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DotQuest: Accessible STEM Games to Support Blind and Visually Impaired Learners

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Abstract: Blind and low vision (BLV) students face persistent barriers to full participation in STEM learning, particularly due to the limited availability of accessible tools. This study introduces DotQuest, a technology probe that integrates haptic feedback, and a conversational agent to create narrative-driven, game-based STEM activities. To examine how such tools might support equitable participation, we conducted interviews with seven Teachers of Students with Visual Impairments (TVIs) across U.S. Analysis revealed that teachers emphasize the importance of simultaneous tactile and auditory access, the need for classroom tools that foster both independence and inclusion, and the value of designing accessibility from the outset rather than as an accommodation. Findings show that multimodal game-based environments can enhance STEM engagement while revealing systemic barriers for BLV learners. This work contributes to the learning sciences by deepening understanding of how multimodal and inclusive design can guide the development of equitable STEM learning environments.

Introduction

STEM subjects often rely heavily on visual representations, yet equivalent multimodal tools that integrate tactile, auditory, and interactive supports remain limited (Ávila-Soto et al., 2017). As a result, Blind and low vision (BLV) students are frequently excluded from the kinds of rich, hands-on learning experiences that promote conceptual understanding, motivation, and equitable engagement (Wu et al., 2025). This study is motivated by the goal of designing accessible, tangible, and interactive learning environments that expand STEM opportunities for BLV learners (Pires et al., 2019; Lang et al., 2023; Kim & Yeh, 2015).

This study represents the first phase of a design-based research (DBR) project aimed at iteratively designing and refining DotQuest, an accessible, multimodal, game-based STEM learning environment for BLV students (Anderson & Shattuck, 2012). To connect theoretical perspectives on learning with the designed features and observed processes of our intervention, we used conjecture mapping (Sandoval, 2014). This phase focuses on eliciting expert insights to refine the system's design conjectures, features, and pedagogical functions before classroom implementation (Sandoval, 2014). By engaging Teachers of Students with Visual Impairments (TVIs) as co-design informants, we seek to connect theoretical principles of multimodal and inclusive learning with the pragmatic realities of STEM teaching for BLV learners (Hutchins & Biswas, 2024).

This work contributes to the Learning Sciences by articulating and refining design conjectures that link multimodal accessibility, narrative game structures, and tactile–auditory integration to equitable STEM engagement for blind and low-vision learners (Chen et al., 2024). Through teacher-informed conjecture mapping, DotQuest demonstrates how inclusive, multimodal game design can operationalize theoretical principles of sociocultural learning (Vygotsky, 1978) and Universal Design for Learning (UDL) into tangible design features (Rose, 2000). The study contributes a model for bridging accessibility research and design-based inquiry, expanding how the field conceptualizes equity-oriented learning environments beyond visual modalities (Uttamchandani, 2018). This study was guided by the following research questions: (1) *How do TVIs conceptualize the design features and pedagogical affordances needed for multimodal, game-based STEM learning environments for blind and low-vision learners?* (2) *How do TVIs' insights inform the refinement of DotQuest's design conjectures that link tactile–auditory integration, narrative-based interaction, and inclusive design principles to equitable STEM engagement?*

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Background

Multimodal learning and accessibility for BLV students

The Learning Sciences community has explored how blind and low vision (BLV) students engage in learning. For instance, researchers such as Foley et al. (2025) examine strategies to strengthen tactile graphicacy for BLV learners, emphasizing the critical role of teachers of students with visual impairments (TVIs) in scaffolding tactile sensemaking to support nonvisual spatial literacy. More broadly, research in BLV education highlights the centrality of tactile and auditory modalities as primary channels for conveying information and underscores educators' role in scaffolding these multimodal learning processes (Foley et al., 2025; Kari et al., 2006).

This study is grounded in sociocultural theories of learning, constructivist, UDL, From a sociocultural perspective (Vygotsky, 1978), learning is mediated by social interaction and scaffolding highlight how tactile, game-based interaction (Plass et al., 2015), and auditory modalities can scaffold sensemaking in non-visual ways, allowing BLV students to engage in STEM content.

Methods

Participants

We conducted virtual interviews via Zoom with seven TVIs across the United States. Each individual interview lasted approximately 60 minutes. Participants were recruited through the researchers' professional and personal networks. Of the seven participants, six identified as female and one as male. Their professional experience ranged from a minimum of 11 years to over 30 years. All participants were employed in public school districts . We conducted teacher interviews as part of the first design research cycle to elicit expert feedback that would inform the refinement of DotQuest's design conjectures, features, and functions. By engaging Teachers of Students with TVIs as design partners, we sought to surface pedagogical insights that could shape the next iteration of the system.

Data sources and analysis

The Zoom interviews were recorded and transcribed using an automatic transcription tool, followed by manual review for accuracy. Each interview began with demographic questions, including teachers' years of experience and the age ranges they serve. We then asked general questions about challenges in their teaching practices during the first 15 minutes. Following this, we introduced a technology probe by presenting our prototype, *DotQuest*, and invited feedback on its applicability and affordances to elicit further design and pedagogical insights. This study was reviewed and approved by the research institute's Institutional Review Board (IRB).

For analysis, we adopted an inductive approach to generate initial codes and identify emergent patterns in the data. To ensure analytic rigor, the research team engaged in iterative coding sessions, meeting weekly over the course of a month to refine codes, resolve discrepancies, and reach consensus. This process emphasized collaborative meaning-making and reflexivity, strengthening the trustworthiness of our interpretations. The final set of codes was then organized into broader thematic categories, including: Simultaneous Tactile + Verbal Access for Multisensory Instruction, Accessible Game-Based Learning for Equitable Engagement, and Inclusive Design in Educational Technology & Classroom Orchestration.

DotQuest: Accessible game design for equitable STEM engagement

DotQuest is a technology probe designed to explore how multimodal, game-based environments can make STEM learning more accessible for BLV students. The system integrates three key components: (1) a refreshable Braille display (RBD) for tactile interaction and Braille literacy (Autonomy), (2) haptic feedback for conveying changes such as temperature, numbers, shapes, or movement (Inclusion), and (3) a conversational agent that guides learners through narrative-driven "quests. (Competence)" Each quest is framed around an interactive story, for example, purchasing ingredients for a recipe or exploring seasonal changes, allowing learners to experience core STEM concepts (e.g., counting, measurement, sequencing) through tactile and auditory modalities. DotQuest structures learning as a series of gamified "Quests" that embed STEM problem-solving within narrative and embodied interaction. Each Quest situates the learner in a story-driven context where the digital character, Dot, acts as a social and pedagogical partner; scaffolding, prompting reflection, and adapting to the learner's evolving understanding. This design leverages narrative framing and game mechanics (e.g., progression, feedback loops, and rewards) to sustain engagement while aligning with constructionist and sociocultural principles of learning through doing and dialogue.

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Findings

Simultaneous tactile + verbal access for multisensory instruction

Teachers highlighted that while existing tools offering auditory support are useful for practice, they fall short of providing the rich, multisensory experiences necessary for deeper learning. In particular, they emphasized that integrating Braille with auditory feedback could be transformative for accessibility, enabling BLV students to engage more meaningfully with STEM concepts. For instance, Ms. Cruz (25 years of experience) said: *"A device like that would provide both auditory and tactile feedback, which is critical for these students. Right now, many assistive technologies only offer one type of feedback, which isn't always enough. I'd love to see how this develops!"*

Teachers emphasized that auditory-only tools are helpful but insufficient. They highlighted the need for integrating tactile and auditory modalities, especially refreshable Braille displays with verbal feedback, as transformative for accessibility, deeper learning, and equitable STEM engagement for BLV students. This will support the *Inclusion* principle, as the game will provide equitable access to the game to accommodate multiple sensory modalities rather than just rely on vision or hearing.

Inclusive design in educational technology and classroom orchestration

Teachers emphasized that accessibility must be built into educational technologies from the outset rather than treated as an afterthought. They noted that assistive tools for BLV students often lag behind general education technologies, creating persistent inequities. As Ms. Wynn (14 years of experience) explained: *"If all educational software were designed with accessibility in mind from the start, it would make a huge difference. Technology also struggles to keep pace with advancements in general education."*

In addition to design, teachers stressed a shared responsibility for inclusion. They argued that general education teachers should integrate BLV students into lessons, rather than relying solely on TVIs to adapt instruction. As Ms. Cruz (25 years of experience) observed: "*Too often, classroom teachers assume that TVIs will handle everything, rather than making their own instruction more inclusive from the beginning. I would love for teachers to provide better verbal descriptions of what they're writing or displaying on screen.*"

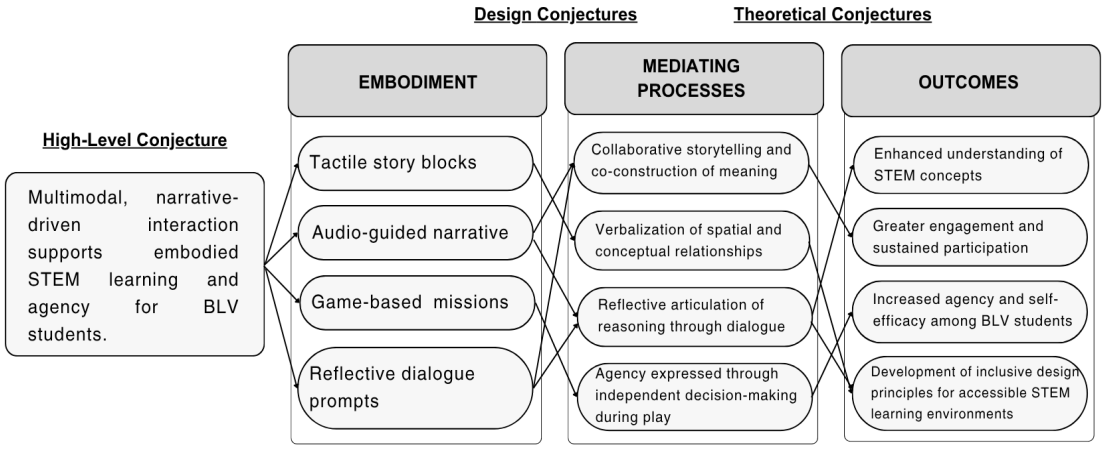
These findings suggest that inclusive design must extend beyond technological innovation to include shared pedagogical responsibility and classroom practices that foster learner independence, ensuring that accessibility translates into equitable participation. Technologies such as DotQuest aim to reinforce learners' *competence* through scaffolded challenges, adaptive feedback, so students' confidence grows when technology supports mastery of the concepts rather than dependency.

Discussion and conclusions

This study advances understanding of how multimodal, game-based environments can foster equitable STEM participation for BLV learners. The DotQuet design provides accessible practice opportunities while fostering motivation and engagement through progress-based, reward-driven structures similar to those commonly experienced by sighted students in digital learning environments (Liu et al., 2023). By situating accessible design not only as a question of accommodation but as a driver of meaningful engagement, this study contributes to ongoing discussions around equity and inclusion in technology-enhanced STEM education (Pires et al., 2019; Uttamchandani, 2018). Through interviews with TVIs, we refined our design conjectures for DotQuest, identifying how synchronized tactile–audio feedback supports non-visual sensemaking, narrative quests sustain motivation and math literacy, and inclusive orchestration promotes learner independence (see Figure 1). Rather than a finished product, DotQuest functions as a technology probe that bridges theory and practice in accessible design. These findings lay the groundwork for the next DBR cycle, which will involve co-design and classroom implementation to examine how multimodal interaction can foster accessibility, agency, and well-being in authentic learning contexts.

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Figure 1
The Conjecture Map for DotQuest for BLV Students.



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