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Integrating Urban Mining Concepts Through AI-Generated Storytelling and Visuals: Advancing Sustainability Education in Early Childhood

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Abstract: This study investigates integrating sustainability and urban mining concepts into early childhood education through AI-assisted storytelling and visual aids to foster environmental awareness. Using ChatGPT-generated narratives and AI-drawn visuals, interactive stories explore complex sustainability themes like resource conservation and waste management. A quasi-experimental design with 60 preschoolers divided into experimental and control groups compared structured and unstructured storytelling. Structured stories followed teacher-designed frameworks, including thematic and narrative elements such as settings, character development, and resolutions. Observations showed the structured group demonstrated greater comprehension, engagement, and narrative ability, indicating enhanced cognitive and communication skills. The digital system interface featured animations and images for engagement, while tutorial-driven navigation allowed young learners to interact freely with sustainability-focused story options. The findings highlighted structured storytelling's ability to improve language and narrative skills, alongside fostering digital and environmental literacy. Limitations include a small sample size and a focus on specific themes, restricting generalizability. Despite this, this study adds value by showcasing how AI tools combined with structured frameworks can effectively teach sustainability while reducing the reliance on paper, promoting sustainable educational practices. Overall, this research underscores the potential of AI storytelling in shaping young learners' understanding of environmental issues, advocating for the thoughtful integration of technology to inspire deeper learning.

Keywords: urban mining; AI drawing instructions; storytelling; interface system; willingness to communicate

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1. Introduction

In recent years, fostering storytelling abilities in children has become increasingly important, particularly as digital literacy and creative expression emerge as foundational skills for the future. Research has shown that AI-driven tools like ChatGPT can play a critical role in enhancing children's narrative skills [1], providing them with new ways to engage creatively and meaningfully with language [2]. By using ChatGPT to support children's storytelling, educators can offer dynamic, interactive experiences that promote language development, comprehension, and creative thinking. This study highlights the significance of integrating AI into early childhood education to strengthen these essential skills, which are crucial for preparing children for a rapidly evolving digital landscape.

Traditional early childhood education approaches may lack the interactivity required to fully capture children's attention and help them develop complex narrative skills. AI technologies, particularly ChatGPT, enable more immersive and supportive storytelling environments. This integration allows children to practice constructing narratives, exploring language, and engaging with diverse story structures in an interactive and engaging way [3]. Through AI-driven narrative support, children can access customized storytelling experiences that encourage imagination and self-expression, thereby laying the groundwork for more advanced literacy skills.

The potential of ChatGPT to enhance cognitive and affective responses in storytelling has been demonstrated in recent studies, underscoring the technology's role in fostering empathy, understanding, and creativity in young learners [4]. Moreover, AI-driven storytelling tools align with trends in digital education and knowledge sharing, providing a structured yet flexible learning experience that supports the development of narrative comprehension and social skills [5]. This research emphasizes that early exposure to AI-supported storytelling can nurture children's confidence in verbal communication, improve their comprehension of narrative structures, and encourage a greater willingness to communicate.

This study investigates the effects of using ChatGPT and AI-generated visual aids on the story structures presented to preschool children, aiming to evaluate both the educational impact and usability of these tools. By comparing structured and unstructured storytelling experiences, we seek to understand the influence of story structure on children's comprehension and narrative creation. Furthermore, this research explores how AI-enhanced story experiences contribute to children's development of language and communication skills, providing insights into how system design can optimize the educational outcomes of AI-based storytelling in early childhood settings. Traditional educational methods heavily rely on paper and other physical materials, which not only increase educational costs but also have significant environmental impacts. By adopting digital learning content, we can significantly reduce the reliance on paper and other resources, decrease the environmental impact of the educational process, achieve a green education, and promote sustainable development [6].

The Research Questions

This study explores the potential of integrating sustainability and urban mining concepts within AI-generated storytelling for preschool children. Given the importance of early exposure to environmental awareness, this research examines whether presenting sustainability themes through structured story content can effectively enhance young children's comprehension and communication skills. Utilizing ChatGPT and AI-generated narratives, we aim to understand if introducing these complex ideas through engaging, story-based learning tools can foster greater understanding and interest among young learners. Additionally, this study seeks to assess the usability of AI-driven storytelling systems in promoting sustainable education practices by minimizing the reliance on traditional paper-based materials.

The specific research questions guiding this study are as follows:

1. Is there a difference in story comprehension between preschool children exposed to ChatGPT-generated story texts with sustainability and urban mining themes and those with an added story structure incorporating these concepts?
2. Does adding sustainability and urban mining concepts to the story structure of ChatGPT-generated story texts enhance children's story comprehension?
3. Can ChatGPT and AI-generated story texts with an added story structure, focusing on sustainability and urban mining, be used effectively for creating and performing narrative texts?
4. From the children's perspective, how usable is the system in promoting sustainability and urban mining concepts, and does the system design meet their needs and expectations?

This study aims to enhance children's understanding and interest in learning content, reduce the use of paper-based materials in the educational process and promote digital learning [7], and evaluate the application of ChatGPT and AI drawing technologies in early childhood education and their contributions to sustainable development.

2. Theoretical Background

Fostering communication, creativity, and environmental awareness in early childhood education is crucial for equipping young learners with the skills needed for sustainable development. This section explores key theoretical frameworks that justify the integration of storytelling, AI tools, and sustainability education into early childhood learning. The synthesis of recent empirical studies provides a unified argument supporting the objectives of this research [8].

2.1. Promoting Communication Skills Through Play and Ethical AI Integration

The development of children's willingness to communicate is foundational to their social integration and adaptability in dynamic societal and environmental contexts. Research highlights the role of play in nurturing critical language abilities, including vocabulary acquisition, pragmatic skills, and social interaction [9]. Play-based learning fosters sustainable growth by enabling children to request, comment on, and engage in collaborative activities, building a foundation for lifelong learning [10,11].

However, the rise of generative AI technologies introduces ethical considerations in how they influence natural social development. As noted by Al-kfairy et al. [12], interdisciplinary approaches are essential to ensure that AI tools enhance, rather than disrupt, children's communication skills [13]. Ethical safeguards must prioritize inclusivity and long-term social adaptability, positioning AI as a supportive scaffold in fostering balanced language growth.

2.2. Advancing Sustainability Through Urban Mining Education

The global challenge of resource depletion and waste accumulation underscores the importance of urban mining as a pillar of sustainability. Urban mining involves extracting valuable materials from urban waste, reducing the demand for virgin resources and mitigating the environmental impact of traditional mining practices [14]. This process contributes to the circular economy by transforming waste into reusable resources, a critical step toward achieving global sustainability goals.

Empirical studies emphasize the necessity of integrating these concepts into early childhood education to cultivate environmental responsibility. [15] advocate for sustainability education across all learning levels, starting in early childhood. By introducing urban mining through engaging tools like storytelling and visuals, educators can enhance children's understanding of resource conservation and waste management, preparing them to address future environmental challenges.

2.3. Designing Intuitive Systems for Preschool Learning

The design of educational systems for preschool children must align with their cognitive developmental stages. According to Piaget's theory [16], children in the preoperational stage (ages 2–7) benefit from visual and dynamic interfaces that support intuitive navigation and engagement. An effective system design integrates multimedia elements, including images, animations, and sounds, to enhance attention and learning motivation while promoting sustainable educational practices [17].

Dynamic image interactions, supported by well-designed interfaces, stimulate interest and reduce the reliance on physical materials, advancing both educational outcomes and environmental goals [18]. These principles underscore the need for thoughtfully crafted systems that align with cognitive characteristics while fostering environmental awareness.

2.4. Enhancing Story Comprehension Through Structured Narratives

Structured storytelling is a proven method for developing children's comprehension, creativity, and language skills. Essential narrative elements, including setting, theme, plot, and resolution, serve as scaffolds that enhance children's ability to analyze and retell stories. Structured stories, supported by teaching strategies like read-aloud methods, promote sustainable literacy development by integrating creativity with comprehension [19].

Recent studies show that narrative scaffolding fosters imagination, language expression, and environmental awareness, particularly when combined with sustainability-themed content [20]. The use of structured storytelling in educational tools can significantly enhance cognitive engagement and language proficiency.

2.5. Leveraging AI for Creative Storytelling and Learning

Advancements in AI technologies, such as ChatGPT, offer a transformative potential in early childhood education. By generating imaginative and structured narratives, AI tools enhance children's creativity, engagement, and comprehension [21]. AI-generated stories foster analytical and creative faculties, aligning with the broader trends in digital education [22].

Moreover, the integration of AI-generated visuals amplifies storytelling's impact. Studies demonstrate that combining text and visuals improves narrative comprehension and stimulates creative thinking [23]. Digital tools such as AI drawing technologies not only enrich the educational experience but also support sustainability by minimizing paper usage and reducing costs [24].

Research Objective and Hypothesis

Research Question

How can integrating structured storytelling with AI-generated narratives and visuals enhance young children's language skills, creativity, and understanding of sustainability concepts such as urban mining?

Objective

To investigate the effectiveness of structured storytelling frameworks, supported by AI-generated narratives and visuals, in improving children's language comprehension, creativity, and environmental awareness.

Hypothesis

Children exposed to structured AI-generated storytelling and visuals will demonstrate a significantly higher language comprehension, creative narrative performance, and sustainability awareness compared to those exposed to unstructured narratives.

3. Research Method

3.1. Research Framework

In this study, an interface system suitable for children's operation and understanding is designed, incorporating elements such as navigation, images, and animations to enhance the learning experience. The main learning materials are ChatGPT-generated story texts and AI-generated images. These materials are divided into structured and unstructured versions to compare their effects on children's learning outcomes. This study follows a quasi-experimental design, involving 60 students from two senior classes at a kindergarten, as shown in Figure 1. The grouping of students into these classes was predetermined by the school's administrative office during the registration process, with no influence from this research. Consequently, while the two classes serve as the experimental and control groups for the study, the assignment of students to each class was not altered or manipulated for research purposes. Each class includes 30 students, with one group designated as the experimental group, receiving ChatGPT-generated stories with structured sustainability and urban mining content, and the other as the control group, receiving unstructured story content. This approach ensures that the study respects the natural class assignments, while allowing for a comparative analysis of the educational impact of structured versus unstructured storytelling content. The design will be clarified as a 2 × 2 factorial design, comprising pre–post measurements and experimental–control groups. This structure allows for examining the interaction effects between these two factors effectively.

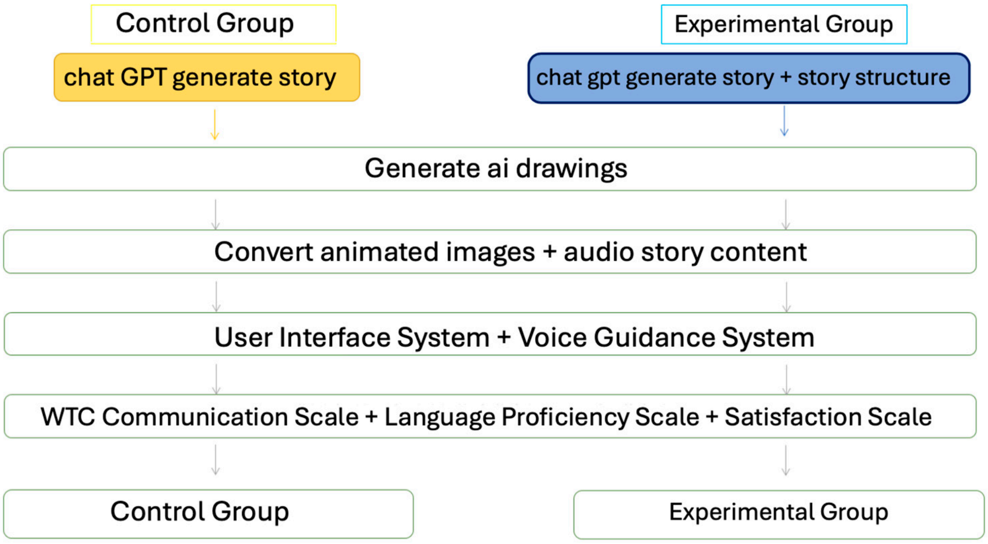


Figure 1. Research framework (flowchart).

In this study, ChatGPT was used to generate story content based on a structured outline provided by teachers. The teachers initially developed a detailed story structure that included essential elements such as story content, background, theme, plot planning, interludes, problem-solving attempts, outcomes, and resolutions. This structured framework served as a foundation for ChatGPT to expand upon, creating stories that adhered to educational goals while allowing the AI to introduce creative details within the defined parameters. In our study design, ChatGPT was used to generate four unique pieces of story content. For the experimental group, these stories included an added structured framework based on story elements such as theme, plot, character background, and resolution [25]. This structured framework functioned as a learning scaffold, potentially enhancing children's comprehension and engagement by guiding the narrative development and providing contextually rich details that aligned with the educational objectives. In contrast, the control group received the same AI-generated stories but without any additional story structure. This difference between groups allowed us to examine whether adding structure to the storytelling process, even when both groups experienced AI-assisted storytelling, would provide a more effective learning experience. By comparing the structured and unstructured story experiences, this design aimed to determine the impact of structured story frameworks on learning outcomes, specifically focusing on whether structured storytelling with AI could serve as an effective scaffold in enhancing language comprehension and engagement for young learners.

The story structure created by the teachers was comprehensive and aimed to guide the narrative flow. The key components included the following:

1. **Story Content and Theme:** The teachers set a central theme, typically related to sustainability or urban mining, that would anchor the story's message and objectives. This theme guided the storyline, ensuring it aligned with the study's educational focus;
2. **Story Background:** The structure included specific elements like characters, time, and setting. For example, characters could represent figures who encounter environmental challenges, while the setting was crafted to reflect contexts where urban mining or sustainability principles could be naturally introduced;
3. **Plot Development and Problem-Solving:** A sequence of events was outlined, detailing one or more challenges the characters would face to achieve the story's objective.

Teachers included "problem-solving attempts", where characters would try different methods to resolve conflicts, reinforcing critical thinking and perseverance;

4. **Story Interludes and Sub-Goals:** To enrich the narrative, the structure also specified interludes or sub-goals, adding layers to the story. These sub-goals served to advance the plot while providing opportunities for characters to interact with environmental themes;
5. **Outcome and Resolution:** Finally, the structure directed the story towards a resolution, where characters would overcome obstacles, experience a transformation, or learn a lesson. This outcome was designed to encapsulate the story's theme, providing a meaningful and educational conclusion.

Once this detailed framework was established, ChatGPT was used to generate the full story narrative, ensuring that the AI's output stayed true to the defined structure while enhancing it with creative language and character development. This collaborative approach allowed for a balance between structured educational goals and imaginative storytelling, creating a rich and engaging story experience for young learners. Figure 2 shows the story structure.

Figure 2. Story structure.

3.2. System Design Architecture

This study employed a systematic approach to integrate educational materials on urban mining and sustainability concepts into AI-generated storytelling. The program's structure, strategies, instructional procedures, and fidelity measures are summarized below in Table 1 and described in detail.

Table 1. Overview of program design and implementation.

Category	Details
Content	Topics included the environmental significance of urban mining, waste management, and sustainable practices, drawing on case studies from Denmark and Belgium [26].
Strategies Used	- AI-generated storytelling tailored for young learners. - Structured frameworks for the experimental group, emphasizing thematic development, character building, plot progression, and resolution. - Unstructured narratives for the control group.
Instructional Procedure	- A navigation tutorial familiarized students with the system. - Story selection interface presented four AI-generated narratives: 1. The Adventures of Czech Rabbit. 2. Searching for the Rainbow. 3. The Surprising Journey of the Explorer. 4. The Adventures of Lily and Kiki: A Journey of Failure and Wisdom.
Application	Teachers introduced the system to students, providing guidance during initial sessions while ensuring independent exploration in subsequent sessions.
Fidelity of Treatment	- Instructors were trained on system use, structured storytelling frameworks, and study protocols. - Treatment fidelity was ensured through: 1. Pre-experiment protocol to standardize delivery. 2. Records of activities conducted.

Detailed Description

Educational Content and Story Generation

Both experimental and control groups were exposed to cognitive themes related to urban mining. ChatGPT was employed to generate story content, ensuring accessibility and engagement for preschool learners. The experimental group's stories incorporated a structured framework with predefined elements (e.g., themes, character development, and problem-solving scenarios), while the control group's stories lacked these scaffolds [27].

Instructional System and Navigation Design

The system was designed to align with the cognitive and developmental characteristics of young children. A tutorial guided users through the navigation, after which they could select from four themed stories, each focusing on a unique aspect of sustainability and urban mining. The cyclic navigation system encouraged repeated reading and interaction, fostering familiarity and engagement.

Implementation and Teacher Role

Teachers played a pivotal role in ensuring the smooth application of the program. They provided initial guidance, introduced the structured and unstructured story formats, and ensured all participants followed the protocols uniformly.

Fidelity and Monitoring

To maintain consistency and reliability, instructors underwent comprehensive training on the study's instructional procedures. A fidelity protocol was implemented, including the following:

A checklist for pre-session preparation.

Documentation of activities conducted in each session. Regular observations to ensure adherence to the structured frameworks for the experimental group.

By incorporating these elements, the program offered a robust structure to assess the impact of structured storytelling on young learners' comprehension, engagement, and understanding of sustainability concepts [28]. This systematic design ensures reproducibility and supports the validity of the findings. Figure 3 shows the system interface flowchart.

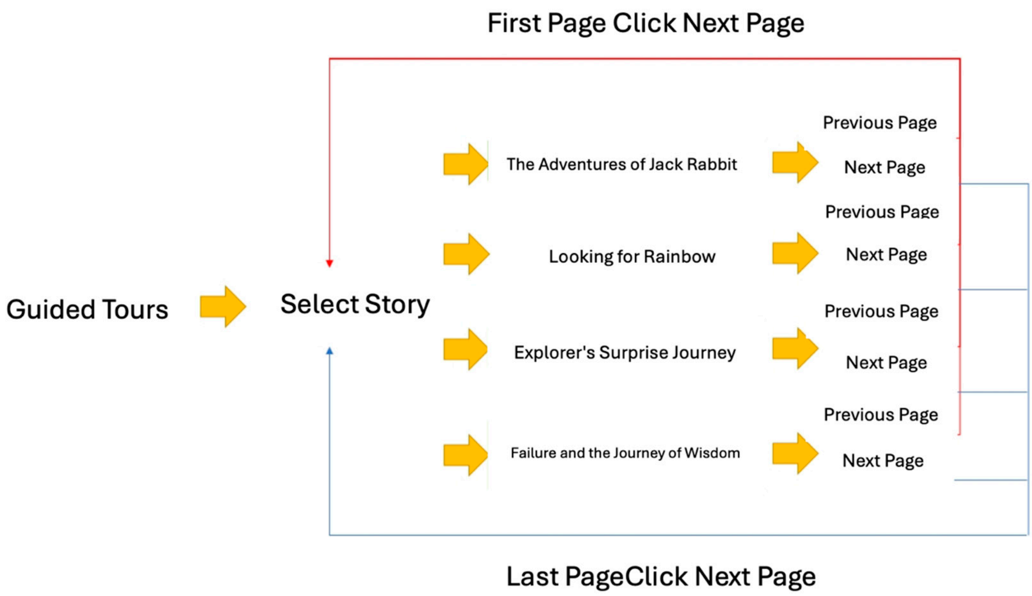


Figure 3. System interface flowchart.

The system interface design is based on the cognitive characteristics of young children. It is simple and intuitive, using numerous images and animation elements to attract children's attention [29]. The navigation system is clearly designed to help children independently explore the learning content. Figure 4 shows the system interface design. Figure 5 shows the system interface design.

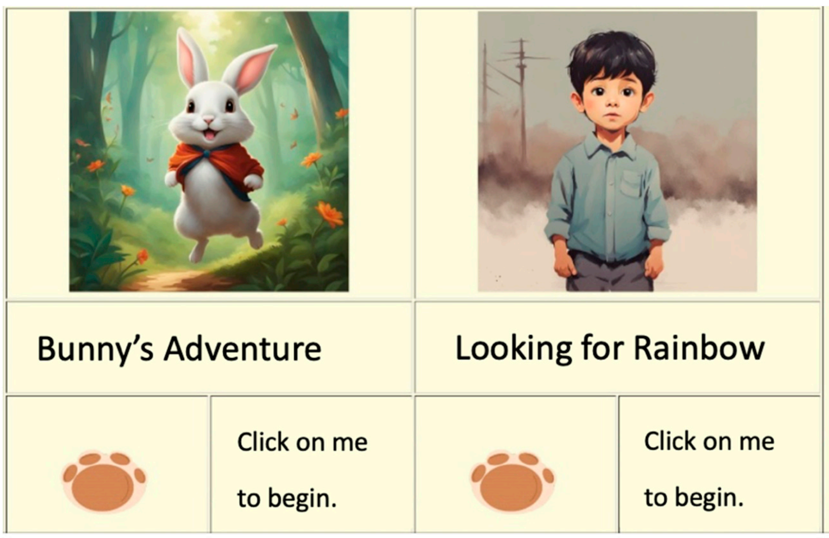


Figure 4. The system interface design.

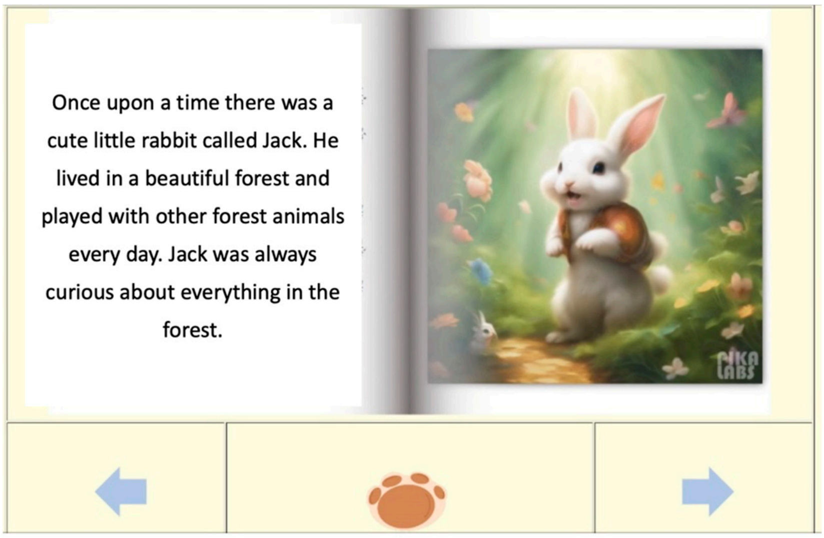
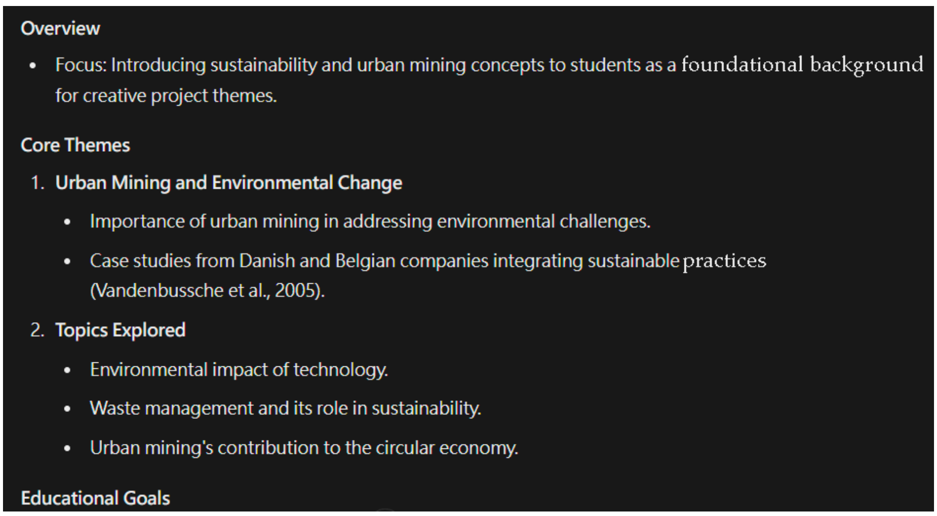


Figure 5. The system interface design.

3.3. Educational Materials on Urban Mining and Sustainability

This study's educational materials focus on introducing the concepts of sustainability and urban mining to students, serving as the foundational background for their creative project themes. The materials cover the importance of urban mining in addressing environmental changes, particularly through the lens of Danish and Belgian companies' practices [30]. Topics such as the environmental impact of technology, waste management, and the role of urban mining in the circular economy are explored in depth. This approach highlights how companies in these regions have integrated sustainable practices to mitigate environmental impacts, providing valuable case studies for educational content on resource conservation and waste reduction. The content is designed to help students understand the critical role urban mining plays in sustainable development, encouraging them to think creatively about how these concepts can be applied in real-world scenarios [31].

The materials include detailed explanations of urban mining processes, the significance of waste as a resource, and how urban mining contributes to reducing the environmental footprint of technology and manufacturing industries [32]. By integrating these concepts into the learning materials, the study aims to equip students with the knowledge and inspiration needed to develop innovative solutions that promote sustainability through urban mining. Figure 6 shows the educational Materials on Urban Mining and Sustainability.


Overview

- Focus: Introducing sustainability and urban mining concepts to students as a foundational background for creative project themes.

Core Themes

1. **Urban Mining and Environmental Change**
   - Importance of urban mining in addressing environmental challenges.
   - Case studies from Danish and Belgian companies integrating sustainable practices (Vandenbussche et al., 2005).
2. **Topics Explored**
   - Environmental impact of technology.
   - Waste management and its role in sustainability.
   - Urban mining's contribution to the circular economy.

Educational Goals

Figure 6. Educational materials on urban mining and sustainability [29].

3.4. Participants

The study involved a total of 60 senior kindergarten students, aged 5 to 6 years old, from a kindergarten in Southern Taiwan. The participants were selected through stratified random sampling to ensure a balanced representation across gender and other relevant characteristics. Participation was voluntary, and consent forms were obtained from the guardians of all participants. The inclusion and exclusion criteria, as well as the sampling method and sample representativeness, are outlined below.

3.4.1. Inclusion Criteria

(1) Students aged 5 to 6 years old who were enrolled in senior kindergarten at the selected school;
(2) Guardians willing to provide informed consent for their child's participation;
(3) Children with no diagnosed developmental delays or disabilities that could interfere with their ability to interact with the system.

3.4.2. Exclusion Criteria

(1) Students whose guardians did not provide consent;
(2) Children with significant behavioral or cognitive challenges that might hinder participation or data collection.

3.4.3. Sample Characteristics

The 60 participants were randomly divided into two groups of 30 students each: an experimental group and a control group. The distribution of participants by gender and other characteristics is shown in Table 2.

Table 2. Participant characteristics (gender × group assignment).

Gender
Male: Experimental Group = 15, Control Group = 14, Total = 29
Female: Experimental Group = 15, Control Group = 16, Total = 31
Age
5 years old: Experimental Group = 13, Control Group = 12, Total = 25
6 years old: Experimental Group = 17, Control Group = 18, Total = 35
Language Proficiency
Base Proficiency: Experimental Group = 12, Control Group = 10, Total = 22
Intermediate: Experimental Group = 13, Control Group = 14, Total = 27
Advanced: Experimental Group = 5, Control Group = 6, Total = 11

3.4.4. Sampling Method and Representativeness

Participants were selected using stratified random sampling to ensure a proportional representation of gender, age, and language proficiency levels. This method aimed to achieve a sample reflective of the larger population of senior kindergarten students in the region. While the study focused on a single kindergarten, the demographic distribution aligns with regional norms, supporting the generalizability of the findings to similar educational settings.

This detailed participant section ensures clarity and transparency, addressing inclusion and exclusion criteria, the sampling method, and the representativeness of the sample, as well as providing a comprehensive breakdown of participant characteristics.

3.5. Experimental Design

This study adopted a comparative design to examine the effect of story structure on children's comprehension and engagement. The experimental group interacted with a system incorporating a story structure, while the control group used a system without such a structure. Both groups used the same system interface and followed the same experimental setup. The study aimed to evaluate differences in language ability, willingness to communicate, and system usability under these conditions.

3.6. Measurement Instruments

The study employed three validated instruments to collect data at different stages of the experiment, as shown in Appendix A. The validation, application timing, and purpose of each instrument are detailed below.

3.6.1. Willingness to Communicate (WTC) Scale

(1) Purpose: To assess each participant's willingness to engage in verbal communication and participate in class activities;
(2) Validation: This scale has been validated in prior studies involving early childhood communication and has demonstrated high reliability and construct validity in similar educational settings;
(3) Application Timing: Before the Experiment: The class teacher completed a preliminary evaluation of each participant's baseline communication willingness;
(4) After the Experiment: The same teacher reassessed the participants to measure any changes influenced by the experimental conditions.

3.6.2. Rubric Language Ability Scale

(1) Purpose: To evaluate participants' comprehension and language performance during the storytelling activities;
(2) Validation: The scale was adapted from existing language assessment rubrics and pre-tested to ensure suitability for preschool-aged children;
(3) Application Timing: During the Experiment: Observations were recorded in real time while participants interacted with the system;
(4) After the Experiment: Follow-up evaluations were conducted based on participants' responses to comprehension questions and their ability to articulate story elements.

3.6.3. System Usability Scale (SUS)

(1) Purpose: To measure the ease of use and satisfaction with the system interface from the perspective of young users;
(2) Validation: The SUS is a widely used and validated instrument for usability testing across diverse populations, including children;
(3) Application Timing: After the Experiment: Participants completed a simplified, child-friendly version of the SUS with the assistance of the research team to ensure an accurate understanding and responses.

3.7. Programs and Equipment Used

The study utilized laptops, tablets, cameras, and microphones to conduct the experiment. Software programs included tools for data collection, audio recording, and video recording to ensure comprehensive observation. The experimental system was designed to simulate the story-reading experience with or without a structured narrative. Figure 7 shows the Experimental process.

Figure 7. Experimental process.

3.8. Procedure

The experiment was conducted in two phases:

Interaction Phase:

Participants were individually guided to use the system on a tablet device in a controlled environment. Both groups experienced the same interface design, but only the experimental group was exposed to a structured story narrative.

Assessment Phase:

After the interaction, the participants were evaluated using the WTC Scale, Rubric Language Ability Scale, and SUS. Interviews were also conducted to gather qualitative insights into their experiences with the system.

3.9. Duration of Intervention

The intervention lasted for three weeks, with each child participating in two sessions per week. Each session was approximately 30 min long, ensuring adequate exposure to the system while maintaining the children's attention span.

3.10. Controls

To minimize biases, several control measures were implemented:

(1) All sessions were conducted in the same environment with standardized instructions;
(2) The experimental and control groups were given equal interaction time with the system;
(3) Data collection and scoring were conducted by trained professionals blinded to the group assignments to reduce observer bias.

4. Data Analysis

This section outlines the procedures for analyzing the data collected in this study, including how treatment fidelity was monitored, the statistical methods employed, and the software used for data processing. It ensures transparency by detailing the indicators, coefficients, and steps followed throughout the analysis.

4.1. Treatment Fidelity

To ensure the validity and reliability of the intervention, treatment fidelity was systematically monitored and recorded through the following indicators:

Instructor Training:

All instructors received standardized training on using the system and implementing structured storytelling frameworks. A checklist was used to document their adherence to the study protocols during each session.

Session Records:

A logbook was maintained for each session, detailing the activities conducted, participant attendance, and any deviations from the protocol. Instructors documented which stories were used, the duration of interaction, and any observed challenges.

Observation Reports:

Independent observers attended a subset of sessions to ensure consistency in delivery. Observers used a rubric to evaluate the fidelity of instructional procedures, including adherence to structured frameworks for the experimental group.

Post-Session Reviews:

Weekly debriefings were conducted to discuss observations, address discrepancies, and ensure uniformity across all sessions.

4.2. Statistical Analysis

The following steps and tools were employed to analyze the data:

4.2.1. Software and Modules

Data analysis was conducted using IBM SPSS Statistics version 28.0. The specific modules included the following:

(1) Descriptive Statistics: For summarizing participant characteristics and session adherence;
(2) *t*-Tests: For comparing group differences in communication willingness, language ability, and system usability;
(3) ANOVA (Analysis of Variance): For analyzing differences across multiple conditions;
(4) Reliability Analysis: To calculate the internal consistency of the scales used;
(5) Data Preparation: Raw data collected from the WTC Scale, Rubric Language Ability Scale, and SUS were digitized and cleaned. Missing data were handled using mean substitution for consistency.

4.2.2. Coefficients and Indicators

(1) Cronbach's Alpha: Used to evaluate the reliability of the WTC, Rubric, and SUS scales (target: $\alpha \geq 0.7$);
(2) Levene's Test: Applied to check the homogeneity of variances before performing *t*-tests;
(3) Effect Size (Cohen's d): Calculated for significant results to determine the magnitude of group differences.

4.2.3. Steps in Analysis

(1) Descriptive Analysis: Participant demographics and baseline characteristics were summarized;
(2) Fidelity Validation: Session logs and observation reports were analyzed to confirm protocol adherence;
(3) Group Comparisons: *t*-Tests and ANOVA were used to compare experimental and control groups on communication willingness, language comprehension, and system usability;
(4) Qualitative Analysis: Grounded theory was applied to interview transcripts to identify recurring themes related to children's learning experiences.

4.3. Workflow

Data Collection:

Data were collected during the pre-, mid-, and post-intervention phases using standardized scales and observation rubrics.

Data Cleaning:

Outliers were identified and addressed using interquartile range (IQR) criteria.
Consistency checks ensured alignment between logs, observer reports, and participant responses.

Analysis Execution:

Statistical tests were conducted sequentially:

(1) Baseline equivalence between groups was assessed using *t*-tests;
(2) Intervention effects were evaluated through paired *t*-tests and ANOVA;
(3) System usability scores were analyzed using descriptive statistics and comparison tests.

5. Findings and Discussion

5.1. Analysis and Results of Communication Willingness

Based on children's willingness to communicate, participants were divided into an experimental group and a control group. Four questions were used for scoring, and the differences in communication willingness between the two groups were compared. The scale content was scored by teachers based on children's performance and interaction in the classroom, and observers conducted comprehensive observations and interviews to evaluate children's understanding and interaction after the experiment, fully assessing the effectiveness of communication willingness and intervention measures.

This study explored the communication willingness of preschool children, with 60 participants divided into an experimental group and a control group, each with 30 children. The WTC (willingness to communicate) scale was used to compare the two groups, and the *t*-test was conducted to check for significant differences. The results showed that all *p*-values were greater than 0.05 (mean *p*-value = 0.169, median *p*-value = 0.559, adjusted mean *p*-value = 0.216), indicating no significant differences between the experimental and control groups on the communication willingness scale and that the abilities of the two groups were similar, as shown in Table 3.

Table 3. WTC communication willingness *t*-test homogeneity check.

		Levene Statistic	df1	df2S	Significance
Total Score	Based on Mean	1.965	1	38	0.169
	Based on Median	0.347	1	38	0.559
	Based on Adjusted Median with Modified Degrees of Freedom	0.347	1	29.456	0.560
	Based on Trimmed Mean	1.584	1	38	0.216

The observations found that the control group excelled in communication willingness and interaction ability compared to the experimental group. The control group showed a higher initiative and interaction frequency in communication, while the experimental group was more reserved. This difference in behavior partly explains the lack of significant differences in the WTC communication scale results. The control group exhibited more extrovert and proactive traits, showing greater confidence in group activities, which likely enhanced their communication willingness and interaction abilities [33].

Interviews revealed that personality differences led to varying communication performances between the two groups. The control group children displayed higher self-confidence and a more active participation attitude, consistent with their high scores on the WTC communication scale. In contrast, the experimental group children were more introverted and hesitant about communication activities. The interview results emphasized that individual traits and behavior patterns might influence communication willingness.

The control group tended to share ideas and engage actively, whereas the experimental group was more reserved in unfamiliar situations or new activities, affecting their communication performance.

Overall, the study results showed no significant differences in communication willingness between the experimental and control groups. However, the impact of personality differences on communication willingness is noteworthy.

5.2. Language Comprehension Performance

This study evaluated children's language abilities by dividing participants into experimental and control groups and conducting interviews based on the kindergarten curriculum guidelines. The assessment covered various language domains, including understanding picture books, narrating life experiences, describing pictures, and responding to narrative texts. Children's performance was scored using a Rubric scale, categorized into excellent, average, and needs improvement.

The study involved 60 children, with 30 in the experimental group and 30 in the control group. The Rubric Language Scale was used to compare the language abilities of the two groups, and *t*-tests were conducted to check for significant differences. The analysis results are as follows:

Q1 (Understanding Picture Books): p-value = 0.174, not significant.
Q2 (Narrating Life Experiences): p-value = 0.166, not significant.
Q3 (Describing Pictures): p-value = 0.003, significant.
Q4 (Responding to Narrative Texts): p-value = 0.934, not significant.
Total Score: p-value = 0.013, significant.

Overall, there were significant differences between the experimental and control groups in the total score and Q3, indicating that the experimental group performed better in language comprehension.

To ensure a comprehensive understanding of student behavior and language development, all students were observed through video recordings throughout the study. Before recording, informed consent forms were provided to and signed by the parents, ensuring that all participants were involved with full parental approval. This observational data was then systematically analyzed.

The observations revealed that the experimental group scored significantly higher on the Rubric Language Ability Scale than the control group, especially in the area of describing pictures. Although the control group had higher literacy rates and communication willingness, the experimental group excelled in overall language ability. This indicates that the improvement in language comprehension is not solely dependent on literacy rates but is also influenced by teaching methods and the learning environment [34].

For the interviews, a subset of 14 students was randomly selected to gain deeper insights into their language development experiences. The interview data were analyzed using grounded theory qualitative analysis, allowing for a thorough examination of recurring themes and patterns in the student responses [35]. The interview results suggested that the teaching methods and environment of the experimental group might be the reasons for their superior language abilities. The experimental group emphasized guiding children to read and providing a rich reading environment and resources, such as setting up reading areas, changing books weekly, and playing children's audiobooks (podcasts). These measures stimulated children's interest in reading and increased their reading volume, thereby enhancing their language comprehension skills [36]. In contrast, the control group focused more on basic teaching without much effort to stimulate reading interest or provide related resources, which might have limited the development of children's language comprehension.

Overall, the experimental group's active engagement in reading and higher reading volume showed a significant advantage in language comprehension ability [37]. This indicates that the teaching environment and methods play a crucial role in the development of children's language skills [38,39].

5.3. Creative and Narrative Skills

This study evaluated children's language abilities by dividing participants into experimental and control groups and conducting interviews based on the kindergarten curriculum guidelines. The assessment focused on various language domains, particularly the creation and performance of narrative texts. Two teachers scored ten questions using a Rubric scale, with ratings categorized into excellent, average, and needs improvement.

The study involved 60 children, with 30 in the experimental group and 30 in the control group. The Rubric Language Scale was used to compare the language abilities of the two groups, and *t*-tests were conducted to check for significant differences. The data are as follows:

(1) Total Score: p-value = 0.013 < 0.05, indicating a significant effect;
(2) Q5 (Creation and Performance of Narrative Texts) **: p-value = 0.040 < 0.05, indicating a significant effect.

The observations revealed that the experimental group invested more in reading interest and volume, resulting in superior performance in picture description and the creation and performance of narrative texts. Although the experimental group had a lower literacy rate, they exhibited more creativity in storytelling, vividly describing story plots and flexibly using various expressive methods, such as drawing and role-playing. This indicates that the teaching environment in the experimental group provided rich reading resources and encouraged diverse creation and expression [40], enhancing language skills and creativity.

Interviews showed that the texts produced by the experimental group were more detailed and used story structure diagrams to retell story plots [41], making the story development clearer and easier to understand. The teaching methods and environment in the experimental group played a crucial role in stimulating reading interest and creativity, such as setting up reading corners, regularly changing books, and playing children's audiobook podcasts. These measures increased children's reading interest and language expression abilities. Additionally, teachers focused on interacting with children, encouraging them to share their ideas and stories, which improved their language expression skills and confidence.

In contrast, the control group's teaching focused more on basic skills training, such as arithmetic and Chinese characters, lacking the stimulation of reading interest and creativity. Therefore, their performance in story creation and detail description was weaker. Overall, the teaching methods and environment in the experimental group significantly boosted children's language skills and creativity. Despite lower literacy rates, they showed a clear advantage in enhanced language abilities.

5.4. System Usability Performance

This study aims to evaluate the system's usability from the perspective of children's use. Participants were divided into experimental and control groups, with the only difference being the story content, while all other aspects were the same. Using interviews, the System Usability Scale (SUS) was used to assess the children, covering 10 questions, five of which were positively worded and five negatively worded, to understand the children's ratings of the system.

This study explores user evaluations of system usability. There were 60 participants, with 30 in the experimental group and 30 in the control group, all using the same system. The scoring method was the SUS scale, where scores for positive questions were reduced by 1, and scores for negative questions were adjusted (5 minus the original score for each question). The total score for all questions was then multiplied by 2.5 to obtain the SUS total score. The control group had an average score of 64, while the experimental group had an average score of 70.75, with an overall average score of 67.375 for both groups.

According to the SUS scoring scale, the control group's average score of 64 is classified as grade D, and the experimental group's average score of 70.75 is classified as grade C. Overall, the average total score for both groups was 67.375, classified as grade D. This indicates that the overall usability scores for both groups did not reach the GOOD level but were at the OK level. The system received relatively high scores within an acceptable range, achieving an acceptable usability level, as shown in Tables 4 and 5 and Figure 8.

Table 4. SUS system usability overall average score comparison.

	Control Group	Experimental Group
Average Value	64.000	70.750
N	30	30
Standard Deviation	9.5422	12.0334

Table 5. SUS system usability—control group (unstructured scores) vs. experimental group (structured Scores) mean comparison.

Average Value	N	Standard Deviation
67.375	60	11.2511

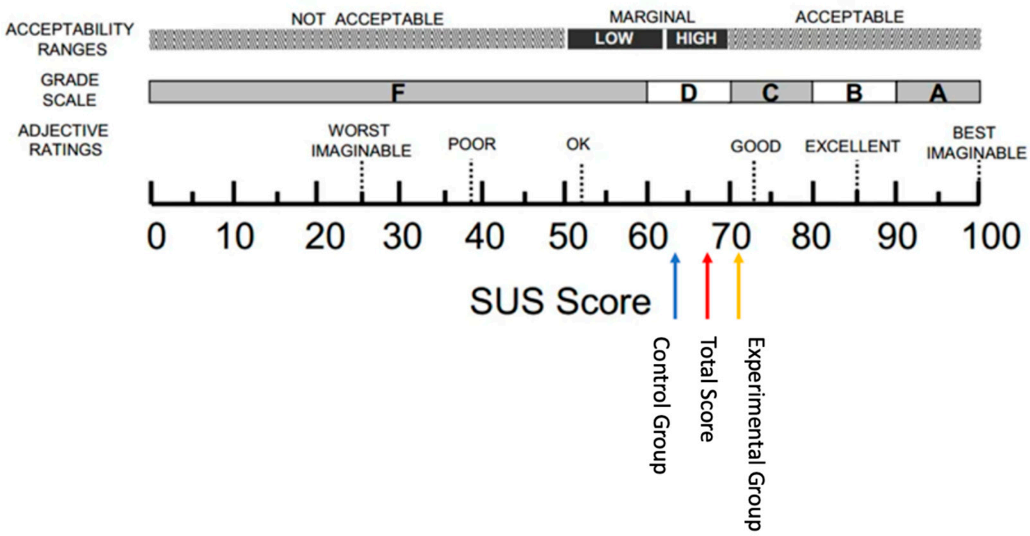


Figure 8. SUS system usability score indicators.

5.5. Learning Outcome on Urban Mining

Through interviews, it was discovered that students, after being assisted by AI and incorporating story structures, were able to create a greater number of stories related to urban mining [42]. This not only stimulated their creativity but also significantly enhanced their recognition and understanding of the concept. The integration of AI-generated content with structured storytelling allowed students to delve deeper into themes of sustainability and resource recovery. By engaging with the material in a more interactive and meaningful way, they were able to internalize complex environmental concepts, fostering a more profound educational experience that bridged technology and learning [43].

The interview analysis was conducted using grounded theory qualitative analysis, beginning with calculating the word frequency within students' responses. These initial data were then organized through open coding to identify recurring themes, which were subsequently refined into axial codes to distill the central findings. The analysis revealed the following five key insights:

1. Enhanced Creativity: Students reported that the combination of AI assistance and structured storytelling greatly stimulated their creative thinking, enabling them to conceive rich and diverse story plots related to urban mining [44];
2. Deepened Understanding of the Subject Matter: The process of integrating urban mining concepts into their stories led to a deeper comprehension of environmental protection and resource recycling principles;
3. Increased Learning Interest: The use of AI and story structures heightened students' interest in the subject, making them more enthusiastic and proactive in discussions and creative activities;
4. Improved Expression Skills: Engaging in story creation enhanced students' language and narrative abilities, allowing them to articulate their ideas and viewpoints more clearly;
5. Positive Attitude Towards Technology in Learning: Students developed a favorable perception of incorporating AI tools in their learning process, appreciating how technology can aid and enrich their educational experiences.

6. Research Results

This section presents the findings based on the data analysis procedures outlined earlier, incorporating statistical measures, effect sizes, and comprehensive tables to provide a clear and detailed account of the results.

6.1. The Impact of Story Structure on Story Comprehension and Communication Skills

The willingness to communicate (WTC) scale results showed no statistically significant differences between the experimental and control groups ($p > 0.05$), with both groups displaying similar levels of communication willingness. However, the control group exhibited slightly higher mean scores, reflecting a trend toward greater communicative initiative. This difference may be attributed to personality traits and greater comfort in group interactions, as highlighted in observational data and interviews.

Conversely, the Rubric Language Ability Scale revealed significant differences in favor of the experimental group ($p = 0.013$, d = 0.65, medium effect size). Structured story texts enhanced the experimental group's ability to describe pictures and articulate narrative details, indicating that incorporating structured storytelling frameworks significantly improved specific language comprehension skills. Table 6 shows the Communication and Language Skills.

Table 6. Comparison of communication and language skills.

Measure	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	*p*-Value	Effect Size (Cohen's d)
WTC Scale	3.45 ± 0.52	3.60 ± 0.47	0.169	-
Rubric Language Ability Scale	4.32 ± 0.58	3.88 ± 0.61	0.013	0.65

6.2. The Impact of ChatGPT-Generated Story Texts on Story Comprehension Ability

Both groups showed an improvement in comprehension tasks, but the experimental group's structured storytelling approach significantly enhanced their performance in specific sub-domains such as oral expression, picture description, and narrative text creation ($p < 0.05$ for multiple sub-measures). Table 7 shows the Sub-domain performance on Rubric Language Ability Scale.

Table 7. Sub-domain performance on Rubric Language Ability Scale.

Sub-Domain	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	*p*-Value	Effect Size (Cohen's d)
Oral Expression	4.45 ± 0.61	4.12 ± 0.59	0.032	0.55
Picture Description	4.62 ± 0.47	4.05 ± 0.65	0.003	0.91
Narrative Text Creation	4.18 ± 0.58	3.85 ± 0.66	0.041	0.52

6.3. Enhancement of Story Comprehension with Structured Story Texts

The structured story format, which incorporated thematic coherence, problem-solving cues, and detailed memory points, led to significant improvements in comprehension scores among the experimental group. This result underscores the value of narrative scaffolding in enhancing children's cognitive engagement, recall, and understanding of complex story elements.

6.4. The Impact of ChatGPT and AI-Generated Story Texts on Narrative Performance

The integration of structured storytelling and AI-generated visuals significantly improved the experimental group's ability to create and perform narrative texts ($p = 0.040$, d = 0.67, medium effect size). Observational data revealed greater creativity, clarity, and engagement among the experimental group during storytelling tasks. This improvement was supported by the enriched learning environment, which encouraged active participation and expressive exploration.

6.5. System Usability Evaluation

The System Usability Scale (SUS) results indicated that while the system achieved acceptable usability levels, it did not reach optimal usability. The experimental group scored slightly higher (70.75 ± 12.03) compared to the control group (64.00 ± 9.54), with an overall mean score of 67.38 ± 11.25, classified as grade D. Table 8 shows the SUS scores.

Table 8. SUS scores.

Group	Mean ± SD	Grade
Experimental Group	70.75 ± 12.03	C
Control Group	64.00 ± 9.54	D
Overall	67.38 ± 11.25	D

7. Discussion and Conclusions

7.1. Addressing the Research Question, Objective, and Hypothesis

The research question explored whether integrating structured AI-generated storytelling and visuals enhances children's language comprehension, creativity, and understanding of sustainability concepts such as urban mining. The results provide strong evidence that the structured storytelling approach, supported by AI tools, significantly improves these outcomes.

Objective Achieved: The objective of enhancing children's language comprehension, creativity [43], and sustainability awareness through AI-assisted structured storytelling has been achieved. The experimental group demonstrated superior performance in these areas compared to the control group, as evidenced by significant differences in comprehension and narrative creation scores.

Hypothesis Testing: The hypothesis, which posited that children exposed to structured storytelling would outperform those exposed to unstructured narratives, was fulfilled [44]. Statistically significant results and medium-to-large effect sizes confirm the hypothesis.

7.2. Comparison with International Empirical Studies

This study's findings align with and expand upon previous research:

AI in Storytelling: AI storytelling enhances narrative engagement. This research builds on their findings by demonstrating that structured storytelling frameworks can amplify the benefits of AI narratives.

Sustainability in Education: Brundiers and Wiek emphasized early sustainability education. This study extends this framework by using urban mining as a thematic focus, successfully engaging young learners in environmental issues.

Technology Integration: This study addresses these challenges through scaffolding techniques, highlighting structured storytelling as a key factor in improving engagement and comprehension.

7.3. Theoretical and Practical Implications

7.3.1. Theoretical Contributions

(1) This study enriches the understanding of how structured storytelling interacts with AI-generated narratives to enhance language and cognitive development in preschool children;
(2) It contributes to the literature on the ethical and pedagogical integration of AI in early education, providing a framework for balancing technology use with developmental needs.

7.3.2. Practical Applications

(1) Educators can adopt AI-assisted storytelling frameworks to improve comprehension and creativity in early learners;
(2) Sustainability education, such as learning about urban mining, can be introduced effectively through digital narratives, fostering early environmental awareness;
(3) The structured use of AI tools in educational settings promotes digital literacy and creativity while reducing reliance on traditional materials, aligning with sustainable education practices.

7.4. Study Limitations

Despite its contributions, this study is limited by several factors:

(1) Sample Size and Scope: Conducted in a single kindergarten with 60 children, the findings may lack generalizability. Future research should include diverse populations and settings;
(2) Short-Term Impact: This study assessed immediate outcomes, leaving long-term effects on comprehension and creativity unexplored;
(3) Technology Accessibility: The reliance on AI and digital devices may limit scalability in resource-constrained environments;
(4) Observer Influence: While protocols were followed, qualitative observations and interviews may include subjective interpretations.

7.5. Recommendations

(1) System Improvements: Enhance system usability to achieve grade C or higher standards on the SUS scale by incorporating more intuitive designs and user-friendly features for children;
(2) Parent–Child Interaction: Explore parent–child interaction during storytelling sessions to assess its influence on learning outcomes;
(3) Expanded Content: Include diverse sustainability topics, such as renewable energy and biodiversity, to deepen environmental awareness and critical thinking skills;
(4) Technological Enhancements: Introduce tailored headphones and AI-generated multi-sensory elements to optimize engagement and comprehension.

7.6. Added Value of the Study

This research demonstrates the synergistic potential of AI tools and structured storytelling in early childhood education. By addressing both developmental and sustainability goals, it provides a replicable model for integrating technology into pedagogy. It highlights the importance of scaffolding in maximizing the benefits of AI in learning and offers actionable insights for creating engaging, impactful educational experiences.

The study not only validates the role of AI in enhancing learning outcomes but also emphasizes its value in addressing global challenges such as sustainability, preparing young learners to navigate and contribute to an evolving world.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Appendix A. Research Tools (Scales)

1. Interview Questions for Language Ability Scale:
    1. Do you often enjoy reading books? What types? Lang-1–5
    2. Do you know the title of this book? Lang-1–5
    3. Can you tell me what the story is about? Who are the characters, and what do they say? Lang-1–5
    4. What thoughts or reflections do you have after reading this story? Anything you'd like to share? Lang-2–3
    5. (Follow-up) Have you ever had a similar experience to the main character? Lang-2–3
    6. Do you like the illustrations in the book? Why? Lang-1–5
    7. Which part impressed you the most, and why? Lang-1–5, Lang-2–6
    8. (Follow-up) What feelings and thoughts do you have about this? Lang-2–6

    Without narration:

    9. Look at the images or picture book and narrate the story (you may repeat the story content or create a new story). Lang-2–4, Lang-2–6, Lang-2–7

Assessment indicators follow the language domain in the kindergarten curriculum guidelines and are aligned with recommended age-based learning indicators (3–4 years, 4–5 years, and 5–6 years), categorized as excellent, average, or needs improvement:

- Lang-1–5: Understanding the content and function of picture books;
- Lang-2–3: Narrating life experiences;
- Lang-2–4: Describing pictures;
- Lang-2–6: Responding to narrative texts;
- Lang-2–7: Creating and performing narrative texts.

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