

BEYOND MY SIGHT: DESIGNING INCLUSIVE TOOLS AND REDESIGNING GAMIFIED VR ACTIVITIES FOR VISUAL IMPAIRMENT

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ABSTRACT

This research presents the findings of an empirical case study evaluating an international academic collaboration focused on the inclusion of higher education students with visual impairments (specifically low or no vision) in project evaluation and engineering management courses. In quantitative disciplines, traditional learning environments rely heavily on "visual-centric" methodologies, creating steep sensory barriers for visually impaired students. To address this systemic inequity, a multidisciplinary team designed, manufactured, and implemented a suite of reproducible, technology-based pedagogical tools in the classroom. These interventions encompass the development of adaptive physical laboratories, specialised computing tools such as a tactile slide rule embossed with Braille scales, and the strategic adaptation of gamified Virtual Reality (VR) simulations optimised for project and financial evaluation. Moving away from traditional digital screen readers—which process data in a strictly serial fashion and generate significant cognitive bottlenecks—these haptic-first, analogue-tactile interfaces leverage physical manipulation to build essential spatial intuition regarding mathematical proportionality, financial magnitudes, and exponential curves. By synthesising institutional comparative frameworks and practical pedagogical testing, this investigation provides an actionable roadmap for educators and instructional designers. Ultimately, this framework champions conceptual translation over passive content conversion, fostering independent operational autonomy, mitigating the professional skills gap, and ensuring competitive workplace readiness for graduates with visual impairments.

Keywords: Higher education, educational innovative, impaired vision, gamification, VR

1 INTRODUCTION

In traditional higher education classroom settings, engineering educators frequently overlook the specific pedagogical needs of students with significant visual impairments (VI). While institutional efforts in Educational Innovation often design cutting-edge techniques for complex quantitative theories, inclusive universal design is routinely omitted from initial planning stages. This systemic omission creates a "sensory barrier" in fields such as Industrial Engineering and Management Education, where complex data analysis, financial modelling, and project evaluation are heavily mediated through digital screens, visual metaphors, and graphical interfaces. For nearly a decade, our research group has sought to address this gap, developing methodologies to effectively teach core competencies in Project Management and Evaluation—such as calculating Return on Investment (ROI), Net Present Value (NPV), and master scheduling via PERT/CPM methods—to diverse student bodies.

To properly address academic accessibility in quantitative fields, it is clinically and pedagogically essential to establish the boundary between mild visual anomalies, severe visual impairments, and total blindness. In the context of this study, Low Vision is formally defined according to the World Health Organisation (WHO) and clinical standards as a chronic visual acuity of less than 6/18 (20/60) up to 3/60 (20/400), or a visual field loss of less than 20 degrees in the better-seeing eye, even after the best possible conventional medical, surgical, or refractive correction.

Crucially, this condition must not be confused with standard refractive errors (such as myopia, astigmatism, or presbyopia) that can be fully mitigated or neutralised through standard prescription glasses or contact lenses. Conversely, low-vision students retain functional residual vision that can be

strategically leveraged, distinguishing them from individuals with total blindness who lack light perception entirely. In countries like Mexico and Spain, the prevalence of low vision in university classrooms has risen sharply due to both accelerated device-driven eye strain post-COVID-19 lockdowns and growing metabolic comorbidities, such as diabetic retinopathy resulting from elevated blood sugar levels[1,2,3,4,5] Because many students choose not to formally disclose their visual health status, faculty members remain largely unaware, inadvertently compounding the fragmentation of visual information delivered through traditional screen readers or whiteboard lectures.

While digital accessibility tools like Optical Character Recognition (OCR) and text-to-speech screen readers exist, they process numerical data in a strictly serial, sequential fashion. This creates a severe cognitive bottleneck for VI students who must grasp the multi-step spatial and proportional logic required for engineering calculations. Therefore, the path toward true academic equity requires a shift from "passive assistance"—where a sighted peer or machine merely describes a visual element—to "active agency," where the student can independently manage data structures.

Building upon the "Beyond My Sight" research paradigm, this paper frames a specific inquiry into how physical, tactile artifacts and inclusive virtual environments can bypass digital serialisation to foster robust mental models of proportionality [7]. Specifically, this case study examines the design, deployment, and pedagogical impact of a disruptive, low-cost Braille Tactile Calculation Rule engineered to restore mathematical intuition and instrumental autonomy for low-vision students in fast-paced engineering curricula.

2 INSTITUTIONAL COMPARATIVE ANALYSIS

Table 1. Institutional comparative analysis

Strategy Dimension	Mondragón University	Tecnologico de Monterrey (Beyond My Sight)
Primary Framework	Cooperative Learning & UDL	Haptic Innovation & Individual Autonomy
Support System	Peer-mentorship and team-based tasks	Specialised tactile artifacts and physical tools
Technological Focus	Digital accessibility (Screen readers/OCR)	Analog-Tactile interfaces for mental mapping

2.1 Mondragón University’s Cooperative Approach

Mondragón University leverages its "Cooperativismo" roots to create inclusive classrooms. Their strength lies in Collaborative Inclusion, where the learning environment is adjusted so that the VI student is a core member of a functional team. However, this can sometimes lead to reliance on sighted peers for interpreting complex quantitative data.

2.2 The "Beyond My Sight" Paradigm

As detailed in the provided research, Tecnologico de Monterrey identifies a gap in existing assistive technology: digital screen readers often fail to provide the "spatial intuition" required for mathematics. The project advocates for Tactile Learning Materials (TLM) that allow the student to "see through their fingers," fostering a deeper cognitive connection to numerical proportions.

3 THE INNOVATION: THE BRAILLE TACTILE CALCULATION RULE

To complement the virtual environment upgrades, a high-fidelity physical computing and analog-tactile artifact was co-designed through a strategic collaboration between the School of Architecture, Art and

Design, and the School of Engineering and Sciences within the R&EIT framework. This specialised device adapts the manual sliding and mechanical positioning logic of a traditional mathematical slide rule to provide students with visual impairments (VI) and low vision with an autonomous method to construct, analyse, and solve Cash Flow Diagrams (CFD). Instead of navigating abstract or sequential rows of data via traditional digital text-to-speech screen readers, this physical instrument externalises financial datasets into tactile spatial constraints. The hardware assembly consists of three core interactive components: The Linear Track Base (Temporal Axis): A rigid, high-contrast horizontal frame machined with linear guide rails and embossed with tactical Braille intervals. This component physically maps the project's timeline (n periods/years), establishing a tangible spatial reference for the passage of time. Perpendicular Sliding Vectors (Cash Flow Pins): A series of mechanical sliders mounted vertically on the linear track. These sliders can be independently locked and moved along the temporal axis. Students manually extend the pins upward to physically represent positive cash inflows (revenues, benefits) or push them downward to signify negative cash outflows (capital expenditures, operating costs). The physical height or depth of the pin establishes a tactile scale of financial magnitude.

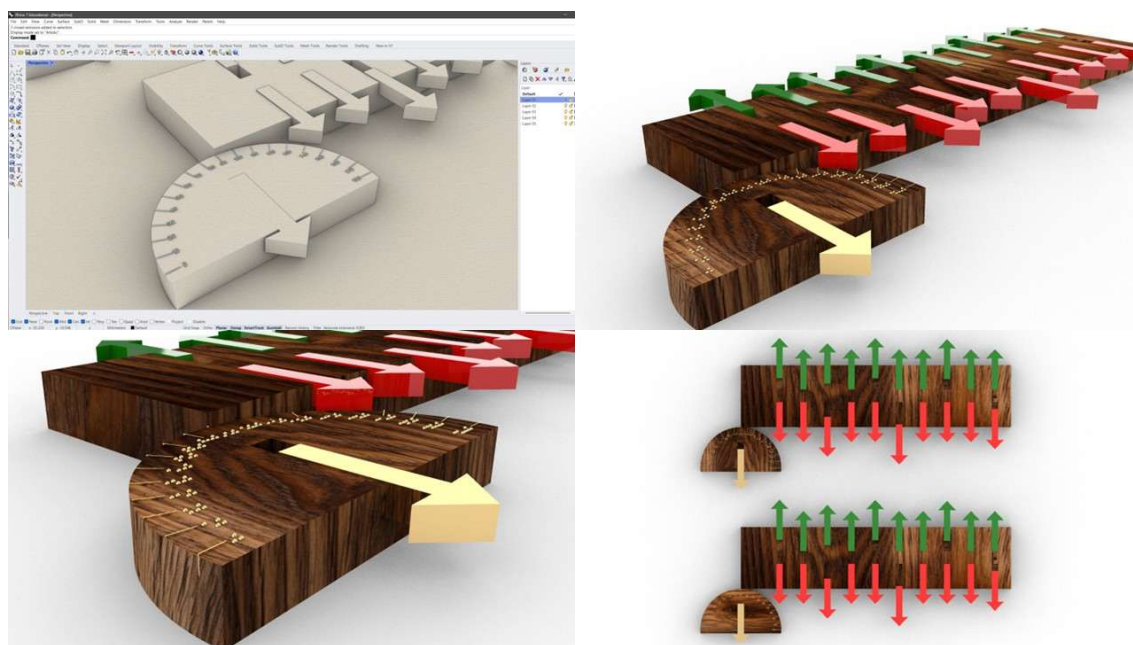


Figure 1. Tactile Calculation Rule for project evaluation, developed by R&EIT

The Rotatable Angular Protractor (Interest Rate Calibration): At the intersection of the coordinate axes, a mechanical circular cursor is integrated. This protractor is precisely graduated from 0% to 100%, featuring tactile notches and Braille labels along its circumference. By rotating this dial to match a project's Minimum Acceptable Rate of Return (MARR) or interest rate (i), the student alters the physical mechanical alignment of a guide bar. This physical angle represents the mathematical slope of continuous compounding or discounting factors (e.g., Present Value factors like $\$P/F\$$ or $\$P/A\$$), mapping financial equivalence across time through geometric tilt and mechanical leverage. By running their hands across the horizontal timeline, feeling the vertical displacement of the cash vectors, and engaging the angular protractor, students with low vision can process complex financial structures in parallel, achieving a structural cognitive mapping of Net Present Value (NPV) calculations that would otherwise be severely bottlenecked by auditory-only software assistance.

For an impaired student, the use of the Financial Calculator Rule is easy, just need the following steps.

1. Temporal Allocation: The student identifies the project duration (n) by counting the physical Braille intervals along the linear track.
2. Vector Mapping: The vertical sliders are unlocked and shifted to their respective temporal coordinates, then extended vertically (up or down) to represent the cash amounts.
3. Rate Adjustment: The angular protractor is turned to the designated interest rate percentage (0% to 100%), dynamically establishing the visual and tactile slope of equivalence.

4. Haptic Synthesis: The student sweeps their hand across the completed physical setup, instantly capturing the overall economic trend, balance, and feasibility of the investment project through spatial intuition.

4 RV, RA, AND SIMULATORS REDESIGN STRATEGIES

The transformation of high-fidelity simulators into inclusive educational artifacts entails a complex intersection of technical, economic, and social factors. Recent advancements in design education have explored synchronous communication through shared visual tracking systems, such as immersive gaze sharing in architectural critiques. However, as demonstrated by Kahlon, Maurya, and Fujii, such information-sharing platforms are inherently bounded by their exclusive reliance on the visual modality. To overcome this sensory barrier and include students with severe visual impairment (VI), educational simulators must transition toward multimodal, non-visual communication channels.

4.1 Technological Implications: From Visual to Haptic Rendering

The current software architecture of advanced simulators, such as our "Milking Parlor" and "Car Assembly Line" environments, is mathematically optimised for visual immersion. Transitioning these existing digital platforms into universally accessible spaces requires a complete architectural overhaul. To achieve this without compromising the core engine for sighted users, a Modular Accessibility Control Panel is integrated into the simulator's user interface. This allows VI and low-vision students to dynamically activate a comprehensive suite of optional accessibility features:

Sensorimotor Integration and Sonification: The software core must pivot from purely visual shaders to a rigid Haptic-First Architecture. This framework requires rewriting traditional collision detection algorithms to trigger distinct, varied tactile waveforms (haptics) alongside spatialised, directional audio cues (sonification). By doing so, mathematical proportionality and spatial volumes are rendered palpable, bypassing the need for sight.

Colour Blindness Adaptive Filters: For students whose low vision is compounded by colour vision deficiencies, the rendering pipeline introduces mathematical matrices that adjust the interactive colour palette in real time. The system allows users to select specific filters tailored to mitigate Deuteranopia, Protanopia, or Tritanopia, thereby ensuring critical operational cues within the project simulation remain highly visible and distinct.

High-Contrast Immersive Modality: When activated via the control panel, the engine strips complex, realistic environmental texturing and renders the interactive scene in a high-contrast visual mode. This modality forces interface frames and critical interactive objects in the environment to display highly differentiated colour values, significantly reducing visual ambiguity, glare, and spatial disorientation for low-vision users.

Dynamic Text Scalability: To resolve interface readability barriers, the layout UI uses a parametric typography system. Users can dynamically upscale the text size of all active interfaces, including simulation sub-menus, instructions, spatial labels, and integrated subtitles, ensuring font enlargement does not break UI boundaries or cause word clipping.

Focused Text-to-Speech (TTS) Synthesis: The simulator integrates an active voice synthesis engine that acts as a real-time auditory guide. Whenever a user selects, targets, or focuses on an interactive button, menu item, or environmental component, the TTS engine instantly reads out the corresponding content and instructional metadata, providing vital feedback that bypasses traditional visual processing bottlenecks.

Assistive Tool Synchronisation via IoT: To bridge the gap between virtual and analogue spaces, the physical Braille-based slide rule is integrated into the simulation cycle through Internet of Things (IoT) protocols or micro-computer vision tracking. This synchronisation ensures that real-time quantitative output from the virtual environment is instantly translated into physical coordinates on the tactile rule, enabling parallel data manipulation.

4.2 Economic Implications: Scalability and Cost-Benefit Analysis

The long-term viability and widespread adoption of inclusive learning tools, particularly those involving specialised technology like Virtual Reality (VR) and tactile prototypes, are fundamentally tied to their economic implications, specifically concerning scalability and the cost-benefit ratio.

Initial R&D Investment: Developing accessible VR environments and gamification platforms demands a high level of expertise in inclusive design principles, accessibility standards (e.g., WCAG, Section 508), and specialised programming for diverse input methods—including haptic feedback integration, real-time shader adjustment, and screen-reader compatibility. This highly technical development necessitates senior-level software engineers, resulting in elevated initial labour costs.

Physical Manufacturing of Tactile Prototypes: The physical manufacturing of learning aids requires specialised polymers, continuous 3D printing operation, and iterative design-testing cycles. Each prototype iteration—moving from initial concept to a robust, classroom-ready tool—involves substantial expenditures for raw materials, machine maintenance, and expert consultations with occupational therapists and educators for clinical validation. This structural complexity contributes to a high initial capital investment compared to purely software-based, mass-distributed solutions.

Long-term Efficiency and Shared ROI: However, a collaborative strategy between international institutions drastically reduces the "duplication of effort". By sharing open-source, inclusive codebases—such as the modular accessibility control panel architecture—and parametric 3D printing files, participating universities can exponentially decrease the marginal cost per inclusive student. Furthermore, these multi-sensory tools have been shown to enhance cognitive retention for sighted students as well, thereby increasing the overall return on investment (ROI) of the deployed educational technology.

4.3 Social Implications and Functional Autonomy

The joint project "Beyond My Sight" has profound social implications, explicitly focused on fostering independent agency and promoting professional parity for individuals who are blind or have low vision [6].

Fostering Active Agency: Our pedagogical strategy deliberately shifts VI students from passive recipients of information to active participants in quantitative engineering tasks. By providing synchronised, accessible tools (haptic feedback, custom UI filters, dynamic TTS, and tactile slide rules), the framework systematically reduces an individual's dependence on sighted peers. Mastery over advanced, cutting-edge technologies like VR and interactive gamification serves as a direct showcase of technical competence.

Promoting Professional Parity: True inclusion is achieved when graduates enter an equitable job market with competitive parity. The integration of physical-tactile calculation rules and adaptive virtual simulation bridges the critical skills gap by providing accessible methodologies for learning high-demand technical fields that traditionally rely on visual data interpretation. Simulating complex, real-world professional scenarios ensure workplace readiness and actively challenges deep-seated societal biases and employer misconceptions regarding the analytical capabilities of visually impaired professionals.

Through this multi-layered redesign, the paradigm pivots away from "passive assistance"—where a sighted classmate merely describes a graphical interface or reading screen—to "active agency," where the student with low vision independently manages, calculates, and executes complex project evaluation tasks with the same speed and rigor as their peers.

5 CONCLUSIONS

The "Beyond My Sight" project at Tecnológico de Monterrey demonstrates that the most effective tool for inclusion is often one that restores the student's ability to interact directly with the logic of the subject matter. While the cooperative models of Mondragón University provide an essential social framework, the **Tactile Calculation Rule** provides the technical independence necessary for success in financial and project evaluation fields. True inclusion of students with visual impairments is achieved when the student no longer requires an intermediary to interpret the world of data.

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