Educational Games for Indirect Length Comparison in Sighted and Blind Students

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Abstract: Length measurement is one of the fundamental axes of Mathematics from early childhood for both sighted and blind children. Despite its curricular importance, many students face persistent challenges in effectively comprehending length measurement. Inclusive classrooms, where sighted and blind students learn together, add further complexity, requiring adaptive instructional materials and strategies to promote equitable learning outcomes. This study investigates the use of play-based learning, specifically Gamification and fully designed educational games, to enhance understanding of length measurement in co-educational environments. Specifically, it presents the results of implementing three (3) designed games in a group of sighted and blind students attending a general education primary school. Game A involved a conventional length measurement task augmented with basic Gamification features (scenario, cards) designed to increase student motivation and engagement without altering the task structure. Game B, incorporated additional Gamification elements such as board and pawns, while Game C was a typical (board) card game, that also included Gamification features (NFC tags). The study aimed to analyze students' behaviors and strategies in tactile exploration when performing indirect length comparisons, as well as their preferences among the three (3) games. Findings indicate that the majority of students in indirect comparisons using arbitrary units (paperclips, string) employed various tactile exploration strategies such as aligning paperclips in the same direction without gaps or overlaps and placing the string from one end to the other. Some students, however, exhibited tactile exploration behaviors that included misalignments, such as placing paperclips with gaps and different directions. When using standard (cubes) and conventional measuring tools (ruler, measuring tape), students primarily structured tactile exploration strategies, ensuring cubes were connected without gaps or overlaps and aligning ruler and measuring tapes from the "0" mark. Importantly, Game C was overwhelmingly preferred by students and led to statistically significant improvements in motivation, engagement, peer interaction, and collaborative problem-solving. The findings suggest that while Gamification elements enhance traditional tasks, purpose-built educational games that combine accessibility with educational design offer superior support for inclusive mathematics instruction. The study recommends wider adoption of such games to facilitate equitable length measurement learning in inclusive classrooms.

Keywords: Gamification, Indirect length comparison, Game design, Tactile exploration, Blind and sighted students

1. Introduction

Length measurement remains a fundamental mathematical skill and serves as one of the simplest ways to quantify continuous quantities (Johnson & Miller, 2021). Children usually grasp it by comparing object attributes like height and length (NCTM, 2023). Although modern curricula emphasize its importance (ACARA, 2024; CCSSI, 2023), teaching often focuses more on procedures than deep understanding (Garcia et al., 2022). Thus, new approaches aim to build conceptual knowledge and refine intuitive understanding (Wang & Chen, 2022).

In inclusive classrooms with sighted and blind students, adaptations like tactile materials and alternative teaching methods are essential (Morris & Sharma, 2011). Game-based learning—especially board games with tactile or audio features—can support engagement and understanding (Vankúš, 2023; Gutschmidt et al., 2021). This study explores how three educational games promote haptic strategies and indirect length comparison among four primary students—one blind and three sighted.

In light of the above, this work presents the design and implementation of three different games aimed at mapping the behaviors and haptic exploration strategies, as well as the game preferences of four (4) students, a blind and three sighted, attending a general education primary school, focusing on the different dimensions of indirect length comparison.

This study is part of broader research aimed at developing criteria for designing differentiated educational materials for the functional co-education of sighted and blind students.

The research question posed was the following:

RQ1: What behaviors and haptic exploration strategies emerge through games regarding the dimensions of indirect length comparison in sighted students and the blind student?

1.1 Theoretical Framework

Indirect Length Comparison

Indirect length comparison represents a crucial developmental stage in children's understanding of length and its measurement. Initially, children perceive length as a quantity but face challenges in accurately comparing objects(Sarama et al., 2021). Over time, they progress from direct comparisons, where objects are aligned to determine relative size, to using third objects as intermediates in indirect length comparison. This stage often involves early difficulties with tools like rulers. Eventually, children understand the relationship between length units and their application, gaining proficiency in using measurement tools such as rulers and flexible instruments for measuring curved paths(Callejo et al., 2021).

This transition marks a significant cognitive leap, as it requires children to understand and manipulate relationships between three elements: the two objects being compared and the third, reference object. Despite its importance, research indicates that many children struggle at this stage. Common challenges include misaligning reference objects, misjudging distances, or misunderstanding the principles behind the tools being used (Sarama et al., 2021). These difficulties often persist even after children are introduced to standard measuring tools like rulers, suggesting the need for sustained, conceptually rich instruction.

In educational settings, children are introduced to different types of measurement units, each with distinct characteristics. Informal or arbitrary units (e.g., paperclips, hands, string) do not require prior knowledge or formal instruction, making them accessible for young learners. However, these units often yield imprecise results and lack universal acceptance. Standard units**,** such as unit cubes or centimeter blocks, offer greater accuracy and comparability while still being easy for children to use without advanced instruction (Skoumpourdi, 2018). Standard composite tools**,** such as pre-measured strips or tactile number lines, reinforce the principle of unit consistency. These tools often bridge the gap between informal experiences and the more sophisticated use of conventional measuring instruments, such as rulers and tape measures, which require specific knowledge about scale reading, zero-point alignment, and unit interpretation (Skoumpourdi, 2018; Callejo et al., 2021).

Research indicates that sighted children face challenges at various stages of development in learning to compare lengths. Children aged 4-6 struggle with indirect length comparison using a third reference object (Matsuo et al., 2023), and those aged 5-8 experience difficulties with consistent use of measurement units. Between the ages of 8-10, children encounter problems with ruler alignment and placement, with limited understanding of the ruler's structure even at ages 9-11 (Clements & Sarama, 2007; Curry et al., 2006; Bragg &Outhred, 2004). Studies on children with visual impairments are limited, but findings suggest that learners aged 9-12 experience similar challenges in using rulers (Klingenberg, 2012; Jones et al., 2012). These children often rely on haptic and kinesthetic strategies, such as using their own bodies, to estimate length (Duran & Tufenkjian, 1969). According to the Common Core State Standards, by the end of second grade, students should be able to estimate and measure object length using a ruler (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010).

Differentiation between Haptic Exploration Behaviors and Strategies

The hand plays a vital role in how we perceive and interact with our environment, particularly through the sense of touch, or haptic perception (Smith & Lee, 2021). Haptic perception relies on two main systems: the skin and kinesthesia, which work together during active exploration (Garcia et al., 2019). Unlike vision and hearing, the haptic system is specialized in identifying material properties of objects.

Exploratory behaviors—how individuals use touch to gather and interpret sensory information—are shaped by factors such as a person's goals, prior experiences, age, and whether they have visual impairments (Johnson et al., 2019; Miller & Wong, 2022). Recent findings show that cognitive abilities like mental rotation influence these exploration strategies, and that having visual experience can improve how effectively individuals explore their surroundings through touch (Taylor & Roberts, 2023).

Designing Differentiated Material for Students with Visual Impairments

Students with visual impairments face considerable challenges when engaging with traditional learning resources. However, these barriers can be addressed through intentional, inclusive design. Research highlights the importance of principles like information economy (streamlining content for clarity), haptic feedback**,** and auditory cues in enhancing spatial understanding and promoting learner independence (Dulin & Park, 2020; Mason & McCall, 2019; Harley et al., 2018; Gutschmidt et al., 2021).

Educational adaptations such as computer-based simulations and tactile materials—crafted from basic or mechanical components—have proven effective in helping visually impaired students build accurate mental models of concepts (Papadopoulos &Koustriava, 2021). Studies consistently show that blind learners can match their sighted peers in texture discrimination, emphasizing the power of touch in learning (Lederman & Abbott, 1981).

More recent research reinforces the importance of multisensory learning tools**,** combining digital simulations with tactile and auditory elements to support deep, meaningful understanding (Papadopoulos &Koustriava, 2021; Kizilaslan& Yilmaz, 2023). The ability of blind students to perform on par with sighted students in tactile perception underlines the critical need for well-designed, accessible materials in achieving educational equity (Lederman & Abbott, 2020; Education Sciences, 2021).

2. Research Methodology

This study presents the findings derived from a group of four fifth-grade students attending a school in Thessaloniki, comprising three sighted individuals and a blind student. Instructional materials were provided in braille, and the student had prior instruction in the concept of length, supported by a special education teacher. For mobility, the student utilized a white cane. All members of the group were determined to be at a comparable cognitive and learning level, as established by their performance on a diagnostic assessment consisting of fifteen (15) tasks administered to the entire class prior to the commencement of the main study.

To preserve anonymity, participants' identities were concealed and instead represented by the capital letter 'S' (denoting "Student") followed by a numerical identifier corresponding to the order in which they participated in Game A (e.g., the first student was labeled S1, the second S2, and so forth).

The research employed a qualitative methodology, specifically participatory observation. The researcher systematically observed and documented behaviors, interpersonal dynamics, and interactions as they naturally occurred, without attempting to influence or alter them. Data collection was conducted with or without the assistance of suitable research instruments. Throughout the study, the researcher maintained a peripheral participatory role—remaining embedded within the social context but refraining from direct intervention in the group's core activities (McKernan, 1996).

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Research Tool

The research tool consisted of three educational games, developed and implemented in two stages based on Gamification principles. In the first stage, the functional characteristics of each game were defined to ensure design diversity. Game A included a narrative, rules, and text-based cards; Game B added a board, pawns, and cards; while Game C featured audio instructions and was designed to foster cooperative learning, allowing students to validate answers collaboratively. The researcher's role varied: in Games A and B, the researcher validated student responses, whereas in Game C, students acted independently.

In the second stage, a set of forty instructional cards was developed, covering topics in Mathematics (indirect length comparison) and Environmental Studies (animal identification, survival mechanisms, and reproduction).

Environmental Studies was chosen for its interdisciplinary character, integrating elements of science, technology, society, and culture. Cards in Games A and B included tactile illustrations and text in both print and braille, while those in Game C provided recorded audio instructions via NFC tags.

All games incorporated accessibility features such as tactile dice, reward cubes, Velcro clips for stable measurement, and magnetic game boards and pieces. Game rules were available in both standard print and braille. All components—cards, containers, boards, pawns, cubes, audio devices, and animal figures—were designed using AutoCAD 2021 and 3D printed with PLA filament. The accuracy of braille text and functionality of materials were validated at the Center for Education and Rehabilitation for the Blind, following procedures similar to those described by Ismah, Muthmainnah, and Damayanti (2019).

The Creation of the Cards

The development of the card content followed a two-stage process. First, the Environmental Studies curriculum and relevant zoo websites were reviewed to select animals suitable for illustrating indirect length comparison and feasible for tactile or visual representation. Next, the selected animals were categorized and linked to specific dimensions of indirect comparison, organized into three tables aligned with distinct learning objectives.

Due to space limitations, card content focused solely on length comparison tasks. Supplementary Environmental Studies information was provided in printed form after gameplay to support interdisciplinary learning.

Research Implementation Process

The research was implemented through the structured administration of three educational games—Game A, Game B, and Game C—conducted on separate days. Each session began with a trial round to acquaint the students with the game rules and mechanics. Four students, selected based on their performance in a diagnostic assessment, participated in the sessions, which were conducted in a specially prepared area outside their regular classroom.

The games were played at a shared workspace consisting of two joined desks, allowing equal access to all materials. In Game A, students took turns drawing cards containing measurement instructions in both braille and print, executing the task, and providing a response. The researcher verified each response, awarding a cube for correct answers and providing no reward for incorrect ones.

Game B maintained the same basic structure but introduced a game board with four individual paths. Correct responses enabled students to advance one square along their respective paths, reinforcing learning through visual progress.

Game C incorporated audio instructions delivered via NFC-enabled cards and a smartphone device. It featured textured paths of increasing difficulty and emphasized both individual and collaborative engagement. Students listened to audio instructions, performed measurement tasks, and then had their answers verified by a peer. Correct answers advanced the player and awarded two cubes, while incorrect answers led to a loss of one cube. Students who verified answers received or returned cubes based on the accuracy of their validation.

Throughout all sessions, video recordings focused on students' hands were used to document haptic exploration strategies, supporting qualitative analysis of their tactile interaction and engagement during gameplay.

3. Results

Before presenting the findings related to students' behaviors and strategies in haptic exploration, a clarification is necessary regarding the distinction between the concepts of *behavior* and *strategy*. In the context of this study, *behavior* refers to the use of various methods for indirect length comparison in a non-systematic manner. In contrast, *strategy* denotes the consistent use of the same method of indirect comparison in two or more of the three games.

3.1 Indirect Comparison Using Arbitrary Units (Paperclips, String)

Student 1 (S1) demonstrated consistency in the placement of paperclips across all three games, aligning them without gaps or overlaps. She assigned measurement units only in Game A. With regard to string usage, she positioned it correctly from end to end in Games A and C (Figure 1); however, in Game B, the measurement did not begin at the correct starting point.

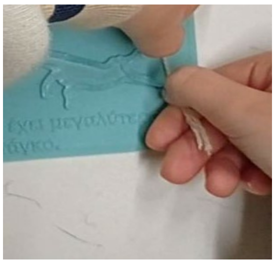

Figure 1: Indirect comparison of objects by placing the string from one end to the other of the objects being compared

Student 2 (S2) initially placed the paperclips directly on the objects in Game A but then repositioned them correctly and consistently above the objects, assigning a unit to the measurement. In Games B and C, she maintained correct placement of the paperclips but did not include a unit. Her use of string was accurate and consistent across all games, applying it from one end of the object to the other.

Student 4 (S4) experienced significant difficulties. In Game A, his placement of paperclips was inconsistent, with overlapping and varied directions. In Game B, although he correctly placed the paperclips on the first path, he reversed their orientation on the second and omitted the unit. In Game C, his placements were correct and consistent, but again lacked unit assignment and varied in their position relative to the object. For the string, he counted knots in Game A, applied it correctly in Game B, and inconsistently in Game C, sometimes measuring only parts of the object or its full length irrespective of the task.

Student 3 (S3) (blind student) consistently placed the paperclips correctly in Games A and C but omitted the unit. In Game B, his placements were incorrect. His string usage was accurate in Games A and B. In Game C, although he measured both paths correctly in two instances, in one case, he measured only one of the two paths, using three fingers for haptic exploration of the second.

3.2 Indirect Comparison Using Standard Units (Cubes)

Student 1 (S1) consistently placed the cubes without gaps across all three games. In Game A, she did not assign a unit, whereas in Game B, both correct placement and unit assignment were observed. In Game C, her performance varied: in one case, she omitted the unit despite correct placement; in another, she included it; and in one instance, the cubes were placed with gaps and no unit was assigned.

Student 2 (S2) also showed generally accurate cube placement but rarely assigned units. In Game A, she placed the cubes correctly in both tasks but omitted the unit each time, including after tactile verification in one case. In Game B, the cubes were correctly aligned but without unit notation. In Game C, one instance showed correct placement without a unit, while another involved cubes positioned outside the objects with gaps (Figure 2), though a unit was included.

Figure 2: Indirect comparison of objects by placing the cubes outside the objects to be compared, with gaps

Student 4 (S4) demonstrated correct cube placement in Games A and B but did not assign any units. In Game C, his performance declined, with placements outside object boundaries and occasional incorrect quantities, although some were correctly aligned. Unit assignment was consistently absent.

Student 3 (S3) (blind student), placed the cubes correctly and assigned a unit in one task each from Games A and B. In later tasks, he omitted the unit despite correct placement. In Game C, most placements were accurate, but one involved gaps and incorrect alignment. Overall, his unit assignment was inconsistent.

3.3 Indirect Comparison Using Conventional Measuring Tools (Ruler, Measuring Tape)

*Student 1(S1)*in Game A used the ruler and measuring tape starting from “0” and correctly assigned a unit. In Game B, while the tools were correctly placed, the unit was omitted. In Game C, she used the tools appropriately across all cards, but only once did she assign a unit to the result.

Student 2 (S2) and *Student 4* (*S4)* consistently placed the ruler and measuring tape from “0” across all games but did not assign a unit in any instance. *Student 3* (*S3)* (blind student) also placed the ruler and measuring tape from “0” in all games without assigning a unit. However, in one instance during Game C, the ruler was placed starting from “1” (Figure 3), and again, no unit was recorded.

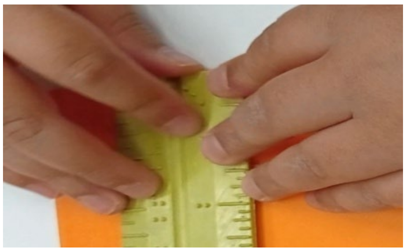

Figure 3: Indirect comparison of objects by placing the ruler from "1"

The participants overwhelmingly preferred Game C, a card-based activity enriched with various Gamification elements and tactile adaptations. This preference was attributed to its original features, ease of auditory over visual instruction, and the inclusion of peer verification, absent in Games A and B. However, several factors appeared to impact student performance: the extended duration of Game C, the large number of cards, and elements such as difficulty levels and point systems, which were ultimately deemed non-essential as they did not influence the flow or outcome of the game.

4. Conclusions

In the domain of indirect comparison using arbitrary units (e.g., paperclips and string), *Student 1 (S1)* and *Student 2 (S2*) predominantly employed haptic exploration strategies, placing paperclips without gaps or overlaps. In contrast, *Student 4 (S4)* displayed irregular placement patterns—marked by inconsistent directions, overlaps, and gaps—indicating a lack of systematicity. *Student 3 (S3)* (blind student) demonstrated some inconsistency in directional placement, particularly in Game B. Regarding the use of string, Student 1 (S1) and *Student 2 (S2)* maintained relatively structured strategies, while *Student 4 (S4)* encountered significant difficulties in accurate placement. Despite his visual impairment, *Student 3 (S3)* applied consistent string placement and utilized three-finger tactile exploration in Game C, reflecting adaptive haptic techniques. These findings echo previous research (Lehrer, 2003; Matsuo & Nakawa, 2019; Matsuo et al., 2023) on the challenges of developing indirect measurement skills through haptic means.

When using standard units (cubes), most students applied tactile strategies, ensuring contact between cubes. Nonetheless, common errors emerged, including gaps between cubes, incorrect quantities, and misaligned placement around instead of along the objects. Such errors align with previous findings (Skoumpourdi, 2018; Strayton, 2018; Sutherland et al., 2020), which reported similar issues in cube placement during length estimation tasks.

In the context of conventional measuring tools (rulers and tape measures), most participants demonstrated basic understanding of measurement, employing haptic techniques and generally starting from “0.” However, a recurring error involved initiating measurements from “1,” a pattern also observed in earlier studies (Lehrer et al., 1999; Bragg &Outhred, 2001; Gómezescobar et al., 2020).

Students—both sighted and blind—expressed a clear preference for Game C, a gamified, card-based activity featuring adaptive elements. This preference likely stemmed from the novelty of its components, auditory instructions, and peer-verification mechanism. Nevertheless, the game’s extended duration, excessive number of cards, and unnecessary complexity (e.g., point systems, difficulty levels) hindered the flow of gameplay.

Based on these findings, it is recommended that inclusive educational settings integrate gamified activities designed to support equitable access, differentiated difficulty, collaboration, and peer feedback. Equal access can be promoted through assistive features such as NFC tags and magnets. Varying difficulty levels can accommodate diverse learning needs, while peer validation processes foster communication, engagement, and reflective learning.

These recommendations aim to enhance educational inclusivity and promote active, collaborative learning experiences for all students.

Ethics Declaration: This research was conducted in accordance with the *Convention on the Rights of the Child*, with primary consideration given to the best interests of the children involved. A key ethical principle adhered to was *Informed Consent* and the *Voluntary Nature of Participation*. The researcher provided comprehensive information about the study's objectives to both the participants and their parents or guardians. It was clearly communicated that participation was entirely voluntary and that both children and their guardians had the right to withdraw from the study at any time, without consequence. A second fundamental principle observed was *Anonymity and Confidentiality*, ensuring that the identities and personal data of participants were protected throughout the research process. Additionally, formal approval to conduct the research was obtained through a consent document authorized by the University of the Aegean and the Institute of Educational Policy.

AI Declaration: No AI tools were used in the creation of this paper.

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