target ratio. Unlike in the original design, the orientation of the bars can be varied on the touchscreen plane. Manipulation with the thumb and index finger is designed to prompt a hand shape called "bent L" in American Sign Language. The bent L is a classifier[4] that is used to refer to a generic number or quantity (Kurz & Pagliaro, 2020), with its concrete integration in a signed expression depending on the

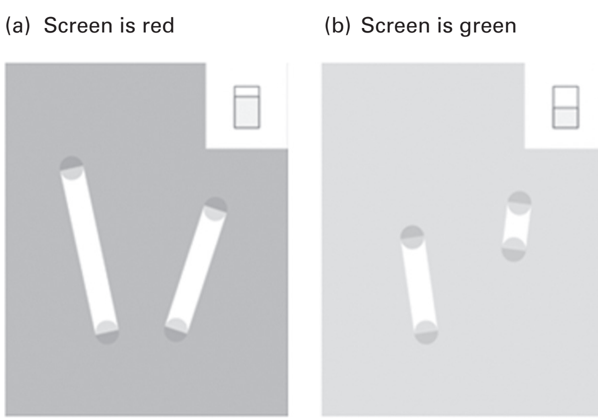

Figure 13.4
Redesign of the MIT-Proportion on tablet interface in the context of SignEd|Math (Krause). The grey dots are touch points that can be moved on the plane, operated by thumb and index finger. The bars span between the touch points such that the lengths of the white bars equal the distance between the thumb and index finger of each hand. The screen turns green when the ratio of the length of the left bar to that of the right bar is 2:1 (b); otherwise, it is red (a). The bar in the upper corner represents an optional extension, linking the relation between the bars to a part-whole relationship (part/whole = length of left bar/length of right bar). To see this in action, visit https://tinyurl.com/SignEdMath-mitp.

context. It hence is not the sign for “number” or “quantity,” but its use can indicate these entities conceptually. In the SignEd|Math MIT-Proportion redesign, integrating the number classifier as a feature in the tablet action attempts to link action, concept, and language in a meaningful way through the idea of “modal continuity” (Krause & Abrahamson, 2020). In this, initial action builds a base for linguistically accurate signed mathematical expression to talk about the embodied experience (Krause, 2019)In a subsequent transfer task, student are invited to collaboratively solve a problem in pairs that elaborates on the notion of proportion first introduced through the tablet activity.

Following socioconstructivist theories, this activity sequence creates an opportunity for shared gestural signs and shared mathematical meaning to be constructed by peers, with the former serving as a preconventional means to address the new mathematical knowledge in development. This process takes advantage of signed languages’ unique potential to iconically incorporate action to ground meaning in activity. Integrating insights from psycholinguistics and deaf education that show an influence of mathematical signs’ iconicity on understanding, the project aims to foster the emergence of conceptually and linguistically generative signed mathematics discourse about the focal math concept.

The Audio-Haptic Mathematical Imagery Trainer for Proportion

A recent project by Abrahamson et al. (2019) examines how an enactivist view of learning can enrich UDL. As an exercise in universally accessible design, the authors pose a redesign of the MIT-Proportion that reimagines how the mathematical construct of proportionality can be represented for sighted and non-sighted learners within a shared activity. The authors critique how commonly used tools such as tactile diagrams and text-to-speech can function as mere replications of visual representations rather than authentic interpretations for spatial understanding. Attempts at shifting learning media from visual to nonvisual formats must be done with consideration for how information might require alternate conceptualization when presented through auditory, tactile, or kinesthetic modalities.

The latest version of the resulting design is the Audio-Haptic MIT-Proportion (henceforth AHM) (figure 13.5). Learners stand on opposite sides of a board featuring knobs in parallel tracks. Peers on either side of the board slide the knobs together. When the ratio of the first knob to the second fulfills the secret ratio, the knobs vibrate, and a sound is produced, functioning similarly to the green color in the original MIT-Proportion design. This design represents proportions with visual, auditory, and haptic feedback such that visual and nonvisual learners achieve equitable independence in their learning and can learn together. The AHM ensures students have equal participation in self-guided and

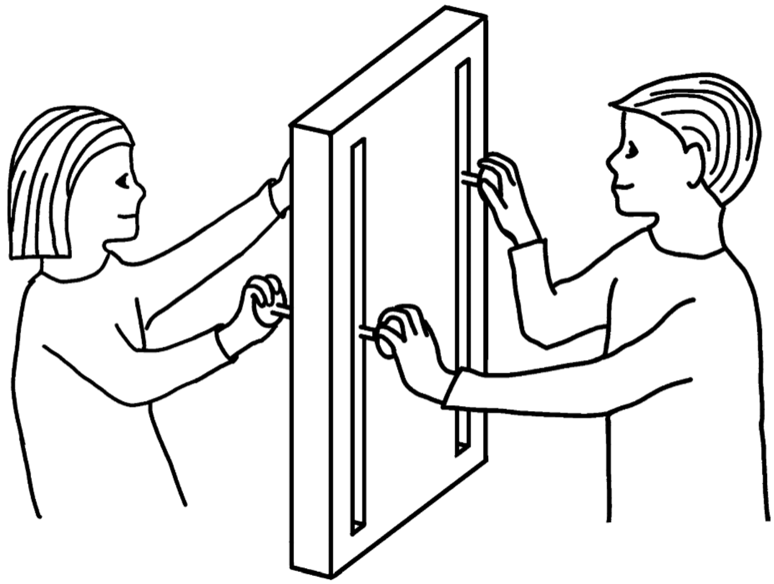

Figure 13.5
The Audio-Haptic Mathematical Imagery Trainer for Proportion (Siu). A blind student collaborates with a typically sighted student to move the sliders in a 1:2 ratio, as guided by visual, auditory, and haptic feedback (Abrahamson et al., 2019). Art: Virginia J. Flood.

coordinated movements, regardless of sensory diversities, optimizing the learning experience for all students.

New Avenues for Accessibility

An enactivist perspective reveals new avenues toward flexible, adaptive education. To map these avenues, we start from UDL and show how SpEED sheds new light on the framework. Rooted in cognitive neuroscience, UDL distinguishes action, representation, and engagement (CAST, 2018). Rooted in enactivism, SpEED highlights the intertwinement of these processes. Through the perception-action loop, action fundamentally participates in perception. Learning from media, then, occurs through learners' actions with those media, such as how a learner moves their eyes over a diagram. This perspective can support greater intentionality in designing for learner actions. For example, consider two activities on graphing: one where a child jumps on a control pad to select a graph from a set of options (for example, jumping on the left pad to select the left image on a screen), and the other where the child's rate of jumping up and down influences the height of a graph (Charoenying, 2013). A given child may be able to participate fully and joyfully in either activity. However, in the former case, the jumping action is incidental to the concept, whereas in the latter, it is directly salient. From an enactivist perspective, concepts themselves must be conveyed through meaningful sensorimotor experience. Beyond the representation/action/engagement divide, SpEED shifts the focus to how educational designs shape perception and action.

SpEED is characterized by reimagining the intertwined factors of media, modality, and semiotic mode underlying learning design (table 13.2). The modalities and semiotic modes available to a given learner population must inform media design. For example, in SignEd|Math, available semiotic modes (sign language and gesture) and modalities (manual kinesthesia) drive the media (tablet application) design. In the BNL, amplifying a given modality (vestibular engagement) shapes media (incorporation of a balance board) in such a way that a new semiotic mode emerges. Traditionally, negative numbers are conceptualized as an extension of the set of natural numbers, but the BNL also establishes a negative number as that which perfectly equilibrates its positive counterpart. By working with the affordances of a given modality, SpEED can generate conceptual restructuration (Wilensky & Papert, 2010) that can envision concepts in new ways.

Interaction Reimagined

SpEED adds greater specification to UDL guidelines for supporting interaction with media and with peers. From an enactivist perspective, feedback informs perceptually guided action on an ongoing basis. UDL guidelines call for feedback to be timely and frequent (CAST, 2018); SpEED must go further to

Table 13.2
Reimagined media, modalities, and semiotic modes in the four SpEED projects

	Balance Number Line	Magical Musical Mat	SignEd|Math	Audio-Haptic MIT-P
Modality	Vestibular, manual kinesthetic, proprioceptive (in mutual interaction)	Auditory, tactile, and kinesthetic	Visual-dynamic, manual kinesthetic	Auditory, tactile, and manual kinesthetic
Semiotic mode	Balance board position and hand movements	Locally developing sound and touch based semiotic modes	Locally developing signs grounded in action, integrated into sign language	Independently coordinated movements guided by audio-haptic feedback
Media	Balance board and number line	Mat and bodies	Manual interaction with tablet, signed conversation	Sliding haptic handles and audio indicators

maximize the consistency and immediacy of the relationship between action and result. In all four of the SpEED designs, feedback is provided at an instantaneous timescale through sensory feedback in one or several modalities available to the learner, be it haptic (vibrating dials in the AHM), auditory (music from touch on the MMM and sonification in the AHM), vestibular (tilt of the balance board in the BNL), or visual (change in color in SignEd|Math). The MMM in particular sets itself apart from other solutions in its domain in this regard: AAC devices typically involve a delay between intention and expression in that a sequence of motor actions must be undertaken to select referential symbols for speech generation. By contrast, the MMM offers interactional immediacy, allowing students to be fully co-present with their peers. In SpEED, feedback is the means by which learners develop and refine new sensorimotor schemes.

SpEED also reframes interaction with peers. Learning is inherently situated in social practice, whether teacher-to-student or peer-to-peer (Vygotsky, 1934/1962). UDL guidelines stipulate that educators should foster collaboration and community by supporting peer interaction (CAST, 2018). SpEED expands upon this perspective by embracing interaction beyond the dominant modalities of speech and the linguistic system to include all sense-making practices involving two or more people. This is exemplified in the MMM, which centers nonspeaking individuals on the autism spectrum for whom verbal language is not a dominant semiotic mode. The nonspeaking student often has to participate in interactions where speech is used by others and where speech generation is expected of them. Designing for touch-based interactions surfaces a mode of interaction available to most—touch—such that nonspeaking students and their neurotypical peers can interact through the same communicative modality (Chen et al., 2020). Through the modalities of touch and sound, the MMM creates a platform for joint attention and co-enactment, fundamentals of social interaction that underlie language production. Rather than adopt predefined semiotic modes, the MMM creates a context within which novel meanings can emerge through joint action. Participants on the mat repeat and adapt movements to jointly create sound events and thereby develop new semiotic modes. This creates a baseline that starts from what individuals can do rather than starting from translating higher order skills emerging from a different developmental trajectory. Through focus on the body, SpEED can offer alternative ways for peers to access interaction.

The AHM and SignEd|Math expand the role of peer interaction to serve as a means of concept construction. Peers interact with a movement-based activity and engage in discourse together about that activity. Coordinated engagement in joint tasks gives rise to mathematical meaning. In the AHM, peers coordinate so that one slider moves at twice the rate of the other. Through performing this coordination, they identify and articulate key properties of proportionality. In SignEd|Math, peers collaborate to solve a problem that builds on their earlier work with the tablet activity; in so doing, they come up with signs to refer back to the former activity and negotiate new meaning. These signs constitute the situated vocabulary for generalizing the mathematical concept encountered in the activity and therefore ground the social discourse in individual concept formation. SpEED occasions dynamic sensorimotor interactions, and through these interactions, access to concept construction.

Surfacing and Challenging Modalism

Special education populations frequently engage the world in ways that differ from neurotypical individuals through modalities that are not traditionally privileged as ways of learning. An enactivist approach calls for semiotic modes that grow from learners' embodied practices in these modalities. Indeed, this theoretical orientation brings to light a new issue of *modalism:* the practice of privileging certain modalities over others and ignoring other possible modal constitutions. We use the term modalism here in the lineage of such terms as ableism, audism, and oralism, wherein specific sensorimotor configurations and modes of interaction are granted supremacy. UDL guidelines invite the use of multiple or alternative modalities (visual, tactile, auditory) and media (sign language, text, physical objects) (CAST, 2018). SpEED offers a means of evaluating the pedagogical and epistemic value of alternative forms. As an example, the AHM challenges the impoverishment of learning materials available to blind students, occasioned by instruction's occulocentrist history (Abrahamson et al., 2019). Learning materials are frequently purported to achieve accessibility when in fact they merely translate visual-based spatial reasoning instruction through other modalities, as a tactile version or description of a graph might do. These media maintain vestiges of the semiotic modes of their original visual-based medium. In contrast, the AHM puts forth a means of rethinking what the concept of proportionality is by setting forth from the ways nonvisual learners dynamically engage with the world. Similarly, SignEd|Math, for example, refuses to mimic the semiotic modes of spoken language in sign language, recognizing that sign language is changing the way Deaf learners structure their experiences and knowledge. (Grote et al., 2018; Krause, 2019). To be accessible, semiotic modes must emerge from dynamic interactions in modalities available to an individual.

Conclusions and Discussion

The SpEED design-based research framework reimagines accessibility from an embodied cognition perspective. In this chapter, we use one lineage of embodied cognition, enactivism, as a starting point toward this reimagination. By establishing roots in the learner's embodied resources and attending to the interrelation of media, modalities, and semiotic modes, SpEED generates designs for interaction and conceptual learning that subvert modalism. Although SpEED research remains in its infancy, the four early stage SpEED projects show that SpEED can offer a foothold on diverse design problems in special education.

Critically, SpEED research also offers a means to evaluate embodied theories of cognition and learning across diverse populations. The SpEED projects presented here show promise for bringing together embodied perspectives, semiotics, and socioconstructivism. Future work in SpEED should expand upon other strands of embodied cognition theory beyond enactivism, such as dynamical systems theory and extended cognition, to analyze how these might reshape accessibility. Moving forward, in addition to expanding work on sensory diversity and learners of different profiles learning together, SpEED research must also address motor differences. As SpEED takes on a broader range of design problems, it is poised to reevaluate epistemological assumptions within and beyond the discipline of mathematics.

The need for SpEED is by no means exclusive to special education. These populations are merely a critical starting point for incorporating the sensorimotor diversities present in any classroom. When reevaluated from an embodied perspective, dominant practices in general and special education classrooms are not yet providing deep disciplinary engagement to all learners. SpEED offers a pathway toward building truly equitable learning opportunities.

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Notes

1. In this chapter, we defer in our language use to preferences expressed by autistic, Deaf, and blind self-advocates for identity-first language over person-first language (Sinclair, 2013; see also Gernsbacher, 2017; Liebowitz, 2015). The term Deaf with a capital D is commonly used to denote the sociocultural identity. We recognize that language use is varied and evolving and invite commentary on language that best honors individuals and their experiences.

2. The Balance Number Line is part of a larger project, Balance Board Math, that targets a range of different mathematical concepts.

3. The labels of sensory processing disorder and sensory modulation disorder are used in some contexts to describe individuals for whom the sensory features of everyday environments cause frequent difficulties. These labels can arise together with or separately from learning disabilities, ADHD, and autism. Within these diagnostic categories, there are heterogeneous sensory profiles. Rather than a specific diagnosis, the Balance Number Line was developed with an eye toward specifically accommodating individual differences in vestibular sensory sensitivity.

4. A classifier is a handshape that represents a specific thing/noun within the context of a larger sign. For example, a classifier might be combined with a movement representing an action of the "thing" (e.g., a car driving or a person going around a corner), or be integrated into a spatial representation. For example, the number classifier can be used in a sign for "improper fraction" as referring successively to a numerator and denominator in relation to a fraction bar, with the distance between index and thumb larger for the numerator than for the denominator (Kurz & Pagliaro, 2020, pp. 89–90).

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