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Computer-based animation system for reading literacy in students with intellectual disabilities

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ABSTRACT

Reading literacy is a central challenge for students with intellectual disabilities, affecting skills such as letter recognition, vocabulary comprehension, and meaning retention. In Indonesian special schools, the problem is exacerbated by limited adaptive computer-based learning media and the lack of quantitatively evaluated digital interventions. To address this, the study designs and evaluates a computer-based digital animation video learning system developed using accessibility-focused human–computer interaction (HCI) and multimedia learning theory. This system was implemented as a software-based intervention and evaluated with a pre-experimental one-group pretest–posttest design involving thirteen students with mild to moderate intellectual disabilities. Quantitative analysis included validity and reliability testing, paired samples t-test, effect size calculation, and normalized gain (N-gain) analysis. Results show significant improvement in reading literacy after the intervention. The N-gain score was high at 0.7038, and the effect size was very large, demonstrating strong educational effectiveness. These findings highlight the promise of computer-based animated video systems as effective, scalable technologies for inclusive education. The study offers a replicable framework for combining multimedia system design and quantitative evaluation in educational technology for learners with cognitive disabilities.

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1. INTRODUCTION

The rapid advancement of computer technology has transformed the delivery of education. It now enables computer-based digital animation videos in instructional design. These systems use multimedia computing, interactive graphics, audio narration, and text-based captions. The result is engaging and adaptive learning environments [1], [2]. In special education, especially for students with intellectual disabilities, such technology can address persistent reading literacy challenges [3], [4]. Reading is a foundational cognitive skill, not only for academic achievement but also for functional independence, such as interpreting traffic signs, reading food labels, or understanding instructions in daily life [3]. However, students with intellectual disabilities often face cognitive barriers, including difficulties in executive functioning, language processing, and memory retention [3], [5]. These challenges necessitate adaptive, contextual, and visually rich instructional approaches that can reduce cognitive load while enhancing engagement and comprehension [6], [7].

In Indonesia, the availability of digital learning media tailored for students with intellectual disabilities remains limited, and teachers in special schools (*Sekolah Luar Biasa* or SLB) often lack adequate training and

resources to develop computer-based materials suited to their students' cognitive profiles [4]. Research has shown that the successful implementation of inclusive education is strongly influenced by teachers' self-efficacy, professional preparation, and perceived institutional support [8]. Without adequate technological readiness, the potential benefits of digital learning systems for inclusive education remain underutilized. Computer-based digital animation offers unique advantages in addressing these challenges. It delivers learning material through dynamic visuals, synchronized audio, and structured narration, which enhance attention, motivation, and learner engagement [9], [10]. Recent studies further indicate that adaptive learning technologies and interactive digital tools can significantly increase student engagement, particularly when aligned with learners' digital literacy levels [11]. Moreover, interactive animated and tablet-based media have been shown to strengthen visual memory, reduce linguistic barriers, and present abstract concepts in concrete and accessible forms for students with intellectual disabilities [6], [12], [13].

Empirical evidence consistently supports the integration of interactive multimedia in special education contexts. For instance, [12] demonstrated that interactive multimedia significantly improves reading skills for students with special needs, while [14] reported improved literacy outcomes through interactive visual multimedia interventions. In addition, studies on accessible digital interventions, such as game-based and multimedia systems, highlight the importance of inclusive design in enhancing engagement, participation, and skill development among learners with cognitive disabilities [15], [16]. However, many of these studies emphasize pedagogical outcomes without integrating rigorous quantitative performance evaluation from a computing perspective. Research on inclusive digital education shows that technology must be designed with contextual sensitivity. This is especially important in low-resource or disadvantaged educational settings to prevent widening digital divides [17]. Digital technologies can foster equity, diversity, and inclusion. They support inclusive participation and learner-centred educational practices [18]. These findings highlight the need for scalable, accessible, and empirically evaluated digital learning systems in special education.

This research addresses these gaps by designing, implementing, and evaluating a computer-based animated video learning system to enhance literacy at a state special school in Kuningan, Indonesia. Using a one-group pretest–posttest design, the system's effectiveness was evaluated quantitatively with paired-samples t-tests and normalized gain (N-gain) analysis [19]. Key findings show that reading literacy improved from pretest ($M=68.46$) to posttest ($M=89.23$), with a statistically significant increase ($p<.001$) and a high N-gain score (0.7038). This demonstrates the strong effectiveness of the proposed system. This study uses principles of human–computer interaction (HCI), multimedia learning theory, and applied computing in education. It contributes to computer science in three ways. First, it demonstrates the design and deployment of computer-based animated video media for learners with cognitive disabilities. Second, it provides quantitative performance metrics to evaluate the effectiveness of multimedia in literacy. Third, it offers a scalable approach aligned with universal design for learning (UDL) to support inclusive education [20], [21]. Therefore, this study is positioned as a pilot evaluation to explore the feasibility and initial effectiveness of the proposed computer-based digital animation video system in a real special education context. From an informatics perspective, this study advances three key areas. First, within information systems, it details the design and implementation of a software-based learning system specifically developed for students with intellectual disabilities. Second, in the field of HCI, it employs accessibility-focused interface design principles to enhance usability for individuals with cognitive limitations. Third, regarding software-based educational systems, it introduces a quantitative performance evaluation framework utilizing statistical and learning analytics methods, such as N-gain and effect size analysis. The research question driving this study is: How effective is the use of computer-based digital animation video in improving the reading literacy of students with intellectual disabilities in a special school context?

Novelty of this study: previous studies have applied multimedia learning tools primarily in a descriptive manner. This research treats the computer-based animated video as a computationally engineered learning system designed for students with intellectual disabilities. There are three novelties: i) the learning media is a software artefact that integrates accessibility-focused HCI design and multimedia learning principles; ii) it uses quantitative performance evaluation methods like N-gain analysis and effect size calculations. These methods are rarely used in prior special education multimedia research; and iii) it proposes a scalable system framework adaptable to multiple platforms and low-resource environments. This positioning aligns the study with applied computing and educational informatics research domains.

2. METHOD

2.1. Research design

This study employed a quantitative, pre-experimental design in the form of a one-group pretest–posttest evaluation [19]. In the computing research context, the animated video system was treated as a software-based learning intervention, and its effectiveness was assessed through empirical performance

evaluation. The independent variable was the computer-based animated video learning system, and the dependent variable was the reading literacy performance of students with intellectual disabilities.

The system was implemented as a stand-alone computer application, integrating digital animation rendering, audio narration, and text synchronization, optimized for visual clarity and minimal cognitive load. The pedagogical content focused on functional reading—specifically vocabulary related to professions and jobs—presented through short animated sequences with synchronized captions and voice-over.

2.2. Participants

The study was conducted at State Special School, Kuningan, Indonesia, in June 2025. Using saturation sampling, which involves selecting the entire population of a small, defined group [19], the entire population of 13 students with mild to moderate intellectual disabilities in the target class was included. All participants met the inclusion criteria of: i) being enrolled in the school during the study period and ii) having basic recognition of letters in the Latin alphabet. The sample comprised 13 students with mild to moderate intellectual disabilities. This number represents the entire student population in the target class at the participating special school. Therefore, a saturation sampling technique was employed, which is considered appropriate for exploratory quantitative studies conducted in small, specialized educational settings. Although the sample size is limited, it reflects real-world classroom conditions in special education settings and enables an in-depth evaluation of the intervention's effectiveness within this population.

2.3. System implementation and procedure

The computer-based video learning system is a standalone computer program made for students with mild to moderate intellectual disabilities. It helps teach functional reading using animation, spoken words, and matched text. The design focuses on making the system easy to use, clear to see, and simple to follow, so it meets the needs of these students. The animated video learning system was developed using Adobe Animate and deployed as a standalone desktop application running on Microsoft Windows 10. The application was executed on desktop computers equipped with Intel Core i5 processors, 8 GB RAM, 1920×1080 display resolution, standard speakers, mouse input devices, and 21-inch LCD monitors to support smooth multimedia rendering and consistent user interaction during all intervention sessions.

Figure 1 presents the overall system architecture of the proposed computer-based digital animation video learning system. The architecture consists of five interconnected modules. The learning content design module is responsible for selecting and structuring vocabulary content relevant to students' daily contexts, including storyboard development and caption preparation. This content is processed by the animation and multimedia module, which manages visual rendering, audio narration, and timing synchronization to ensure a coherent multimedia presentation.

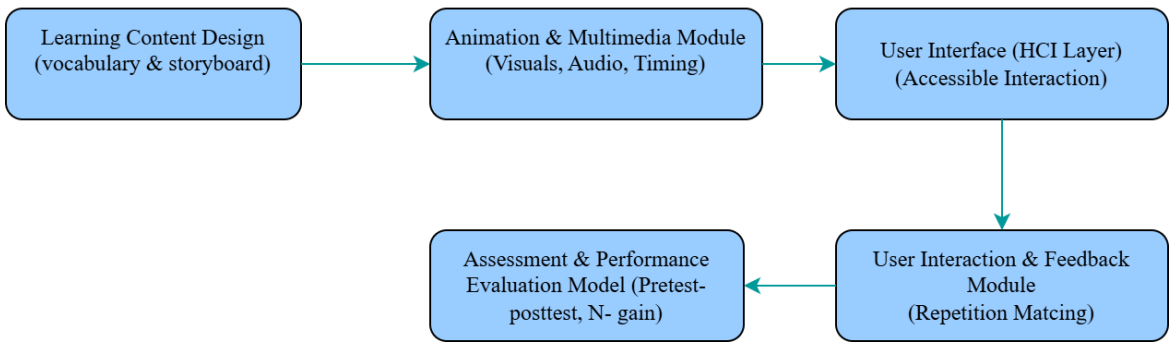

Figure 1. System architecture of the computer-based digital animation video learning system

The user interface module serves as the HCI layer, implementing accessibility-oriented design principles such as large interactive elements, high-contrast visuals, and simplified navigation. User interactions are managed through the interaction and feedback module, which provides immediate responses through repetition prompts, letter–word matching activities, and corrective feedback to reinforce learning. Finally, the assessment and performance evaluation module records learners' responses and supports quantitative evaluation through pretest–posttest comparison, N-gain analysis, and effect size calculation. Together, these modules form an integrated system that enables both effective learning delivery and systematic performance evaluation within a special education context.

The intervention was executed over four sessions in June 2025, as follows:

- Pretest phase–participants completed a computer-assisted reading test consisting of matching images of professions to corresponding English words. The test interface was developed with clear, high-contrast graphics and minimal on-screen distractions.
- Treatment phase–over two consecutive sessions, participants engaged with the animated video learning system. the application delivered animated scenes (e.g., a teacher in a classroom, a doctor in a clinic) with synchronized English captions and voice narration. Interactive prompts allowed students to repeat words, match letters, and identify vocabulary items.
- Posttest phase–the same test as in the pretest phase was administered via the computer interface to measure performance changes.

During the treatment, HCI principles were applied to ensure accessibility: large clickable elements, simple navigation, and redundancy in information presentation (visual+audio).

2.4. Data collection instruments

Two primary instruments were used:

- Computer-based reading test–developed in digital format to assess recognition, pronunciation, and recall of target vocabulary.
- Engagement observation sheet–logged participants' attention, interaction frequency, and responsiveness during system use.

All test items were validated for content validity using pearson product–moment correlation. Of the 10 items tested, 7 met the validity criteria ($r>0.553$). Reliability testing with Cronbach's alpha yielded 0.717, indicating acceptable internal consistency. Classroom observations were conducted using a structured observation sheet by the classroom teacher together with one researcher. The observation focused on students' attention, participation, and interaction with the system. To minimize observer bias, both observers followed the same observation protocol and discussed any differences in interpretation immediately after each session before finalizing the observation records.

2.5. Data analysis

The performance of the animated video system was evaluated using three statistical metrics:

- Normality test–shapiro–wilk test confirmed that both pretest and posttest score distributions were normal ($p>.05$).
- Paired samples t-test–used to determine the statistical significance of differences between pretest and posttest means. The test yielded $p<.001$, indicating a statistically significant improvement in reading performance after using the system.
- N-gain–applied to measure the relative improvement in performance. The mean N-gain score was 0.7038, classified as high effectiveness [14], [22].

2.6. Ethical considerations

Ethical approval for this study was obtained from the school administration and the university's research ethics committee. Participants' parents or guardians provided informed consent. All learning activities were conducted in the presence of the class teacher to ensure participant comfort and familiarity.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Pretest–posttest performance overview

The computer-based animated video learning system was evaluated through a one-group pretest–posttest design involving 13 students with mild to moderate intellectual disabilities. Before the intervention, participants' reading literacy scores showed considerable variation, with pretest scores ranging from 50 to 80 and a mean score of 68.46 (SD=8.17). This indicated that while some students had partial recognition of the target vocabulary, others struggled significantly with basic word–image matching.

Following the intervention, the posttest results demonstrated a marked improvement, with scores ranging from 70 to 100 and a mean score of 89.23 (SD=8.71). This reflects a 20.77-point average increase in performance. Importantly, the minimum score after the intervention (70) exceeded the maximum score before the intervention (80) for several participants, suggesting that the learning system helped lower-performing students reach and even surpass the pre-intervention highest achievement level. Table 1 summarizes the descriptive statistics of students' reading literacy performance in the pretest and posttest phases.

Table 1. Pretest and posttest mean scores (n=13)

Test	Mean	SD	Min	Max
Pretest	68.46	8.17	50	80
Posttest	89.23	8.71	70	100

3.1.2. Validity and reliability of assessment

Instrument validation using pearson product–moment correlation yielded 7 valid items out of 10 ($r>0.553$). The retained items covered a balanced range of vocabulary difficulty, from simple (e.g., "teacher," "nurse") to moderately complex terms (e.g., "dentist," "pilot"). The Cronbach's alpha value of 0.717 indicated a reliable measurement tool suitable for repeated assessment in educational technology evaluations [23], [24].

3.1.3. Normality test and assumption compliance

Shapiro–Wilk normality tests indicated that both pretest ($p=.078$) and posttest ($p=.066$) scores were normally distributed ($p>.05$). This ensured compliance with parametric testing assumptions, thereby validating the use of the paired samples t-test for statistical inference.

3.1.4. Hypothesis testing and effect size

Paired-samples t-test results ($t(12)=-15.17$, $p<.001$) revealed a statistically significant improvement in reading literacy following the intervention. The mean improvement from pretest to posttest was 20.77 points (95% CI [17.79, 23.75]). The paired-samples effect size was very large (Cohen's d_z=4.20), indicating substantial practical significance.

3.1.5. Normalized gain effectiveness analysis

The N-gain analysis produced a mean value of 0.7038, categorized as high effectiveness [14], [22]. This means the intervention achieved over 70% of the maximum possible learning improvement. Several students who initially scored in the lowest quartile showed gains exceeding 0.8, highlighting the system's capacity to elevate the performance of the most struggling learners.

3.1.6. Observational findings

Qualitative observation during the treatment sessions showed an increase in engagement indicators, including:

- Focused attention during animation playback.
- Active verbal participation when repeating vocabulary prompted by the system.
- Independent interaction with on-screen elements (e.g., matching letters) without teacher prompting in later stages.

These behavioral improvements reinforce the quantitative results, suggesting that the system's design encouraged sustained learner engagement, an important factor in technology-mediated instruction. The consistency between the observational findings and the quantitative learning outcomes strengthens the credibility of the evaluation. The structured observation procedure also reduced subjective interpretation during classroom monitoring.

3.2. Discussion

3.2.1. Addressing the research question

The research question: How effective is the use of computer-based digital animation video in improving the reading literacy of students with intellectual disabilities in a special school context?—is answered through both statistical and observational evidence. The high N-gain score (0.7038) and significant paired t-test results ($p<.001$) confirm that the system is highly effective in this specific learning context. The magnitude of improvement, combined with observed behavioral changes, indicates that the system's design successfully met the learners' cognitive and accessibility needs.

3.2.2. Relation to existing literature

These findings corroborate prior studies showing that interactive multimedia can enhance literacy in special education [12]. However, this research goes further by positioning the animated video as a computationally engineered learning system, rather than merely an instructional aid. The explicit application of multimedia computing principles, HCI accessibility standards, and performance evaluation metrics distinguishes it from pedagogical-only interventions [10], [15]. The findings of this study are consistent with previous research demonstrating the effectiveness of technology-based multimedia interventions for learners with intellectual disabilities. Al-Naim [6] reported that tablet-based and video modelling technologies positively support communication and higher-order skills among students with intellectual disabilities, findings

that align with the significant literacy gains observed in the present study. Similarly, adaptive and interactive digital learning systems have been shown to enhance learner engagement and participation when instructional content is aligned with learners' capabilities and when feedback mechanisms are in place [11]. Evidence from accessible, game-based digital interventions further supports the importance of inclusive, user-centered design in improving engagement and skill development among children with cognitive disabilities [16].

3.2.3. Technological factors driving effectiveness

From a computer science perspective, the system's effectiveness can be attributed to several technical design decisions:

- Optimized rendering and timing control–animation playback was synchronized with audio narration and captions, ensuring cognitive alignment between visual and auditory channels, as supported by mayer's cognitive theory of multimedia learning.
- Accessible interface engineering–applying UDL-aligned HCI principles [20], [21], the interface minimized extraneous visual elements, increased clickable area sizes, and ensured high contrast for visual clarity.
- Interactive feedback mechanisms–letter-matching and repetition activities provided immediate, clear feedback, reinforcing correct responses and prompting self-correction for errors.

These findings align with studies showing that adaptive digital systems with structured feedback mechanisms can significantly enhance learner engagement and learning outcomes [11].

3.2.4. Novelty and contribution to computer science

The novelty of this research lies in bridging educational needs analysis with software performance evaluation in a special education context. While prior works often stop at reporting learning gains, this study:

- Quantifies system performance using educational data analytics (pre/post differential, N-gain, and effect size).
- Treats the learning media as a software artefact, applying usability, and accessibility principles common in HCI research.
- Demonstrates scalability potential, where the same architecture could be adapted to other learning domains or deployed via networked systems for broader reach.

This approach contributes to applied computing in the education domain by demonstrating that rigorous software evaluation methods can and should be integrated into the assessment of learning technologies, especially for diverse user groups. To facilitate reproducibility, the overall system architecture, instructional procedures, and evaluation workflow are described in sufficient detail. The application prototype, supporting instructional materials, and additional implementation details can be made available by the corresponding author upon reasonable request.

3.2.5. Broader implications

The success of this system suggests potential application in early literacy for mainstream education and adult literacy programs. The data-driven evaluation process also provides a model for iterative educational software development based on measurable learning outcomes. Beyond individual learning outcomes, this study's findings highlight clear opportunities for advancing inclusive digital education. Research in low-resource contexts shows that digital technologies must be inclusively designed to prevent the amplification of digital divides [17]. Digital learning systems can directly foster equity, diversity, and inclusion by supporting learner-centered, accessible practices [18]. Teachers further report that educational technologies can enhance motivation, reduce learning-related stress, and support literacy development among students with intellectual and developmental disabilities [25]. Future studies may also examine responsible AI-based adaptation to personalize learning content and pacing for students with learning disabilities [26].

3.2.6. Limitations

Despite its promising results, this study has several limitations:

- Sample size and scope–conducted with only 13 students from a single special school, limiting the generalizability of findings.
- Short intervention duration–the study involved only two treatment sessions; long-term retention of reading skills was not assessed.
- Technology environment constraints–the system was tested on a single hardware configuration; performance on other devices (e.g., tablets and low-spec computers) was not evaluated.
- Content specificity–the animated content focused on a narrow set of vocabulary (professions and jobs), so effectiveness for broader literacy skills remains untested.

Given these limitations, particularly the small sample of 13 students from a single special school, the findings should be interpreted as preliminary and not broadly generalizable. Future studies involving larger samples, additional schools, longer intervention periods, varied hardware configurations, and broader literacy content are needed to validate the system's scalability, adaptability, and long-term impact across diverse educational and technological contexts.

4. CONCLUSION

This study demonstrated that the computer-based digital animation video learning system significantly improved the reading literacy of students with mild to moderate intellectual disabilities. The participants' mean scores increased from 68.46 in the pretest to 89.23 in the posttest, with a statistically significant difference ($p<.001$) and a high N-gain score of 0.7038. These findings indicate that the system effectively supported reading literacy within the specific special education context examined in this pilot study.

The primary contribution of this study is the design and empirical evaluation of an accessible software-based learning system that integrates HCI principles, multimedia learning, and quantitative performance assessment. The system provides a practical framework for developing inclusive digital learning technologies for students with cognitive disabilities. Further studies involving larger samples, multiple schools, longer intervention periods, and different technological platforms are needed to confirm its generalizability and long-term effectiveness. At the same time, responsible AI-based adaptation may also be explored to personalize learning content and pacing for students with learning disabilities. Further studies involving larger samples, multiple schools, longer intervention periods, and different technological platforms are needed to confirm its generalizability and long-term effectiveness.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Aah Sumiah						✓	✓			✓			✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. The application prototype and supporting instructional materials are also available upon reasonable request for research purposes.

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