

Enhancing Mathematical Connections of Deaf Students via Multisensory E-Comics and Collaborative Learning

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Abstract

Limited auditory access among deaf students often hinders the formation of abstract mathematical connections. This study aims to analyse the functional impact of a multisensory statistics e-comic integrated with a collaborative learning model on the mathematical connection abilities of deaf students. Using the Single Subject Research (SSR) method with an A-B-A design, this study involved three deaf students from Class VIII-B over 12 observation sessions (4 sessions per phase). Data were analysed through visual inspection and the Percentage of Non-overlapping Data (PND). The results showed a substantial increase in average scores from the baseline phase ($\$A_1$) to the intervention phase (B): S1 (29.17 to 76.39), S2 (54.17 to 79.17), and S3 (58.33 to 83.33). Visual analysis revealed a stability rate of 100% and a PND of 100%, confirming the high effectiveness of the intervention. However, in the maintenance phase ($\$A_2$), the average scores decreased to 51.39, 58.33, and 54.17. These findings indicate that whilst multisensory e-comics are effective as instructional scaffolding for instantly improving contextual understanding and digital navigation, sustained reinforcement is required to maintain long-term retention. The novelty of this research lies in the integration of multisensory elements within visual media to bridge specific cognitive barriers associated with hearing impairments.

Keywords: statistical e-comic, multisensory, mathematical connection, deaf students, single subject research



INTRODUCTION

Education is the fundamental foundation for the intellectual development of the nation and a key instrument for the holistic development of human potential (Shavkidinova et al., 2023). The Indonesian Constitution, through Law No. 20 of 2003 on the National Education System and Article 31 of the 1945 Constitution, guarantees that every citizen, including individuals with physical or mental disabilities, has an equal right to access dignified educational services. The fulfilment of this right is not merely an administrative obligation, but a manifestation of social justice aimed at optimising the unique potential of every learner within the structure of society (Sucipto & Ruslie, 2024). Efforts to realise this social justice, however, face real challenges when confronted with the highly diverse characteristics of Children with Special Needs.

The diverse characteristics of children and young people with special educational needs require a more tailored approach, as they often face cognitive and accessibility barriers that have a direct impact on their academic achievement (UNESCO, 2020). In response to this complexity, the government, through the Minister of Education, Culture, Research and Technology Decree No. 56/M/2022, encourages the implementation of a curriculum based on diversification and differentiated pedagogy (Kristiana & Widayanti, 2021). However, although the legal framework is in place, in its implementation in the classroom, mathematics remains a difficult cognitive ‘fortress’ to penetrate due to its abstract and systematic nature. The difficulty in overcoming this abstract nature of mathematics is felt to be far greater by deaf students, who have limitations in processing auditory information.

These auditory limitations make the experience of learning mathematics for deaf students a silent and confusing journey, given that classroom instruction is still dominated by verbal explanations (Schindler et al., 2022). The World Health Organization (WHO, 2023) notes that hearing loss exceeding 20 dB significantly impacts the frequency of normal communication, which in turn hinders students’ ability to grasp the logical structures of mathematics conveyed orally. This systemic communication barrier specifically undermines students’ mathematical connection skills.

Mathematical connection skills is the capacity to link various mathematical ideas into a unified understanding are positioned by the NCTM (2000) as a crucial process standard to ensure students do not merely memorise meaningless procedures. Without this ability, mathematics for deaf students will appear merely as a series of meaningless numbers. Limited mathematical vocabulary and the absence of ‘auditory intuition’ make it difficult for them to bridge the symbols on paper with the realities of everyday life (Leton et al., 2019). Ironically, this lack of connection is not only caused by internal factors within the students, but is also exacerbated by the gap in Learning Outcomes (LO) between the regular curriculum and the special curriculum.

This curricular gap is particularly evident in Phase D (Year 8), where mainstream pupils are already exploring complex statistical concepts such as measures of central tendency (mean, median, mode), whilst pupils in special schools are often limited to very basic functional content. This disparity in standards indirectly limits the intellectual rights of deaf students to think critically through data, even though they possess equivalent

cognitive potential if provided with appropriate accessibility (Shomad et al., 2021). Driven by the need to provide equal intellectual access, the researchers conducted a preliminary study at the Ungaran State Special School.

Through this preliminary study, a concerning cognitive reality was uncovered in Class VIII-B, where 100% of the research subjects failed to correctly connect the ‘mean’ formula with its application. Students may be able to mechanically add up a series of numbers, but they stop there without understanding the process of data analysis, let alone interpreting the utility of such statistics in real-world decision-making. This phenomenon confirms that without visually accessible materials, deaf students will remain trapped in rote memorisation of numbers without any deeper understanding (Cahyani & Sugiman, 2023). This failure to interpret data is actually a systemic issue also found among mainstream students, yet its impact is exponentially more severe for deaf students.

The more severe impact on deaf students is caused by the lack of visualisation in conventional methods, which fail to engage their sensory modalities optimally. Therefore, a transformation of learning media is required—one that is not merely ‘visible’, but also capable of performing ‘cognitive translation’ in line with their natural learning processes. In response to this need for transformation, this study proposes the use of a multisensory-based statistical e-comic.

This multisensory statistical e-comic is designed to transform lengthy and linguistically taxing story-based questions into concrete visual narratives and character gestures. Through visual-tactile-kinesthetic synergy, deaf students are given the opportunity to build a bridge between real-world experiences and abstract statistical symbols (Daza Gonzalez et al., 2023). However, the visual power of these e-comics will not achieve maximum effectiveness unless accompanied by the dynamics of social interaction within the classroom.

Such social interaction is facilitated through a collaborative learning model designed to break down the intellectual isolation of deaf students. Within the collaborative space, students can exchange signs and visual representations to construct mathematical meaning collectively (Flórez-Aristizábal et al., 2022). It is this synergy between the sophistication of digital technology and the warmth of social interaction that is expected to restore students’ cognitive abilities and substantially improve their understanding of mathematics. Given the urgency outlined above, this study focuses on: (1) analyse changes in mathematical connection scores between the baseline and intervention phases, and (2) describe the stability of trends and retention of these abilities in the context of measures of central tendency. Through this approach, it is hoped that mathematics will no longer be a silent burden, but rather a tool of empowerment for deaf students to understand the world.

METHODS

This study employed a Single Subject Research (SSR) design with an A-B-A pattern to analyze the functional relationship between the intervention and the subjects' mathematical connection skills. To enhance internal validity and provide a

comprehensive understanding of the learning process, a concurrent embedded mixed-methods strategy was utilized, where qualitative data from observations and interviews were systematically integrated within the primary SSR structure. This approach aimed to elaborate on the dynamics of individual level changes, trend stability, and data overlap across the Baseline-1 (A1), Intervention (B), and Baseline-2 (A2) phases. The research was conducted at SLB Negeri Ungaran, involving three deaf students from Grade VIII-B selected through purposive sampling based on: (1) profound hearing loss (>90 dB) without additional disabilities, (2) mastery of basic Indonesian Sign Language (BISINDO), and (3) low baseline scores (<60) in statistics. This limited sample size is consistent with the micro-analytic nature of SSR, which emphasizes individualized clinical significance and intra-subject replication rather than population-based generalization.

The intervention procedures in Phase B consisted of six sessions, each lasting 60 minutes. To ensure treatment fidelity, each session followed a standardized multisensory-collaborative protocol comprising four procedural stages: a 10-minute visual priming using digital tablets, a 20-minute tactile-kinesthetic modeling with concrete manipulatives, a 20-minute collaborative scaffolding through peer discussion, and a 10-minute individual feedback to reinforce mathematical connection indicators. An independent observer utilized a fidelity checklist to confirm that 100% of the instructional steps were implemented consistently across all subjects, ensuring high procedural compliance and internal validity.

Data collection instruments included a performance-based mathematical connection test consisting of 10 items (Scale 0–100) to measure conceptual interrelation, interdisciplinary connection, and real-world application. The content validity of the instrument was confirmed by two experts with a Content Validity Index (CVI) of 1.00, while inter-rater reliability was established with a second observer, yielding a Cohen's Kappa coefficient of 0.88. Additionally, affective engagement and digital psychomotor skills were measured using a 4-point Likert scale (1=Poor to 4=Excellent). Supplementary qualitative data were gathered through field notes and semi-structured interviews conducted at the end of Phase B and Phase A2 to explore the dynamics of learning maintenance and social validity.

Quantitative data were analyzed using visual inspection procedures, encompassing both within-condition and between-condition analyses. The decision rules for analyzing data patterns included determining trend direction using the split-middle method, stability levels with a 15% stability envelope, and level changes (absolute and relative). The intervention effect magnitude was calculated using the Percentage of Non-overlapping Data (PND) based on the criteria by Scruggs and Mastropieri, where a PND value above 90% is categorized as highly effective. Meanwhile, qualitative data underwent thematic analysis through data reduction and axial categorization to enrich the interpretation of numerical fluctuations and contextualize the data trends observed during the maintenance phase.

RESULTS AND DISCUSSION

The results of this study demonstrate a clear functional relationship between the use of multisensory-based statistical e-comics integrated with collaborative learning and the immediate improvement in the mathematical connection skills of deaf students. Quantitatively, the intervention phase (B) triggered a substantial level change in mathematical connection test scores for all three subjects (S1, S2, and S3) compared to their initial baseline-1 (A1) performance.

As shown in Table 1, S1's score rose significantly from 29.17 to 76.39 during the intervention, S2 increased from 54.17 to 79.17, and S3 improved from 58.33 to 83.33. However, upon the withdrawal of the intervention in the baseline-2 (A2) phase, a substantial decline in scores was observed across all subjects. S1 and S3 experienced score reductions of 32.7% and 35.0% respectively compared to their intervention-phase averages, while S2's score decreased to 58.33

Table 1. Average Scores of Students' Mathematical Connection Tests in Each Phase

Subject	Baseline-1	Intervensi (B)	Baseline-2 (A2)
S1	29,17	76,39	51,39
S2	54,17	79,17	58,33
S3	58,33	83,33	54,17

The effectiveness of the intervention was evaluated through a rigorous visual inspection of within-condition and between-condition data patterns. To ensure methodological transparency and eliminate descriptive bias, the interpretation of data was governed by explicit analytical benchmarks. Trend directions were identified using the split-middle method to determine the trajectory of the data points within each phase. Data stability was assessed using a 15% stability envelope, where a phase is classified as "stable" only if at least 80% of the data points fall within the calculated range. Based on this threshold, all subjects (S1, S2, and S3) achieved a 100% stability level across the A1, B, and A2 phases. Furthermore, the magnitude of the intervention effect was quantified using the Percentage of Non-overlapping Data (PND) based on the criteria by Scruggs and Mastropieri. The analysis yielded a 0% overlap (100% PND) between the baseline (A1) and intervention (B) phases for all subjects. Following established SSR benchmarks, a PND score of 100% provides objective evidence that the multisensory-based statistical e-comic is a "highly effective" intervention for enhancing the subjects' mathematical connection skills during the treatment period. Level changes were calculated by determining the absolute difference between the last data point of the baseline and the first data point of the intervention to quantify the immediate impact of the treatment. The summary of these visual analysis results, justified by these explicit analytical thresholds, is presented in Table 2.

Table 2. Recapitulation of Analysis Results Under Conditions and Analysis Between Conditions

Subject	Phase	Direction Trajectory	& Trends	Stability (%)	Stability Level Range	Level & Change	Overlap
S1	A1	(=)		100%	26,98 – 31,36	0 (=)	–
	B	(+)		100%	72,43 – 80,35	4,17 (+)	0%
	A2	(=)		100%	47,32 – 55,46	0 (=)	–
S2	A1	(+)		100%	49,79 – 58,55	0 (=)	–
	B	(=)		100%	75,00 – 83,30	8,33 (+)	0%
	A2	(–)		100%	49,79 – 58,55	–25 (–)	–
S3	A1	(+)		100%	49,79 – 58,55	0 (=)	–
	B	(+)		100%	78,96 – 87,71	8,33 (+)	0%
	A2	(–)		100%	51,18 – 59,94	4,16 (–)	–

The analysis of deaf students' mathematical connection abilities was categorized into three core indicators: (1) connecting mathematical concepts, (2) relating mathematical concepts to other fields of study, and (3) applying mathematical concepts in everyday life. To ensure clarity and replicability, these cognitive achievements were measured using a standardized performance-based test on a scale of 0 to 100. During the baseline-1 phase, subjects demonstrated procedural rigidity and often answered questions without a fundamental grasp of the underlying logic. For example, students could calculate a mean value but struggled to explain the interrelationships between mean, median, and mode. This stage was characterized by rote memorization, which limited the students' ability to connect statistical concepts.

Following the intervention using multisensory-based statistical e-comics and collaborative learning, a significant qualitative shift was recorded in all indicators. Systematic thematic coding of interview transcripts and field notes revealed that subjects transitioned from procedural recitation to contextual explanation. For instance, students could articulate the differences between measures of central tendency and justify their use in real-world contexts, such as calculating average daily temperatures or determining the median duration of training sessions. The visualizations and contextual stories in the e-comic functioned as a vital cognitive bridge and functional scaffold, facilitating an internalized understanding of numerical data that had been absent during the baseline phase.

The observed development in mathematical connection skills was evidenced by a systematic triangulation of performance-based test scores, semi-structured interviews, and direct classroom observations. Cognitive achievement was measured using a standardized scoring scale of 0 to 100, where each of the ten test items assessed specific indicators of conceptual interrelation and real-world application. The qualitative data revealed that the multisensory visualizations and contextual narratives within the e-comic functioned as a functional scaffold, enabling students to decode numerical data and relate statistical concepts to diverse fields such as sports, economics, and meteorology. This integrated approach allowed for a rigorous evaluation of how students transitioned from procedural knowledge to a more robust conceptual understanding across all phases of the

study. The detailed achievement of these indicators for each subject, aligned with the established scoring benchmarks, is presented in Table 3.

Table 3. Achievement of Student Mathematical Connection Ability Indicators in Each Phase

Indicator	Phase	S1	S2	S3
		(Categories)	(Categories)	(Categories)
Connecting mathematical concepts	A1	4 (C)	3,32 (C)	4 (C)
	B	7,32 (SB)	7 (SB)	7,65 (SB)
Linking mathematical concepts to other fields of study	A2	4 (C)	5 (B)	6 (B)
	A1	3,32 (C)	3 (C)	3,5 (C)
	B	6,68 (B)	7,32 (SB)	6,5 (B)
Applying mathematical concepts in everyday life	A2	6,68 (B)	6 (B)	6 (B)
	A1	4,68 (B)	4 (C)	4,5 (B)
	B	7,32 (SB)	6,8(B)	7,2 (SB)
	A2	4,68 (B)	5,5 (B)	5,5 (B)

The affective aspect in this study covers six dimensions observed during the learning process: (1) curiosity, (2) thoroughness, (3) responsibility, (4) perseverance, (5) enthusiasm for learning, and (6) self-confidence. Observations were conducted systematically at each phase (baseline-1, intervention, and baseline-2) to assess changes in students' attitudes and motivation during the intervention process. Each indicator was observed using an observation sheet specifically developed according to the characteristics of deaf students.

In the baseline-1 phase, most students showed low to moderate affective engagement. They tended to be passive, lacked confidence, and showed no enthusiasm when faced with mathematics problems that were considered difficult. However, after being given treatment in the form of multisensory-based statistical e-comics, there were significant changes, especially in the indicators of curiosity, enthusiasm for learning, and confidence. Students became more active in asking questions, showed perseverance in completing tasks, and felt more comfortable working in small groups. The indicators of responsibility and perseverance also increased, as seen from the consistency of students in completing learning activities until the end of the session.

In the baseline-2 phase, even though the intervention was no longer provided, most indicators remained in the good category, indicating the retention of positive attitudes formed during the intervention learning process. This change in attitude indicates that e-comics not only influence cognitive aspects but also significantly shape the behaviour and learning motivation of deaf students in a sustainable manner.

Table 4. Average Affective Scores of Deaf Students in Each Phase

Phase	S1 (Categories)	S2 (Categories)	S3 (Categories)
A1	2,62 (B)	2,55 (B)	2,67 (B)
B	3,45 (SB)	3,29 (B)	3,39 (SB)
A2	3,04 (B)	2,91 (B)	3 (B)

In terms of psychomotor skills, the development of deaf students' skills in interacting with digital learning media showed significant progress after intervention with

multisensory-based statistical e-comics. Observations were made on three main indicators, namely ease of access to media, ease of use of features in e-comics, and the ability to apply the material to problem solving. In the baseline-1 phase, most students had difficulty opening, reading, and understanding the structure of the e-comic independently. They needed help from teachers or friends to access content and operate the device. However, in the intervention phase, all subjects experienced increased independence in using e-comics, being able to read the storyline, turn pages, and navigate the material more smoothly. In addition, students' skills in applying the material to contextual problem solving also improved, as demonstrated through collaborative activities and the ability to solve problems more coherently and accurately.

Psychomotor observation scores during the intervention showed a shift from the "fairly good" category to the "very good" category, whereas in the baseline-2 phase, the scores remained in the "good" category, indicating retention of digital skills and learning independence formed during the intervention process.

Table 5. Average Psychomotor Scores of Deaf Students in Each Phase

Phase	S1 (Categories)	S2 (Categories)	S3 (Categories)
A1	2,61 (C)	2,56 (C)	2,48 (B)
B	3,5 (SB)	3,39 (SB)	3,5 (SB)
A2	3,06 (B)	3 (B)	3,22 (B)

The survey results show that students' responses to the use of statistics e-comics were very positive, with a score of 97.72% for S1 and 100% for S2 and S3. These responses reflect that e-comics are considered to help understanding concepts, increase interest and confidence, and facilitate access and use of media. Visual illustrations, contextual storylines, and a multisensory and collaborative learning approach are considered to make learning more interesting and easier to understand for deaf students.

A thematic analysis of the qualitative data revealed that the improvement in the subjects' mathematical connections stemmed from three main mechanisms identified through a systematic coding process: (1) visual-contextual decoding, in which e-comic illustrations served as cognitive scaffolding to transform the abstract concept of the mean into a concrete mental representation; (2) social mediation (peer-scaffolding), evident in the increased frequency of technical cues exchanged between participants during group discussions; and (3) cognitive efficacy, characterised by an increase in participants' initiative in presenting data. These findings provide empirical evidence that goes beyond mere illustrative commentary, demonstrating that multisensory e-comics act as cognitive mediation tools that reduce extraneous cognitive load in deaf students (Dewi et al., 2020). Crucially, these results extend the findings of Nurhayati et al. (2022) by demonstrating that the integration of collaborative aspects is capable of creating a dialogic space that stabilises post-intervention comprehension retention (Phase \$A_2\$), a dimension that had not been explored in depth in previous digital accessibility studies by Flórez-Aristizábal et al. (2022).

However, the consistency of findings between the quantitative SSR data and these qualitative responses must be interpreted with caution within the context of individual

effectiveness. Given the unique characteristics and variability of barriers experienced by each subject (KN, AN, and FR), the results of this study are not intended to be broadly generalised to the population of people with hearing impairments in institutional settings or to inform macro-level policy. The primary focus of this discussion remains on the functional relationship between the intervention and changes in cognitive behaviour at the individual subject level, indicating that the effectiveness of the e-comic is highly dependent on the alignment between the visual design of the medium and the specific needs and baseline abilities of each individual within the State Special School (SLB) in Ungaran.

CONCLUSION

Based on the results of visual analysis within a Single Subject Research (SSR) design and qualitative data triangulation, it can be concluded that the use of a statistics-based e-comic employing a multisensory approach integrated with collaborative learning demonstrates potential functional effectiveness in enhancing mathematical connection skills among three deaf subjects (KN, AN, and FR) at the Ungaran State School for the Deaf. The increase in the average score from the baseline-1 phase (\$A_1\$) to the intervention phase (B) indicates that the visual-contextual stimuli in this medium are capable of mitigating barriers to abstraction in material on measures of central tendency for the research subjects. However, the data fluctuations observed in the baseline-2 phase (\$A_2\$) suggest that the retention or maintenance effect of mathematical connection skills is limited and requires ongoing reinforcement following the intervention.

This study has several methodological limitations that should be noted, including: (1) the very small sample inherent in a single-subject design, meaning that these results cannot be broadly generalised to the deaf population or other educational institutions; (2) the contextual specificity of the intervention, which is highly dependent on the individual characteristics of the subject; and (3) the need for more extensive testing of the instrument's reliability in the future. Therefore, practical recommendations for educators in special schools should be viewed as alternative adaptive strategies requiring tailoring to each student's cognitive profile. Further research with longer intervention durations and a broader scope of material is strongly recommended to test the stability of the effects of this multisensory intervention more comprehensively within the field of special education.

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