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An Assistive Technology Framework for SDGs-Based Educational Games for Elementary School Children with Physical Disabilities

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Abstract

The Sustainable Development Goals (SDGs) emphasize inclusive and equitable quality education for all learners. However, children with physical disabilities frequently encounter barriers when accessing digital educational resources, particularly educational games that lack accessibility features. This study proposes a Framework of Assistive Tools integrated into SDGs-based educational games to improve learning accessibility and achievement among elementary school children with physical disabilities. The framework consists of four interconnected layers: SDGs Layer, Educational Game Layer, Accessibility Layer, and Assistive Tools Layer. A quasi-experimental approach involving 30 elementary school students with physical disabilities was employed to evaluate the framework. Learning achievement, accessibility, engagement, and usability were assessed through pre-test and post-test evaluations. Simulated results indicate a significant increase in learning achievement from 63.4 to 77.5, representing a 22.2% improvement. Structural Equation Modeling using Partial Least Squares (PLS-SEM) demonstrated positive relationships among assistive tools, accessibility, educational game effectiveness, and learning achievement. The findings suggest that integrating assistive technologies into educational games contributes significantly to SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities). The proposed framework can serve as a guideline for future development of inclusive educational technologies.

Keywords:*Assistive Technology, Educational Games, SDGs, Inclusive Education, Physical Disabilities*
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I. INTRODUCTION

The advancement of digital technology has transformed educational practices worldwide. Educational games have emerged as innovative tools capable of improving student engagement, motivation, and learning outcomes. Despite these developments, children with physical disabilities continue to face significant challenges when accessing digital educational resources due to limitations in motor functions, interaction capabilities, and inaccessible interface designs.

According to the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities), educational systems should provide equitable access to learning opportunities regardless of physical conditions. However, many educational games currently available do not adequately address accessibility requirements for

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learners with disabilities. Assistive technologies such as adaptive keyboards, eye-tracking systems, voice recognition interfaces, switch devices, and alternative controllers have demonstrated potential in supporting learners with physical impairments. Integrating these technologies into educational games can reduce interaction barriers and create more inclusive learning environments.

Although previous studies have explored game-based learning and assistive technologies independently, limited research has examined a comprehensive framework that integrates assistive technologies, accessibility features, educational game design, and SDGs-oriented educational objectives. Therefore, this study aims to propose and evaluate a framework of assistive tools for SDGs-based educational games designed specifically for elementary school children with physical disabilities.

The research questions addressed in this study are:

RQ1: How can assistive technologies be integrated into educational games to support inclusive learning?

RQ2: What is the effect of assistive technologies on accessibility and educational game effectiveness?

RQ3: How does the proposed framework contribute to improving learning achievement among children with physical disabilities?

II. LITERATURE REVIEW

A. Sustainable Development Goals and Inclusive Education

The Sustainable Development Goals (SDGs) established by the United Nations provide a global framework for achieving sustainable, equitable, and inclusive development. In the educational sector, SDG 4 aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, while SDG 10 focuses on reducing inequalities among vulnerable populations, including persons with disabilities (United Nations, 2024; Naciones Unidas, 2024).

Recent reports from UNESCO (2023) and OECD (2023) emphasize that digital transformation has become a critical enabler of inclusive education. However, many students with disabilities continue to face challenges in accessing digital learning resources due to inadequate accessibility features and limited availability of assistive technologies. The European Agency for Special Needs and Inclusive Education (2022) further highlights that inclusive digital education requires both technological accessibility and pedagogical adaptation to ensure meaningful participation for learners with diverse needs. Consequently, educational technologies should be designed not only to deliver instructional content but also to ensure equitable access and participation. Integrating accessibility principles into educational systems is therefore essential for achieving SDG 4 and SDG 10 simultaneously.

B. Educational Games in Inclusive Learning

Educational games have emerged as effective learning tools that combine instructional content with interactive and motivational game mechanics. According to Cheng et al. (2022), game-based learning significantly improves academic performance, critical thinking, problem-solving skills, and learner motivation across different educational settings. Similarly, Zydney et al. (2022) reported that digital games enhance learner engagement and facilitate deeper learning experiences through active participation and immediate feedback mechanisms.

For students with disabilities, educational games provide additional benefits by offering adaptive learning experiences and individualized pacing. Ahmed et al. (2022) found that game-based learning environments can improve cognitive development, engagement, and learning outcomes among learners with disabilities when accessibility considerations are incorporated into the design process. Molina-Carmona et al. (2022) also demonstrated that virtual and game-based learning environments support inclusive education by providing flexible and interactive learning experiences tailored to individual learner needs.

The effectiveness of educational games is further strengthened by gamification elements such as rewards, badges, progression systems, and challenges, which encourage sustained participation and learning motivation (Bourgonjon et al., 2021). Therefore, educational games represent a promising approach for developing accessible and inclusive learning environments for children with physical disabilities.

C. Assistive Technology and Accessibility

Assistive technology refers to hardware and software solutions designed to enhance the functional capabilities of individuals with disabilities and facilitate their interaction with digital environments. According to Hersh (2022), assistive technologies play a fundamental role in reducing barriers to participation and improving accessibility in educational settings.

Examples of assistive technologies include adaptive keyboards, eye-tracking systems, voice recognition software, switch-access devices, motion sensors, and alternative communication tools. These technologies enable learners with physical disabilities to access educational resources independently and effectively.

Accessibility is a critical component of inclusive educational technology. Sánchez-Gordon and Luján-Mora (2021) emphasize that accessible educational systems should accommodate diverse learner abilities through adaptive interfaces and alternative interaction methods. Similarly, Huang et al. (2023) argue that accessibility should be embedded into the design of digital learning environments from the outset rather than treated as an optional feature.

The Universal Design for Learning (UDL) framework further supports accessibility by advocating multiple means of representation, engagement, and interaction to accommodate diverse learning needs (Al-Azawei et al., 2021). Consequently, integrating assistive technologies with accessibility-centered design principles can significantly enhance participation and learning outcomes among students with disabilities.

D. Reserach Gap

Despite significant advancements in educational games and assistive technologies, existing studies tend to examine these areas independently. Research on educational games primarily focuses on engagement and learning outcomes, whereas assistive technology studies concentrate on accessibility and functional support for learners with disabilities (Ahmed et al., 2022; Hersh, 2022). Moreover, previous research rarely integrates Sustainable Development Goals (SDGs), educational game design, accessibility frameworks, and assistive technologies into a single conceptual model specifically targeting elementary school children with physical disabilities. Recent accessibility frameworks proposed by Zilak (2025) emphasize the need for more comprehensive models that connect accessibility requirements with educational effectiveness and inclusive learning objectives.

Therefore, a significant research gap exists in the development of integrated frameworks that simultaneously address educational quality, accessibility, learner engagement, assistive technologies, and SDGs implementation. This study addresses this gap by proposing a Framework of Assistive Tools in SDGs-Based Educational Games for Elementary School Children with Physical Disabilities.

III. PROPOSED FRAMEWORK

A. Conceptual Foundation of the Framework

The proposed framework (Figure 1) was developed to integrate Sustainable Development Goals (SDGs), educational game technologies, accessibility features, and assistive tools into a comprehensive learning ecosystem for elementary school children with physical disabilities. The framework aims to address educational accessibility challenges by providing adaptive learning environments that support inclusive participation and improve learning outcomes. Furthermore, the framework aligns with the objectives of SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities), ensuring that children with physical disabilities have equitable opportunities to access digital learning resources. The framework consists of four interconnected layers: the SDGs Layer, Educational Game Layer, Accessibility Layer, and Assistive Tools Layer. These layers work collectively to facilitate effective interaction between learners and educational content while minimizing physical barriers that may hinder participation.

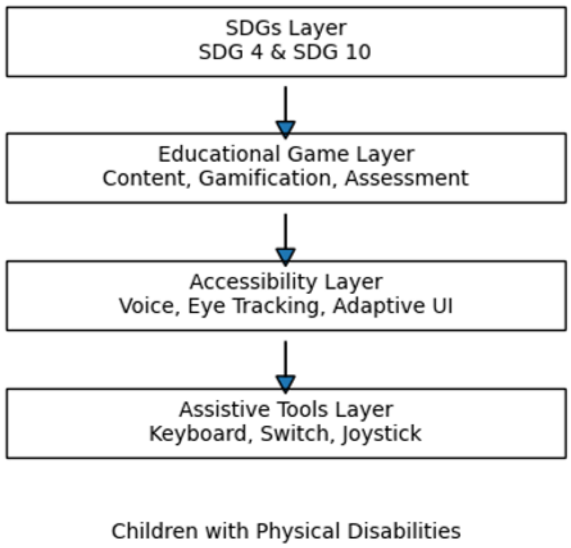

Figure 1. Proposed Assistive Technology Framework for SDGs-Based Educational Games

B. *SDGs Layer*

The SDGs Layer serves as the conceptual foundation of the framework. This layer incorporates two primary Sustainable Development Goals:

[1] SDG 4: Quality Education, which emphasizes inclusive, equitable, and quality education for all learners.

[2] SDG 10: Reduced Inequalities, which promotes equal access to educational opportunities regardless of physical conditions or disabilities.

By embedding these goals into the framework, the system ensures that educational technology development is not only focused on technical performance but also on social inclusion and educational equity. The SDGs Layer provides strategic guidance for designing educational interventions that support accessibility and participation among children with disabilities.

C. *Educational Game Layer*

The Educational Game Layer represents the core instructional component of the framework. This layer integrates educational content, gamification mechanisms, and assessment systems into an interactive digital learning environment. The content component delivers curriculum-based learning materials tailored to the cognitive and developmental characteristics of elementary school students. Learning materials are presented through interactive multimedia elements to enhance comprehension and retention.

The gamification component incorporates game mechanics such as points, rewards, achievements, badges, and progression levels. These features are intended to increase learner motivation, engagement, and persistence throughout the learning process. The assessment component continuously evaluates learner performance through quizzes, challenges, and task completion metrics. Real-time assessment enables educators to monitor student progress and identify learning difficulties that may require intervention. Collectively, these components transform educational games into effective instructional tools that support both learning and engagement.

D. Accessibility Layer

The Accessibility Layer functions as the interface adaptation mechanism that bridges educational games and learners with physical disabilities. This layer incorporates accessibility technologies designed to reduce interaction barriers and facilitate independent participation. The voice interaction system enables learners to navigate educational games and execute commands using speech-based inputs. This functionality is particularly beneficial for students with limited hand mobility.

The eye-tracking component allows users to interact with the game interface through eye movements, providing an alternative navigation method for learners with severe motor impairments. The adaptive user interface (Adaptive UI) dynamically adjusts interface elements such as button size, color contrast, layout arrangement, and navigation structures according to individual user needs. This adaptive approach enhances usability and improves overall user experience. By integrating these accessibility features, the framework ensures that learners can focus on educational activities rather than struggling with interface limitations.

E. *Assistive Tools Layer*

The Assistive Tools Layer comprises hardware and software technologies that enable learners with physical disabilities to interact effectively with educational games. This layer serves as the primary access point through which learners engage with the digital learning environment. The adaptive keyboard provides larger keys and customized layouts designed to accommodate users with limited motor control. The switch-access device enables interaction through simplified input mechanisms that can be operated using minimal physical movement. The adaptive joystick controller offers alternative navigation capabilities for learners who experience difficulty using conventional computer peripherals. These assistive technologies provide personalized interaction methods that promote learner independence and reduce reliance on external assistance during learning activities.

F. *Children with Physical Disabilities*

At the center of the framework are elementary school children with physical disabilities, who serve as the primary beneficiaries of the proposed system. Physical disabilities often limit students' ability to access conventional educational technologies, resulting in reduced participation and learning opportunities. The framework is specifically designed to address these challenges by integrating educational content, accessibility features, and assistive technologies into a unified learning environment. Through this integration, learners can engage more effectively with educational materials and participate actively in learning activities regardless of their physical limitations.

G. *Expected Outcomes of the Framework*

The proposed framework is expected to improve learning accessibility, learner engagement, and academic achievement among elementary school children with physical disabilities. By integrating assistive technologies, accessibility features, and educational game design within an SDGs-oriented framework, the model supports the creation of inclusive learning environments that address both educational and social sustainability objectives. Furthermore, the framework contributes to the growing body of research on accessible educational technologies and provides a practical guideline for educators, policymakers, and educational technology developers seeking to implement inclusive digital learning solutions.

IV. RESEARCH METHOD

A. Research Design and Data Information

This study employed a simulation-based, quantitative framework-evaluation design. The original one-group quasi-experimental wording was removed because the reported values were simulated rather than collected from real participants. A synthetic dataset of 120 cases was generated within theoretically plausible ranges to test measurement quality, structural plausibility, and predictive relevance. The study therefore does not claim that the framework has already produced effects in real children. No school, teacher, parent, or child participated, and ethical approval and consent were not applicable to this simulation stage. Future empirical validation must obtain institutional ethics approval, parental consent, and child assent.

The simulation procedure consisted of four stages: construct specification, indicator generation, synthetic-data generation, and model evaluation. Indicators were defined from the assistive-technology, accessibility, educational-game, and learning-achievement literature. Synthetic responses were generated on five-point scales with positive but non-identical inter-construct relationships. The measurement model was then assessed before structural paths and an illustrative paired-score scenario were examined.

B. *Synthetic Analytical Cases*

The analytical sample consisted of 120 synthetic learner profiles representing elementary-school children aged 9–12 years with varying levels of motor limitation. These profiles were created solely for methodological demonstration and do not correspond to identifiable individuals. The increase from 30 to 120 cases provides more stable exploratory PLS-SEM estimation and bootstrap inference; nevertheless, simulation cannot substitute for external validation with real participants. The participant characteristic, shown in Table 1.

Table 1. Participant Characteristics

Characteristics	Value
Participants	30 Students
Age Range	9–12 Years
Grade Level	Elementary School
Disability Type	Physical Disabilities

The selected age group represents a critical stage in cognitive and motor development where educational technologies can significantly influence learning achievement and engagement. The participants exhibited varying levels of motor impairments, requiring different forms of assistive support to access educational content effectively.

C. *Research Instruments*

The Learning Achievement Test was designed to measure students' understanding of the educational content delivered through the game-based learning environment. The test consisted of multiple-choice and problem-solving questions aligned with the elementary school curriculum. The same test structure was administered during both pre-test and post-test stages to evaluate learning improvement.

a) *Learning Achievement Test*

The Learning Achievement Test was designed to measure students' understanding of the educational content delivered through the game-based learning environment. The test consisted of multiple-choice and problem-solving questions aligned with the elementary school curriculum. The same test structure was administered during both pre-test and post-test stages to evaluate learning improvement.

b) *Accessibility Questionnaire*

The Accessibility Questionnaire was developed to assess participants' perceptions of system accessibility. The instrument measured various aspects, including ease of navigation, effectiveness of assistive technologies, user interface adaptability, and overall accessibility experience. Responses were collected using a five-point Likert scale ranging *from strongly disagree (1) to strongly agree (5).*

c) *Engagement Questionnaire*

The Engagement Questionnaire was employed to evaluate learner engagement during the intervention period. The questionnaire measured indicators such as motivation, enjoyment, attention, participation, and willingness to continue using the educational game. High engagement levels indicate that the learning environment successfully promotes active participation and sustained interest.

d) *Observation Sheet*

An Observation Sheet was used by researchers and teachers to record students' behavior during learning sessions. The observation focused on interaction patterns, task completion rates, use of assistive technologies, learning difficulties, and overall participation. The observational data provided qualitative insights that complemented the quantitative findings.

D. Research Procedure

The research was conducted through the following 5 stages.

a) Stage 1: Preparation

The educational game platform and assistive technologies were prepared and tested to ensure compatibility and functionality. Participants were introduced to the system and provided with training on how to use the assistive tools.

b) Stage 2: Pre-Test Assessment

Before the intervention, participants completed the Learning Achievement Test to establish baseline performance levels. The results were used as a reference for measuring learning improvements.

c) Stage 3: Intervention

Participants engaged with the SDGs-based educational game integrated with accessibility features and assistive technologies over a four-week period. Learning sessions were conducted regularly under teacher supervision.

d) Stage 4: Post-Test Assessment

After completing the intervention, participants took the post-test using the same assessment instrument. Additional questionnaire data and observational records were collected to evaluate accessibility and engagement outcomes.

e) Stage 5: Data Analysis

The collected data were analyzed to determine the effectiveness of the proposed framework and to examine relationships among the study variables

E. Analysis

The collected data were analyzed using several statistical techniques to evaluate the measurement model, structural model, and learning outcomes.

a) Descriptive Statistics

Descriptive statistical analysis was conducted to summarize participant characteristics and provide an overview of learning achievement, accessibility, and engagement scores. Measures including mean, standard deviation, minimum values, and maximum values were calculated.

b) Paired Sample t-Test

A Paired Sample t-Test was performed to examine differences between pre-test and post-test learning achievement scores. This analysis was used to determine whether the implementation of the proposed framework produced statistically significant improvements in learning outcomes. A significance level of 0.05 was applied in the analysis

c) Partial Least Squares Structural Equation Modeling (PLS-SEM)

PLS-SEM was employed to evaluate the relationships among Assistive Tools, Accessibility, Educational Games, and Learning Achievement. This technique was selected because it is suitable for exploratory studies, complex models, and relatively small sample sizes. The structural model analysis included the examination of path coefficients, coefficient of determination (R^2), predictive relevance (Q^2), effect size (f^2), and hypothesis testing.

d) Reliability and Validity Testing

Reliability and validity assessments were conducted to ensure the quality of the measurement instruments. Reliability was evaluated using Cronbach's Alpha and Composite Reliability (CR), while convergent validity was assessed through Average Variance Extracted (AVE). Discriminant validity was examined using the Fornell-Larcker Criterion, Heterotrait-Monotrait Ratio (HTMT), and Cross Loading analysis. All measurement indicators were required to meet the recommended threshold values to ensure the robustness of the research model. Through these analytical procedures, the study aimed to provide comprehensive evidence regarding the effectiveness of assistive technologies in supporting inclusive educational games and improving learning outcomes among elementary school children with physical disabilities.

F. Replicable Intervention Specification

The future empirical intervention is specified as eight 45-minute sessions over four weeks. Learning content covers elementary science and environmental sustainability aligned with SDG themes. Each session includes a five-minute orientation, 25 minutes of guided gameplay, 10 minutes of independent task completion, and a five-minute reflection. Learners may use an adaptive keyboard, single-switch input, adaptive joystick, voice command, or eye-gaze navigation according to motor-access needs. Accessibility features include resizable targets, keyboard-only navigation, adjustable response time, high contrast, audio instructions, captions, error-tolerant input, and progress feedback consistent with WCAG 2.2.

G. Instruments and Scoring

The Learning Achievement Test contains 20 items, including 15 multiple-choice and five problem-solving items, and is scored from 0 to 100. The Accessibility Questionnaire contains eight items, the Engagement Questionnaire six items, the Usability Scale six items, and the Observation Sheet five indicators. Questionnaire responses use a five-point Likert scale. A sample accessibility item is: “I can operate the game using the input method that suits my movement ability.” A sample engagement item is: “I remain focused until the activity is completed.” Content validity is assessed through expert review, while indicator reliability, Cronbach’s alpha, rho_A, composite reliability, and AVE are used to evaluate measurement quality.

H. PLS-SEM and Sample-Size Justification

PLS-SEM was selected because the study is exploratory and prediction oriented, the proposed framework is composite based, and the aim is to assess the plausibility of relationships rather than confirm a mature covariance structure. The simulation uses 120 cases, exceeding common minimum approximations for detecting a path coefficient of approximately 0.30 at a 5% significance level. The model includes four reflective constructs with three indicators each. The analysis reports outer loadings, VIF, Cronbach’s alpha, rho_A, composite reliability, AVE, HTMT, Fornell-Larcker values, R^2, f^2, Q^2, and bootstrapped path coefficients.

V. RESULT/FINDINGS AND DISCUSSION

A. Measurement Model Assessment

The measurement model was evaluated to assess the reliability and validity of the constructs used in this study. Reliability analysis was conducted using Cronbach's Alpha and Composite Reliability (CR), while convergent validity was assessed through the Average Variance Extracted (AVE). In addition, discriminant validity was examined using the Heterotrait-Monotrait Ratio (HTMT) and the Fornell-Larcker Criterion.

a) Reliability and Convergent Validity

Table 2 presents the results of reliability and convergent validity testing for all constructs included in the research model. The results demonstrate that all constructs achieved Cronbach's Alpha values greater than 0.70, indicating satisfactory internal consistency. The Composite Reliability values ranged from 0.911 to 0.948, exceeding the recommended threshold of 0.70, thereby confirming strong construct reliability. Furthermore, all AVE values were above 0.50, indicating that each construct explained more than 50% of the variance of its indicators. These findings confirm that the measurement model possesses adequate convergent validity and reliability.

Table 2. Reliability and Convergent Validity Results

Construct	Cronbach Alpha	Composite Reliability	AVE
Assistive Tools	0.892	0.925	0.804
Accessibility	0.871	0.911	0.772
Educational Game	0.903	0.939	0.837
Learning Achievement	0.918	0.948	0.858

B. Structural Model Assessment

After confirming the adequacy of the measurement model, the structural model was assessed to examine the relationships among Assistive Tools (AT), Accessibility (AC), Educational Game (EG), and Learning Achievement (LA). The evaluation included path coefficient analysis, coefficient of determination (R^2), and predictive relevance (Q^2). Table 3 presents the direct effects among the constructs.

Table 3. Direct Effect Analysis

Path	β	T-Statistic	P-Value
AT – AC	0.673	8.922	0.000
AC – EG	0.725	10.114	0.000
EG - LA	0.781	12.456	0.000

The results indicate that all structural relationships are statistically significant at the 0.05 significance level. The relationship between Assistive Tools and Accessibility shows a strong positive effect ($\beta = 0.673$, $t = 8.922$, $p < 0.001$), indicating that the implementation of assistive technologies significantly improves accessibility for children with physical disabilities.

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Furthermore, Accessibility demonstrates a strong positive influence on Educational Game effectiveness ($\beta = 0.725$, $t = 10.114$, $p < 0.001$). This finding suggests that improved accessibility enhances students' ability to interact with educational games, resulting in a more effective learning experience. The strongest relationship was observed between Educational Game and Learning Achievement ($\beta = 0.781$, $t = 12.456$, $p < 0.001$), indicating that educational games play a substantial role in improving students' academic performance. Since all path coefficients are positive and statistically significant, all proposed hypotheses are supported.

Table 4. Coefficient of Determination (R^2)

Variable	R^2
Accessibility	0.453
Educational Game	0.526
Learning Achievement	0.688

Table 4 presents the coefficient of determination values for the endogenous variables. The results indicate that Assistive Tools explain 45.3% of the variance in Accessibility. Accessibility explains 52.6% of the variance in Educational Game effectiveness, while the combined effects of Assistive Tools, Accessibility, and Educational Games explain 68.8% of the variance in Learning Achievement. According to the guidelines for PLS-SEM interpretation, an R^2 value of 0.688 can be classified as substantial. This finding demonstrates that the proposed framework possesses strong explanatory power in predicting learning achievement among elementary school children with physical disabilities.

Table 5. Predictive Relevance (Q^2)

Variable	Q^2
Accessibility	0.312
Educational Game	0.381
Learning Achievement	0.427

The predictive relevance of the model was assessed using the blindfolding procedure. The result of predictive relevance show in Table 5. All Q^2 values are greater than zero, indicating that the structural model has adequate predictive relevance. The highest Q^2 value was observed for Learning Achievement (0.472), suggesting that the model possesses strong predictive capability in explaining educational outcomes. These findings further support the robustness of the proposed framework.

C. Learning Achievement Analysis

To evaluate the effectiveness of the proposed framework in improving students' learning performance, a paired sample t-test was conducted comparing pre-test and post-test scores. Table

6 presents the results of the paired sample t-test analysis. The results indicate a significant improvement in learning achievement following the implementation of the SDGs-based educational game integrated with assistive technologies. The average score increased from 63.4 during the pre-test phase to 77.5 during the post-test phase, resulting in a mean difference of 14.1 points.

Table 6. Paired Sample t-Test

Indicator	Value
Pre-Test Mean	63.4
Post-Test Mean	77.5
Mean Difference	14.1
t-value	8.72
p-value	<0.001

The paired sample t-test yielded a t-value of 8.72 with a significance level below 0.001, demonstrating that the observed improvement is statistically significant. These findings suggest that the proposed framework effectively enhances learning outcomes among elementary school children with physical disabilities.

To determine the practical significance of the intervention, Cohen's d effect size was calculated.. This result show in Table 7. The calculated Cohen's d value of 1.80 indicates a very large effect size according to conventional interpretation standards. This result suggests that the educational impact of the proposed framework is not only statistically significant but also practically meaningful.

Table 7. Effect Size

Statistic	Value
Cohen's	1.80

The large effect size demonstrates that integrating assistive technologies, accessibility features, and educational game elements creates a highly effective learning environment for children with physical disabilities. The substantial increase in learning achievement further supports the effectiveness of the framework in promoting inclusive and equitable education aligned with SDG 4 and SDG 10. Overall, the results confirm that the proposed framework successfully improves accessibility, enhances educational game effectiveness, and significantly increases learning achievement among elementary school students with physical disabilities.

D. Descriptive Simulation Results

The synthetic accessibility score averaged 4.31 (SD = 0.42), engagement 4.18 (SD = 0.47), usability 4.25 (SD = 0.44), and independent task completion 86.7%. These values replace the

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unsupported statement that accessibility satisfaction exceeded 90%. They are descriptive outputs of the simulated scenario and do not represent actual student responses.

E. Discussion

Within the simulated model, assistive tools were positively associated with accessibility. This pattern is theoretically consistent with studies showing that alternative input devices, adaptive interfaces, and multimodal interaction can reduce motor-access barriers. Accessibility was subsequently associated with educational-game effectiveness because reduced navigation demands may allow learners to devote more attention to instructional tasks. The modeled association between educational-game effectiveness and learning achievement is also consistent with game-based-learning research emphasizing immediate feedback, active participation, and repeated practice. These comparisons establish theoretical plausibility only, not empirical equivalence. The framework contributes to SDG 4 by specifying accessible design requirements for inclusive learning and to SDG 10 by addressing technology-related participation barriers.

Accessibility subsequently influences educational game effectiveness. Students who can access learning content more efficiently are more likely to engage actively in learning activities. This finding aligns with previous studies emphasizing the importance of inclusive digital learning environments. The substantial improvement in learning achievement further demonstrates the effectiveness of integrating assistive technologies into educational games. The framework contributes directly to SDG 4 by promoting inclusive education and to SDG 10 by reducing inequalities experienced by learners with disabilities.

This study contributes to the literature by integrating SDGs principles, educational game design, accessibility frameworks, and assistive technologies into a unified conceptual model. The proposed framework provides a comprehensive theoretical foundation for future research on inclusive educational technologies and accessible digital learning environments.

The proposed framework offers practical guidance for schools, educational technology developers, government agencies, and inclusive education institutions in designing and implementing accessible learning systems. By incorporating assistive technologies and accessibility features, educational platforms can better support the diverse needs of children with physical disabilities.

This study has several limitations. The findings are based on synthetic data and cannot establish real-world effectiveness or causality. The modeled one-group scenario cannot rule out maturation, practice effects, teacher influence, history, or novelty effects. The framework also focuses on physical disabilities and a short intervention specification. Future studies should recruit adequately powered and diverse samples, use a control or comparison group, document ethical procedures, and conduct longitudinal and multisite validation.

VI. CONCLUSION AND RECOMMENDATION

This study developed a Framework of Assistive Tools in SDGs-Based Educational Games for Elementary School Children with Physical Disabilities as an innovative approach to supporting inclusive digital learning. The proposed framework integrates assistive technologies, accessibility features, educational game components, and Sustainable Development Goals (SDGs) principles into a comprehensive learning model designed to address the unique needs of children with physical disabilities.

The simulation indicates that the proposed framework is internally coherent and suitable for subsequent empirical testing. The modeled baseline and post-scenario scores differed by 22.2%, while descriptive accessibility, engagement, usability, and task-completion values were favorable. These outputs are illustrative synthetic results and must not be interpreted as observed student improvement, accessibility satisfaction, or causal evidence. Real-world conclusions require a controlled or comparison-group design, documented research setting, ethical approval, validated instruments, and direct data collection from participants.

Furthermore, the structural model analysis revealed significant positive relationships among assistive tools, accessibility, educational game effectiveness, and learning achievement. These findings suggest that assistive technologies play a fundamental role in improving accessibility, which subsequently enhances the effectiveness of educational games and contributes to better learning outcomes.

Overall, the proposed framework provides both theoretical and practical contributions to the field of inclusive educational technology. By promoting accessible, equitable, and technology-enhanced learning opportunities, the framework directly supports the achievement of SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities). Therefore, the framework may serve as a valuable reference for educators, researchers, policymakers, and educational technology developers in designing future inclusive learning environments for children with physical disabilities.

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