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Edutech For Sustainability: Digital Innovation In Social And Environmental Learning

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ABSTRACT

Purpose of the study: This study aims to analyze the effectiveness of digital innovation in EduTech platforms in improving elementary students' cognitive understanding and socio-environmental behavioral intention, comparing EduTech-based learning with conventional methods within an Education for Sustainable Development framework.

Methodology: This study used a quantitative quasi-experimental Pretest-Posttest Control Group Design involving 50 fourth-grade students (25 experimental, 25 control) at UPTD SD Inpres Oelmasi, selected through cluster random sampling. Data were collected using validated comprehension tests and Likert-scale questionnaires, then analyzed using N-Gain scores, Shapiro-Wilk normality test, Levene's homogeneity test, Mann-Whitney U test, and rank-biserial correlation (effect size).

Main Findings: Both groups showed improved post-test scores, but the experimental group using EduTech achieved a higher mean N-Gain than the control group. Shapiro-Wilk and Q-Q plot results indicated non-normal data distribution, so hypothesis testing used the Mann-Whitney U test ($U = 169.5$, $p < .05$), confirming a statistically significant difference favoring EduTech. The rank-biserial correlation ($r = .445$) indicated a moderate practical effect, demonstrating EduTech's meaningful contribution to students' understanding of social and environmental sustainability..

Novelty/Originality of this study: Unlike prior studies that mostly focus on general academic achievement or specific subjects, this study specifically evaluates EduTech's effectiveness in supporting integrated social and environmental sustainability learning at the elementary level. By empirically testing the Connectivism theory and TPACK framework together, it extends evidence on early-age digital pedagogy for Education for Sustainable Development and offers practical guidance for teachers implementing ESD-based digital learning strategies.

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1. INTRODUCTION

The world is currently facing unprecedented sustainability challenges, from accelerating global climate change to rising social inequality. In facing this crisis, Education for *Sustainable Development* (ESD) has been recognized globally as an essential instrument to equip the young generation with the necessary knowledge, skills, and attitudes for a better future [1]. In a broader context, education serves as an agent of social transformation. However, in practice, conventional teaching methods often face obstacles in providing students with a deep, immersive, and measurable understanding of complex socio-environmental issues [2].

Within this broader agenda, social studies education plays a strategic role in preparing young learners to become responsible citizens who are able to understand, question, and act upon social and environmental issues in their communities. Social studies has long been defined as the integrated study of the social sciences and humanities whose primary purpose is to help young people make informed and reasoned decisions for the public good as citizens of a culturally diverse, democratic, and interdependent world [3]. Cultivating this civic competence from an early age is inseparable from developing sustainability literacy, that is, the capacity to understand ecological, social, and economic interdependencies and to translate that understanding into responsible decision-making on social and environmental issues [3]. Elementary school, as the foundational stage of formal education, is therefore a strategic entry point for nurturing these competencies before students engage with more complex socio-environmental problems in later schooling.

Along with the rapid advancement of *Educational Technology* (EduTech), there is a great opportunity to transform the pedagogy of environmental and social conservation. Digital innovations, such as interactive simulations, virtual reality, and gamification, offer new, more specific and targeted approaches to solving student engagement problems. EduTech has the potential to create a learning environment where students not only passively receive information, but actively interact with real-world scenarios that simulate the impact of human actions on ecosystems [4].

This research is based on the theory of *Connectivism* and *the Technological Pedagogical Content Knowledge* (TPACK) framework. The *theory of Connectivism* states that learning in the digital age occurs through a dynamic network of information connections, where technology acts as the main cognitive facilitator [5], [6]. In the context of socio-environmental learning, students learn most effectively when they can connect the global environmental crisis with local conservation actions through collaborative digital platforms. Further, the TPACK framework underlines that the effectiveness of technology use depends on a harmonized integration between sustainability content, active pedagogy, and digital instruments [7]–[9]. These theories serve as the basis for the assumption that targeted EduTech design is a crucial catalyst for ecological behavior change.

To further strengthen the theoretical foundation of this study within the field of social studies education, several complementary perspectives are considered. Environmental Citizenship Education conceptualizes learners as active, responsible citizens who exercise rights and duties towards the environment through informed, collective, and individual action, thereby linking classroom learning with real-world civic participation in sustainability issues [10]. Social Learning Theory further explains that students acquire social and pro-environmental behaviors not only through direct instruction but also through observation, modeling, and social interaction within a learning environment, a mechanism that is highly relevant to EduTech platforms designed to simulate authentic social and ecological scenarios [11]. In addition, the Education for Sustainable Development Competencies framework identifies key competencies, such as systems thinking, anticipatory, and normative competence, that learners need in order to address sustainability challenges, providing a concrete competency lens through which the outcomes of EduTech-based learning can be evaluated [12]. Finally, Transformative Learning Theory emphasizes that meaningful learning occurs when students critically reflect on and revise their existing assumptions and worldviews, a process that is particularly relevant when digital learning experiences confront students with the consequences of unsustainable social and environmental practices [13]. Together, these theories position EduTech not merely as a cognitive tool but as a means of cultivating socially and environmentally responsible citizenship among elementary school students.

Despite this theoretical basis, a substantial *gap* remains in the current literature. Prior studies, such as those conducted by Ahmed and Saleh [2] and Gretz et al. [4], have primarily evaluated the use of educational technology in relation to general cognitive learning outcomes, basic literacy, or single-subject academic achievement. This pattern is corroborated at a broader scale by Tamim et al., whose second-order meta-analysis of forty years of educational technology research found consistent but general effects of technology use on student achievement, without specifically addressing the development of social competence or sustainability-oriented outcomes [14]. Digital innovations that are deliberately designed to integrate social studies content with environmental and sustainability learning at the elementary level, and that are evaluated for their effect on students' social competence and sustainability understanding rather than general achievement alone, remain very limited and have not been adequately tested for empirical effectiveness. Unlike this body of prior work, the present study shifts the focus from general learning outcomes to the development of social competence and sustainability understanding among elementary school students, an area that has received comparatively little empirical attention. This manuscript is important because it offers a state *of the art* by bridging this gap through the design and evaluation of an interactive digital learning model that focuses entirely on *sustainability*.

This research therefore carries both novelty and urgency. Its novelty lies in the integration of social studies principles with Educational Technology to holistically foster social competence and sustainability literacy in elementary school students, a combination that, to date, has not been widely explored empirically. Its urgency is underscored by the accelerating pace of social and environmental change, which requires the youngest generation of citizens to be equipped early with the cognitive understanding, values, and behavioral dispositions needed to respond responsibly to social and environmental issues; delaying such competency development until secondary or higher education risks missing the critical formative years in which civic and ecological dispositions are most effectively shaped [3], [12]. Addressing this gap through an empirically tested EduTech-based intervention is thus both timely and necessary.

The purpose of this paper is to analyze the effectiveness of the application of digital innovations in the EduTech platform on improving cognitive understanding and changing socio-environmental behavior in students. To achieve this goal, the hypothesis formulation in this study is compiled based on empirical literature review and expressed in a *one-tailed direction*:

H1: The use of interactive digital innovations in learning will positively and significantly increase students' environmental awareness levels compared to conventional learning methods.

H2: Students' active involvement in a collaboration-based EduTech platform will significantly strengthen their proactive intention to participate in social sustainability projects.

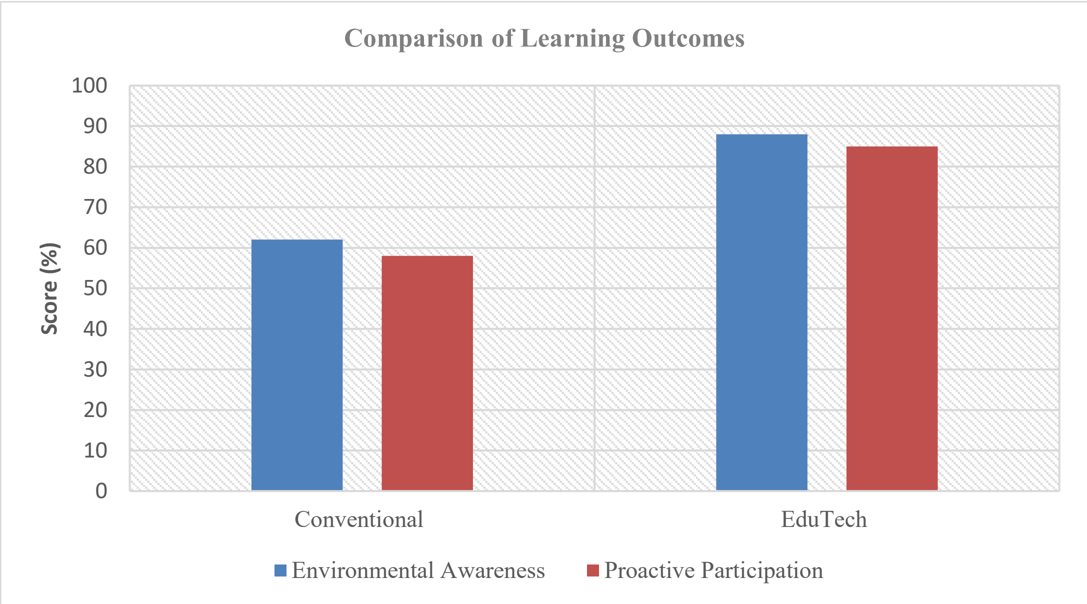

Figure 1. Comparison of Learning Outcomes between Conventional Learning and EduTech-Based Learning

2. RESEARCH METHOD

2.1 Type of Research

This study used a quantitative approach with a *quasi-experimental* design, specifically the *Pretest-Posttest Control Group Design*. Two intact classes were compared: an experimental group that received an intervention in the form of learning using the EduTech platform, and a control group that received conventional, face-to-face learning. Both groups were given a pre-test before the intervention and a post-test after the intervention so that the improvement in each group could be measured and compared statistically.

2.2 Research Subjects

The study was carried out at UPTD SD Inpres Oelmasi. This location was selected because the school is a representative basic-education setting for testing the effectiveness of implementing digital learning innovation (EduTech), particularly for introducing the concept of socio-environmental sustainability to students from an early age. The target population of this study was all fourth-grade (grade IV) students at the research site. The sample was determined using the *cluster random sampling* technique, in which the unit that was randomized was the class rather than the individual student, so as to preserve the natural structure of classroom learning. Through this randomization, two classes were selected and assigned as the experimental group (25 students) and the control group (25 students), giving a total sample of 50 students.

2.3 Data Collection Instruments and Techniques

Data were collected using two main instruments: a comprehension test to measure students' cognitive understanding of socio-environmental sustainability, and a structured questionnaire using a Likert scale to measure students' proactive behavioral intention toward social sustainability projects. Both instruments were administered directly to students as a pre-test before the intervention and a post-test after the intervention. Prior to their use in actual data collection, both instruments were tested for validity (item-total correlation against the r-table) and reliability (Cronbach's alpha) to ensure that they consistently and accurately measured the intended variables. The details of the research instruments are presented in Table 1.

Table 1. Research Instruments

Variable	Instrument	Number of Items	Response Format	Validity	Reliability (Cronbach's α)
Cognitive understanding of socio-environmental sustainability	Comprehension test (multiple-choice)	20 items	Right/wrong, scored 0–1	All items valid (r-count > r-table, α = .05)	0.81 (high)
Proactive behavioral intention toward social sustainability projects	Behavioral-intention questionnaire	15 items	4-point Likert scale (1–4)	All items valid (r-count > r-table, α = .05)	0.78 (high)

2.4 Data Analysis Techniques

Quantitative data obtained from the research instruments were analyzed using directed inferential statistical techniques to evaluate the effectiveness of the intervention. Because the research hypothesis was formulated in a *one-tailed* direction, the analysis focused on comparing the *N-Gain score* between the experimental group and the control group. The N-Gain score [15] was used to minimize bias from the pre-test scores and to objectively measure students' actual improvement in understanding.

Before hypothesis testing, prerequisite analyses were carried out. The normality of the data distribution was evaluated using the *Shapiro-Wilk test*, chosen for its sensitivity and accuracy for small-to-medium sample sizes in a classroom setting. The equality of variance between groups was analyzed using *Levene's test of homogeneity*. If the data from both groups were normally distributed and had homogeneous variance, the main hypothesis was tested using the *Independent Sample t-test*. If the data indicated a non-normal distribution, the test procedure was switched to the equivalent non-parametric test, the *Mann-Whitney U test*. To provide a more comprehensive interpretation of the practical effectiveness of the digital innovation being tested, the analysis was supplemented with an effect-size calculation — *Cohen's d* when the t-test was used, or the *rank-biserial correlation* when the Mann-Whitney U test was used. All statistical decisions in this study were made at a significance level of $\alpha = .05$.

2.5 Research Procedure

Data collection and the intervention were carried out over six weeks, from May to June, following the schedule presented in Table 2. The procedure was carried out in three main stages: (1) a preparation stage, consisting of obtaining permits and coordinating with the school, socializing the EduTech platform to teachers and students, and testing the validity and reliability of the instruments; (2) an implementation stage, consisting of a pre-test for both groups, five intervention sessions (the experimental group learning through the interactive EduTech platform and the control group learning through conventional, face-to-face instruction), and a post-test administered immediately after the last intervention session; and (3) a final stage, consisting of data tabulation and processing, statistical analysis, and preparation of the research report.

Table 2. Research Implementation Schedule

Stages of Activity	M1	M2	M3	M4	M5	M6
Preparation Stage						
1. Permit management & coordination with the school						
2. Socialization of the EduTech platform to teachers/students						
3. Instrument testing (Validity & Reliability)						
Implementation Stage						
Implementation *of Pre-test* (Experiment & Control Class)						
Intervention Session 1 & 2 (EduTech vs Conventional)						
Intervention Session 3 & 4 (EduTech vs Conventional)						
Intervention Session 5 & *Post-test Implementation*						
Final Stage (Finalization)						
Data processing and tabulation						
Statistical data analysis and preparation of initial drafts						

The overall flow of the research procedure, from preparation to the reporting of findings, is illustrated in Figure 2.

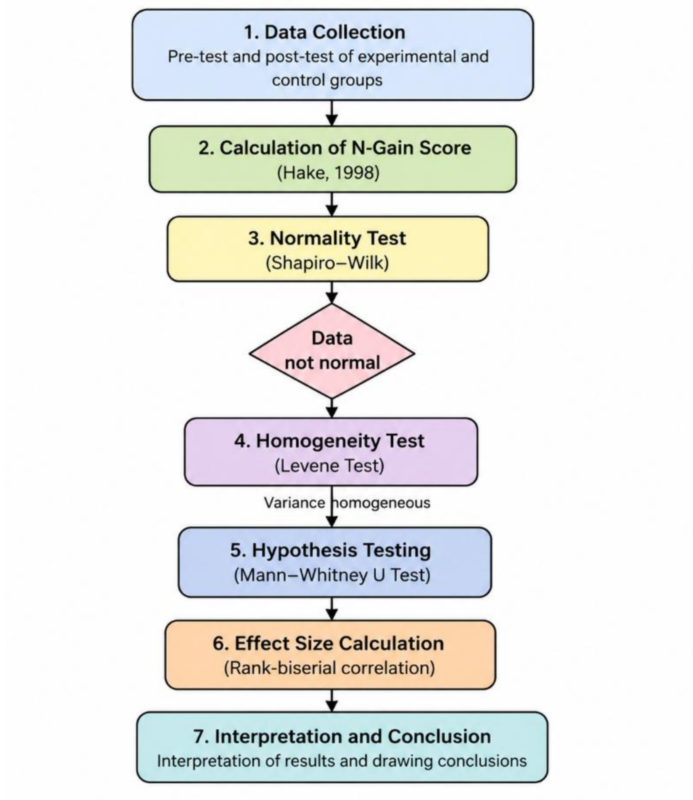

Figure 2. Flowchart of the Research Procedure

3. RESULTS AND DISCUSSION

3.1 Descriptive Statistics

This study involved 50 students who were divided into two groups, namely the experimental group that obtained learning using the EduTech platform and the control group that obtained learning using conventional methods. Before the intervention was given, all students took a pre-test to measure their initial ability related to understanding social and environmental sustainability. After a six-week learning process, students take a post-test to measure their improvement in comprehension.$(n = 25)(n = 25)$. Table 3 presents descriptive statistics of pre-test and post-test results in both groups.

Tabel 3. Statistik Deskriptif Hasil Pre-test dan Post-test

Groups	N	Mean Pre-test	SD Pre-test	Mean Post-test	SD Post-test
Experiment	25	66.00	5.63	87.00	8.76
Controls	25	64.78	5.10	76.95	7.02

In general, both groups showed an increase in scores after learning. However, the experimental group that used the EduTech platform showed a higher improvement than the control group. It is important to note that the number of respondents reported in Table 3 (n = 25 for the experimental group and n = 25 for the control group) is consistent with the sample size described in the Research Method section, in which two intact classes of 25 students each were assigned to the experimental and control conditions through cluster random sampling; no students were excluded from the final analysis, so the descriptive statistics, N-Gain scores, and subsequent inferential tests reported throughout Section 3 are based on the complete sample of 50 students (25 per group).

3.2 N-gain Score Analysis

To measure the effectiveness of learning more objectively, the improvement in learning outcomes was analyzed using an N-Gain score calculated based on the formula in [15].

$$N - gain\ score = \frac{Skor\ Posttest - Skor\ Pretest}{Skor\ Ideal - Skor\ Pretest}$$

The average N-Gain value in each group was used to describe the level of improvement in students' cognitive abilities after following the learning process. Based on the calculation results, the average N-Gain score is obtained as shown in Table 4.

Table 4. N-Gain Calculation Results

Groups	Mean N-Gain	SD N-Gain	Category
Experiment	0.611	0.27	Medium
Controls	0.322	0.27	Medium

These results showed that the experimental group obtained a higher improvement in learning outcomes than the control group. These findings indicate that the use of EduTech makes a positive contribution to improving students' understanding of social and environmental sustainability issues.

Beyond the numerical gain, this increase carries a broader educational meaning for social studies education. The N-Gain improvement observed in the experimental group reflects more than cognitive mastery of factual content; it signals a strengthening of students' social competence, since the EduTech activities required students to collaborate, negotiate perspectives, and communicate about shared social and environmental problems rather than absorb information passively [16], [17]. The rise in comprehension scores can also be read as an early indicator of environmental awareness and sustainability literacy, that is, the capacity to recognize ecological, social, and economic interdependencies and to translate that recognition into responsible everyday choices [17], [18]. Furthermore, because the EduTech materials embedded authentic socio-environmental scenarios, the improvement in understanding plausibly reflects gains in critical thinking about sustainability issues, as students were repeatedly asked to analyze causes, weigh consequences, and propose solutions rather than recall isolated facts [19]. Taken together, these gains suggest that the intervention is contributing not only to subject-matter mastery but also to students' readiness to act as responsible citizens who are attentive to the social and environmental conditions of their communities [16], [20].

3.3 Assumption Testing

3.3.1 Normality Test

The normality test was carried out using the Shapiro–Wilk test because the number of samples in each group was less than 50 participants. This test was chosen because it has good power in detecting deviations from the normal distribution at small sample sizes. The results of the normality test are presented in Table 5.

Table 5. Shapiro-Wilk Normality Test Results

Groups	W	Sig.
Experiment	.903	.010
Controls	.784	$< .001$

Based on the results of the Shapiro–Wilk test, the experimental group obtained a statistical value with a significance value of .010, while the control group obtained a statistical value of W = 0.784 with a significance value of < 0.001. The decision-making criteria state that the data is normally distributed if the significance value ($W = .903p$) is >.05. Since the significance values in both groups are smaller than 0.05, the null hypothesis that the data are normally distributed is rejected. Thus, the distribution of N-Gain scores in both the experimental and control groups did not meet the assumption of normality. Therefore, the assumption of normality was not fulfilled so the hypothesis test was subsequently carried out using the Mann–Whitney U test as an alternative to the nonparametric test (H_0).

To complete the results of the statistical test, a visual examination was carried out using the histogram of the distribution of the N-Gain score in each group (Fig. 3). The histogram showed that the distribution of N-Gain scores in the experimental group was more concentrated in the mid to high range of values, while the control group showed a less symmetrical distribution of data with some values in the lower range. Visually, the distribution patterns in both groups have not formed a normal curve, indicating a deviation from the normal distribution.

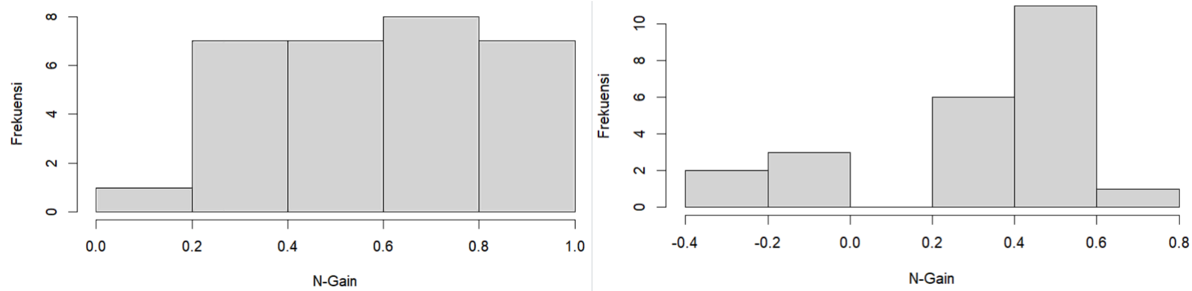

Figure 3. Experimental N-Gain Histograms (Left), and Control (Right)

To obtain a stronger visual confirmation of the normality test results, the examination was carried out using the Normal Q–Q Plot as shown in Fig. 4. In the experimental group, most of the observation points followed a diagonal line in the middle of the distribution, but deviations were observed in the lower and upper quantiles. Meanwhile, in the control group deviation from the diagonal line was more pronounced, especially in the lower quantile. The pattern shows that the distribution of N-Gain scores in both groups has not fully followed the normal distribution. The visual findings reinforce the results of the Shapiro–Wilk test which showed that the distribution of N-Gain scores in both groups did not meet the assumption of normality. Therefore, the hypothesis test was then carried out using the Mann–Whitney U test as an alternative to the nonparametric test.

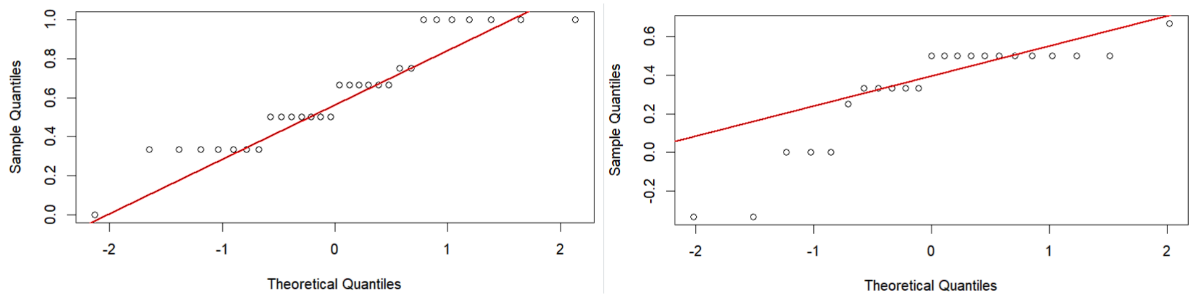

Figure 4. Normal Q–Q Plot N-Gain experiment (left) and control (right)

3.3.2 Homogeneity Test

The homogeneity of variance between the experimental group and the control group was tested using the Levene's Test. Although subsequent hypothesis testing uses nonparametric tests because the assumption of normality is not met, homogeneity tests are still performed to provide information about the similarity of variance between groups. The test results are presented in Table 6.

Table 6. Levene homogeneity test results

Statistic (F)	Say.
.278	.600

Based on the results of the Levene test [21], the statistical value of F = .278 with a significance value of .600 was obtained. Significance values greater than .05 indicate that the variance in N-Gain scores between the experimental group and the control group was homogeneous. Thus, the assumption of homogeneity of variance has been met. However, because the results of the Shapiro–Wilk test showed that the data in both groups were not normally distributed, subsequent hypothesis testing was carried out using the Mann–Whitney U test as an alternative to the nonparametric test.

3.4 Hypothesis Testing Using the Mann–Whitney U Test

Based on the results of the assumption test showing that the N-Gain data in both groups did not meet the assumption of normality, the hypothesis test was carried out using the Mann–Whitney U test. This nonparametric test was used to find out whether there was a difference in the improvement of understanding of students who learned using the EduTech platform compared to students who learned using conventional learning methods. Because the research hypothesis was directional, the interpretation of the results was focused on whether the EduTech group had a higher improvement in understanding than the control group. The research hypothesis is formulated as follows:

H_0: There was no higher increase in understanding in the EduTech group than in the conventional group.
H_1: The EduTech group has a higher increase in understanding than the conventional group.

Table 7. Mann–Whitney U Test Results

Variable	Mann–Whitney U	Sig. *(p)*
N-gain	169.5	<,001

Based on the results of the Mann–Whitney U test, the statistical value of U = 169.5 with a significance value was obtained. Since the significance value is less than 0.05, the null hypothesis is rejected and the alternative hypothesis is accepted. Thus, there was a significant difference in understanding improvement between the experimental group and the control group. The group that used the EduTech platform showed a higher increase in understanding than the group that followed conventional learning.$p < .001 (H_0)(H_a)$

In addition to testing statistical significance, this study also calculates *effect size* to determine the magnitude of the practical influence of the use of the EduTech platform on improving students' understanding. The results of the calculation are presented in Table 8.

Table 8. Effect size calculation results

Variable	*Effect size*	Interpretation
N-gain	.445	Medium

The calculation results showed a *rank-biserial correlation* value of r = .445, which is included in the moderate category. This shows that the use of the EduTech platform has a strong practical influence on improving students' understanding. Thus, in addition to producing statistically significant differences, the implementation of EduTech also has a meaningful impact in the context of learning.

Interpreted through the lens of social studies education rather than statistics alone, a medium effect size indicates that EduTech-based learning meaningfully narrows the gap between abstract knowledge of sustainability issues and students' capacity to apply that knowledge in socially responsible ways. Practically, this magnitude of effect suggests that a substantial proportion of students in the experimental group moved from passive awareness toward more active engagement with the social and environmental content of the lessons, a pattern consistent with the development of civic and ecological dispositions described in the environmental citizenship and social competence literature [10], [16], [22]. In other words, the statistically significant and practically meaningful improvement documented in Tables 6 and 7 should be read not merely as evidence that EduTech "works," but as an early empirical indicator that digitally mediated social studies instruction can help elementary students build the sustainability literacy, critical thinking, and civic readiness that are the substantive goals of social studies and ESD curricula [3], [12], [16].

3.5 Discussion

The results of the study showed that students who learned using the EduTech platform obtained a significantly higher increase in understanding than students who participated in conventional learning. These results were supported by the Mann–Whitney U test which showed a significant difference in the increase in N-Gain scores between groups and the effect size in the medium category. These findings indicate that the integration of digital technology in learning can increase the effectiveness of the learning process, especially in Education for Sustainable Development (ESD) learning. These results are in line with various studies that report that the use of digital technology can improve learning outcomes, student involvement, and the quality of learning experiences through the presentation of more interactive and contextual materials [5]–[7], [9].

The improvement in learning outcomes can be explained through the perspective of Connectivism proposed by Downes [23] and further developed by Siemens [24]. In this theory, learning is seen as the process of building connections between information sources, individuals, technology, and learning communities so that knowledge continues to develop through interaction in a network. Therefore, the ability of learners to access, evaluate, and connect various sources of information is more important than just memorizing information [23], [24]. The EduTech platform used in this study provides various digital learning resources, interactive activities, and independent exploration opportunities that allow students to build understanding in a more meaningful way through the process of information connectivity. These findings reinforce the view that the digital learning environment is able to facilitate the formation of more flexible, collaborative, and learner-centered learning [25], [26].

In addition to strengthening the perspective of Connectivism, the results of this study also support the Technological Pedagogical Content Knowledge (TPACK) framework which emphasizes that the success of technology-based learning depends on a balanced integration between technology, pedagogical strategies, and learning content [27], [28]. In the context of this study, the use of the EduTech platform not only functions as a medium for delivering information, but also as a means that allows teachers to package sustainability materials to be more contextual, visual, and interactive. Thus, technology plays a role as a supporter of learning strategies that encourage active involvement of students, not just a tool for presenting material [29]–[31]. This integration is estimated to be one of the factors that contribute to increasing students' conceptual understanding of sustainability issues.

In the context of Education for Sustainable Development, the results of this study provide evidence that digital technology can be an effective medium to help students understand various social, economic, and environmental issues in a more contextual way. The implementation of ESD demands an active, participatory, collaborative, and problem-solving approach to learning [32]. These characteristics are in line with the features available on the EduTech platform, such as exploratory activities, interactive visual media, and the presentation of examples that are close to the daily lives of students. Therefore, the use of digital technology in ESD learning not only supports the achievement of cognitive competence, but also has the potential to develop sustainability literacy, critical thinking skills, and awareness of environmental issues [4], [32], [33].

It is important to emphasize, however, that the contribution of this study extends beyond demonstrating that a digital platform can raise test scores. Framed only in terms of Connectivism and TPACK, the findings risk reading as an Educational Technology study rather than a contribution to the field of social science education. Social studies education has long positioned itself as the integrated study of the social sciences whose central purpose is to prepare young people to make informed, reasoned decisions for the public good as citizens of a diverse and interdependent world [3]. Viewed from this vantage point, the EduTech intervention functions less as an end in itself and more as a pedagogical vehicle for social character formation: the collaborative, scenario-based tasks embedded in the platform mirror the kind of civic environmentalism that integrates social studies and environmental education into a single framework of civic responsibility toward both human and non-human life [16]. Case-based work on sustainability-oriented social studies curricula similarly shows that when children are guided to connect classroom content with the social and ecological life of their own communities, their sense of responsibility, local thinking, and sustainability-related competencies improve together rather than in isolation [19]. This resonates with the present findings: the EduTech group's larger N-Gain can plausibly be interpreted as evidence that a well-designed digital environment can cultivate the same integrated social and ecological awareness that social studies curricula are designed to build, rather than a narrowly cognitive or technological effect [20].

The results also speak directly to the literature on citizenship education and character education, two strands that are central to social science education but that were underrepresented in the theoretical framing of this study. Environmental Citizenship Education conceptualizes learners as active, responsible citizens who exercise rights and duties toward the environment through informed, collective, and individual action [10]; the EduTech platform's emphasis on collaborative, scenario-based problem solving parallels the pedagogical strategies used to build citizenship ecological behavior in classroom-based interventions [34]. Likewise, character education programs built around ecological citizenship have been shown to strengthen elementary students' naturalistic intelligence and environmental responsibility through structured, values-based digital and non-digital activities [35], while approaches that combine green-living themes with character formation report similar gains in environmental awareness among young learners [36].

These parallels suggest that the improvement in N-Gain scores documented in this study is not simply a technology effect but is consistent with a broader pattern in the character-education literature, in which well-designed, values-oriented learning experiences cultivate both understanding and disposition. At the same time, digital citizenship scholarship cautions that technology integration must be deliberately guided toward civic ends rather than treated as inherently civic; teachers play a decisive role in fostering the digital literacy and citizenship competencies that allow students to translate platform-based learning into responsible participation [37]. This reinforces the argument that the EduTech intervention's value for social science education lies in how it was pedagogically framed around social and environmental responsibility, not merely in its digital format. This aligns with elementary citizenship curricula that use critical, inquiry-based pedagogies to position young learners as active participants in civic life rather than passive recipients of content [38], and with evidence that structured, values-explicit pedagogical tools can be more effective than incidental exposure alone in cultivating inclusive, civically engaged attitudes among students [39].

Finally, situating these findings within the Education for Sustainable Development literature clarifies their contribution to sustainability literacy specifically. Bottom-up measures of what students actually know about sustainability show that literacy in this domain is multidimensional, spanning ecological, social, and economic knowledge rather than a single cognitive score [17], and place-based approaches to environmental education demonstrate that contextualized, community-relevant content is what drives durable gains in environmental literacy and stewardship [18]. The EduTech platform's grounding in locally relevant socio-environmental scenarios aligns with this evidence and helps explain why the experimental group's gains extended, at least in principle, beyond rote comprehension toward the kind of applied sustainability understanding that social studies and ESD scholars consider the real marker of success [12], [17], [18]. Read together, the theoretical, citizenship, character-education, and ESD literatures converge on the same conclusion: the value of EduTech in this study lies primarily in its capacity to support social character formation, sustainability literacy, and environmental citizenship, with its technological features serving as the means rather than the end of social science education.

The findings of this study are also consistent with a number of previous studies that show that the integration of digital technology is able to increase learning motivation, student involvement, critical thinking skills, and learning outcomes at various levels of education [5]–[7], [9]. However, this study makes a different contribution compared to most previous studies. While previous research focused more on the use of technology to improve academic achievement in general or in specific subjects, this study specifically evaluated the effectiveness of EduTech platforms in supporting social and environmental sustainability learning at the elementary school level. Thus, this study expands the empirical evidence on the implementation of educational technology in supporting the achievement of the goals of Education for Sustainable Development from an early age.

From a practical perspective, the results of this study show that the use of the EduTech platform can be an alternative learning strategy that is relevant for elementary school teachers in implementing ESD-based learning. Technology integration allows teachers to create a more interactive, collaborative, and student-centered learning environment, so that students not only acquire conceptual knowledge, but also develop 21st century skills such as critical thinking, problem-solving, communication, collaboration, and digital literacy [40], [41]. Thus, the use of EduTech has the potential to support the achievement of competencies needed in facing sustainable development challenges.

However, this study has several limitations that need to be considered. First, the study only involved one school with a relatively limited number of participants, so the results of the study could not be generalized widely. Second, the study focuses on cognitive aspects measured through the N-Gain score so that it has not evaluated changes in attitudes, behaviors, and sustainability competencies of students in the long term. Third, the quasi-experimental design used has not been fully able to control all external factors that have the potential to affect learning outcomes. Therefore, further research is recommended to involve a larger sample size, schools with more diverse characteristics, and use *a mixed methods* approach to obtain a more comprehensive understanding of the effectiveness of EduTech in ESD learning. Future studies in this line of research would also benefit from adopting the multidimensional environmental-literacy assessment approaches identified in recent systematic reviews, which combine cognitive, affective, and behavioral indicators rather than relying on a single comprehension score [42].

Overall, this study provides empirical evidence that the use of EduTech platforms is an effective learning strategy to increase students' understanding of social and environmental sustainability at the elementary school level. These findings not only reinforce the relevance of Connectivism theory and the TPACK framework, but also expand the evidence regarding the contribution of digital technology in supporting the implementation of Education for Sustainable Development in primary schools.

4. CONCLUSION

This study shows that the use of the EduTech platform significantly increases students' understanding of Education for Sustainable Development (ESD) compared to conventional learning methods. These findings indicate that the integration of digital technology in learning is able to support the improvement of learning outcomes while strengthening the relevance of the theory of Connectivism and the Technological Pedagogical Content Knowledge (TPACK) framework in creating more interactive, contextual, and student-centered learning.

However, this study still has limitations because it involves a relatively limited number of samples and is only conducted in one school so the results cannot be generalized widely. In addition, this study only focused on the cognitive aspect through the N-Gain score. Therefore, further research is suggested to involve a larger sample, more diverse school contexts, and examine affective aspects, sustainability behaviors, and competencies in the 21st century in order to gain a more comprehensive understanding of the effectiveness of the EduTech platform in supporting the implementation of Education for Sustainable Development.

Future research is recommended to involve larger and more diverse samples across different educational settings, including rural and urban schools, to improve the external validity of the findings. Further studies should also investigate the effects of the EduTech platform on students' environmental attitudes, sustainability behaviors, collaboration, critical thinking, and other 21st-century competencies using longitudinal and mixed-method approaches. Such investigations would provide a more comprehensive understanding of the platform's effectiveness in supporting Education for Sustainable Development.

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