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Development Foundations of Interactive Media: The Role of Socio-Educational Environment and Paperless Learning as Predictors of Eco-Digital Literacy

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ABSTRACT

The rapid transformation of digital education has increased the need to integrate technological competence with environmental responsibility in primary education. Previous studies on digital literacy and environmental education have generally been conducted separately and remain predominantly technocentric, with limited attention to socio-educational interaction and sustainable digital practices in developing eco-digital literacy. This study aims to examine the relationship between the socio-educational environment, paperless learning, and eco-digital literacy among primary school students. A quantitative correlational design was applied involving 135 students from digitally integrated primary schools in West Java, Indonesia. Data were collected using Likert-scale questionnaires and analyzed through Pearson correlation and multiple linear regression using SPSS 27.0. The findings revealed that the socio-educational environment had a stronger positive relationship with eco-digital literacy ($r = 0.64$, $p < 0.01$) than paperless learning ($r = 0.51$, $p < 0.01$). Regression analysis showed that the socio-educational environment was the strongest predictor ($\beta = 0.52$, $p < 0.001$), while paperless learning also contributed significantly ($\beta = 0.29$, $p < 0.01$). The study highlights that paperless learning alone is insufficient without teacher guidance, social interaction, and a sustainability-oriented school culture.

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1. INTRODUCTION

The transformation of education in the 21st-century digital era has triggered a fundamental paradigm shift in global learning systems [1], [2], [3]. The integration of information technology is no longer merely a supporting instrument but has become an urgent necessity to address the global sustainability challenges outlined in the Sustainable Development Goals (SDGs), particularly Goals 4 on quality education and 13 on climate

action [4], [5], [6]. Educational institutions are increasingly required to integrate digital competence with sustainability awareness, as technological advancement without environmental responsibility can contribute to ecological degradation and unsustainable consumption patterns. Amid increasingly visible threats of environmental degradation, the world of education is called upon to equip the younger generation with competencies capable of harmonizing technological proficiency with ecological responsibility. Eco-digital literacy emerges as a crucial skill that must be integrated from the primary education level onward to form students who are not only digitally savvy but also deeply aware of environmental sustainability [7], [8].

Conceptually, eco-digital literacy is defined as an individual's ability to use digital technology wisely to understand, analyze, and mitigate environmental impacts [9], [10]. This literacy transcends the technical use of digital devices; it encompasses an ethical understanding of the digital carbon footprint and the ability to use technological platforms to campaign for pro-environmental behaviors. Eco-digital literacy is also closely related to constructivist and socio-cultural learning theories, which emphasize that students develop knowledge, attitudes, and environmental awareness through social interaction, digital experiences, and contextual learning practices [11], [12]. At the primary school level, instilling eco-digital literacy is strategic because students are at a critical developmental stage for forming habits, values, and responsible behavior toward technology and the environment. Early exposure to sustainable digital practices may strengthen long-term ecological awareness and responsible digital citizenship. A proper understanding among students can transform them from mere technology consumers into agents of change capable of leveraging digital innovation to safeguard the earth's ecosystem, an urgency that has become a primary focus of future education in the Society 5.0 era [13]. However, many previous studies on digital learning have tended to be technocentric, focusing mainly on infrastructure and hardware, thereby often overlooking the influence of social variables and school culture in determining the success of sustainable digital literacy. Research conducted by previous scholars primarily examined digital literacy competence, technology acceptance, or environmental education separately, whereas limited studies have explored the integration of socio-educational interaction, sustainable digital practices, and eco-digital literacy simultaneously within primary education contexts.

Paperless learning innovation is one of the concrete manifestations of integrating technology and sustainability in the digital classroom. Through the use of Learning Management Systems (LMS) and other digital devices, the learning process can be carried out efficiently by minimizing the use of physical resources such as paper [14], [15], [16]. This practice not only contributes directly to waste reduction and forest preservation but also provides students with empirical experience of how digital solutions can have a positive impact on nature. Paperless learning creates an adaptive and inclusive learning ecosystem while simultaneously serving as a practical laboratory for the direct development of students' eco-digital literacy [17]. Several recent studies have demonstrated that paperless learning improves digital engagement and resource efficiency; however, these studies have largely focused on higher education and technology adoption, without specifically examining its contribution to the development of eco-digital literacy among primary school students.

Although these three elements (socio-educational environment, paperless learning, and eco-digital literacy) are closely interrelated, current literature still indicates a significant research gap. Most previous studies remain partial, focusing either on the effectiveness of digital technology in isolation or on traditional environmental education, without fully addressing its digital dimension [18], [19]. Studies discussing eco-digital literacy generally emphasize digital competence or environmental awareness separately, whereas limited research examines how socio-educational environments and paperless learning practices jointly contribute to the development of eco-digital literacy among primary school students. Furthermore, research specifically targeting the primary school context as a critical period for character building remains very limited, making it difficult to develop comprehensive educational intervention models. This study, therefore, proposes a conceptual integration of socio-educational support, paperless learning practices, and eco-digital literacy development to strengthen sustainable digital education at the elementary school level.

Given these conditions, this research was conducted to address the existing gap in the literature. This study aims to examine the relationship between the socio-educational environment and eco-digital literacy, and to analyze the extent to which paperless learning practices strengthen eco-digital literacy among primary school students. This study also seeks to provide empirical insight into how social interaction, teacher support, school culture, and sustainable digital learning practices interact in shaping students' eco-digital awareness and behavior. Explicitly, this research is expected to provide a strong empirical basis for the development of advanced learning models that holistically integrate social, technological, and ecological aspects. The findings are expected to contribute theoretically to the development of eco-digital literacy studies and, practically, to serve as a reference for curriculum designers, teachers, and schools in designing sustainable technology-based learning environments at the primary education level.

2. METHOD

This research employs a quantitative, correlational study design to systematically investigate the relationships among the socio-educational environment, paperless learning, and eco-digital literacy. As a cross-sectional study, data collection was conducted at a single point in time to provide a comprehensive overview of current educational conditions for sustainable digital learning practices. This design was specifically chosen to test the strength and direction of relationships among variables, providing an empirical foundation for the development of more comprehensive educational intervention models in the future. The conceptual research model illustrating the relationships between these variables is presented in Figure 1.

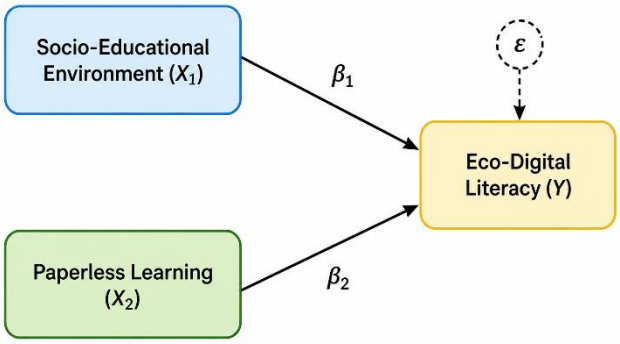

Figure 1. Conceptual research model

As a systematic overview of the research stages, the research flow is presented in Figure 2.

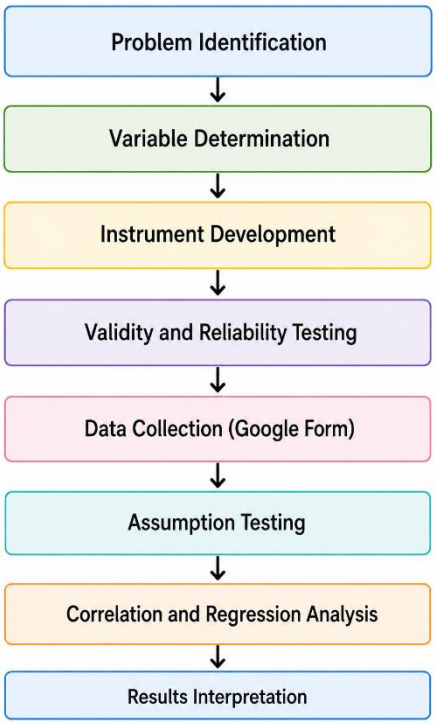

Figure 2. Research flow diagram

The research participants were selected from several digitally integrated primary schools in West Java, Indonesia, that have actively implemented digital-based instruction within their daily learning activities. A purposive sampling technique was used to ensure that respondents met specific inclusion criteria: consistent use of digital learning platforms and active involvement in paperless learning initiatives for at least 1 academic year. The final sample comprised 135 primary school students, a figure deemed sufficient for correlation and regression analyses. Based on methodological standards, a sample size exceeding 100 is generally considered adequate for a preliminary correlational study to achieve sufficient statistical power and minimize the risk of Type II errors [20], [21]. Although the sample was geographically limited, the selected schools represented learning

environments that had already integrated sustainable digital practices into classroom instruction.

Data collection was conducted using a structured questionnaire with a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). This instrument was designed with indicators derived from the latest literature (2020–2025) to ensure contemporary relevance. Questionnaire items were developed through several stages, including literature review, indicator mapping, expert validation, and readability testing adapted to the cognitive characteristics of primary school students. The instrument consisted of 10 items for the socio-educational environment variable, 8 items for paperless learning, and 10 items for eco-digital literacy. Prior to data collection, the questionnaire was piloted on students outside the research sample to ensure clarity of language, comprehension of terminology, and suitability of the statements for elementary school learners. The operationalization of variables in this research is presented in Table 1.

Table 1. Operational Research Variables

Variable	Indicators	Sample Statement
Socio-Educational Environment (X_1)	Teacher support, social interaction, and school culture	My teacher helps me with digital learning
Paperless Learning (X_2)	Use of digital resources, task efficiency, and physical waste reduction	I submit my assignments digitally without paper
Eco-Digital Literacy (Y)	Digital environmental awareness, responsible technology use	I use technology wisely and in an environmentally friendly manner
Variable	Indicators	Sample Statement

To ensure the scientific integrity of the instrument, rigorous validity and reliability tests were conducted. Validity was assessed using the Pearson Product-Moment correlation, ensuring that each item contributed significantly to the measured construct [22]. Reliability was verified through Cronbach's Alpha, with a minimum threshold of 0.70 applied across all variables to confirm internal consistency [23]. The reliability analysis showed that the socio-educational environment variable had a Cronbach’s Alpha of 0.86, paperless learning had 0.82, and eco-digital literacy had 0.88, indicating strong reliability across all constructs. Only items meeting these strict psychometric criteria were included in the final analysis to ensure that the collected data reflected students' actual perceptions of the relationship between digital and ecological aspects.

Data collection was conducted via an online survey platform (Google Forms) to support the paperless theme of the research. Given that the respondents were elementary school students, the questionnaire was administered under the direct supervision of classroom teachers to clarify any terminological ambiguities without influencing students' independence in their responses. Teachers were instructed only to explain unfamiliar vocabulary or technical terms and were not allowed to direct or influence student responses. In addition, several questionnaire statements used simple contextual examples to help students understand the meaning of eco-digital behavior and paperless learning practices. Ethical considerations were prioritized throughout the process; formal approval from the

school administration was obtained, and written informed consent was obtained from parents or guardians. To protect respondent anonymity, no personally identifiable information was collected, and participants were informed of their right to withdraw from the study at any time without penalty.

Data analysis was performed in three distinct stages using SPSS version 27.0 software. First, a preliminary analysis was conducted to verify that the data met parametric testing assumptions, including normality tests (Shapiro-Wilk), linearity tests, and diagnostics for multicollinearity. Pearson correlation analysis was then used to determine the direct relationship between each independent variable and the dependent variable. Finally, regression analysis was applied, including simple linear regression to examine individual influences ($X_1 \rightarrow Y$ and $X_2 \rightarrow Y$) and multiple linear regression to evaluate the simultaneous impact of the socio-educational environment and paperless learning on eco-digital literacy. Statistical significance was set at $p < 0.05$, and the coefficient of determination (R^2) was calculated to assess the extent to which the independent variables could explain the variance in the dependent variable.

Nevertheless, this study acknowledges that the use of self-reported questionnaires among primary school students may potentially produce subjective responses influenced by social desirability and limited self-reflection abilities. Therefore, teacher supervision and readability adaptation were implemented to minimize potential misunderstanding during questionnaire completion. The subsequent steps derived from the analysis results not only provide empirical evidence regarding the relationships between variables but also serve as a conceptual basis for formulating the development direction of digital-based interactive learning media. The findings of this research provide an initial foundation for designing pedagogical interventions aligned with the characteristics of the socio-educational environment and paperless learning practices in elementary schools. The link between the analysis results and the direction of media development is presented in Figure 3.

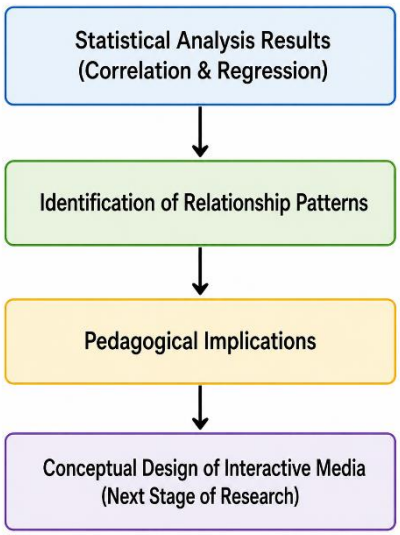

Figure 3. Relationship between analysis results and the direction of interactive media development

3. RESULTS AND DISCUSSION

3.1 Result

This research begins by presenting the descriptive statistical profile of the collected data to provide an overview of the variables studied. Based on the analysis of 135 elementary school student respondents, the Socio-Educational Environment (X_1) variable had a mean of 3.92 (SD = 0.65), indicating that students' perceptions of teacher support, peer interaction, and a sustainability-oriented school culture were categorized as high. This finding suggests that most students already experience a supportive digital learning environment that encourages responsible technology use and environmental awareness. The Paperless Learning (X_2) variable recorded a mean of 3.75 (SD = 0.72), reflecting a fairly intensive adoption of digital platforms through online assignments, digital materials, and electronic classroom communication, although variations among students indicate that the consistency of paperless practices remains uneven across learning contexts. Meanwhile, the dependent variable, Eco-Digital Literacy (Y), had a mean of 3.88 (SD = 0.58), indicating a competent level of digital-based environmental awareness regarding responsible technology use and ecological understanding.

Table 2. Descriptive statistics of research variables

Variable	Minimum	Maximum	Mean	Std. Deviation
Socio-Educational Environment (X_1)	2.50	5.00	3.92	0.65
Paperless Learning (X_2)	2.25	5.00	3.75	0.72
Eco-Digital Literacy (Y)	2.60	5.00	3.88	0.58

Before testing the hypotheses, a series of classical assumption tests was conducted to ensure the validity of the analysis. The Shapiro-Wilk normality test indicated that all variables were normally distributed ($p > 0.05$). The linearity test showed a significant and linear relationship between the independent and dependent variables. Furthermore, the multicollinearity test showed a Variance Inflation Factor (VIF) value below 10 and a Tolerance value above 0.1, ensuring that no multicollinearity issues occurred in this regression model. These findings confirm that the data fulfilled the statistical assumptions required for regression analysis and strengthened the robustness of the analytical model.

A Pearson correlation analysis was performed to assess the strength and direction of relationships among variables. The results show that the Socio-Educational Environment has a strong and significant positive correlation with Eco-Digital Literacy ($r = 0.64$, $p < 0.01$). The correlation coefficient for the socio-educational environment indicates a stronger association than for paperless learning, suggesting that social support factors contribute more substantially to students' eco-digital literacy development. This correlation matrix confirms that increases in social environment factors or paperless innovations tend to be followed by consistent increases in students' eco-digital literacy skills.

Table 3. Correlation matrix between variables

Variable	X_1	X_2	Y
Socio-Educational Environment (X_1)	1.00	0.42**	0.64**
Paperless Learning (X_2)	0.42**	1.00	0.51**
Eco-Digital Literacy (Y)	0.64**	0.51**	1.00
*Note: ** Significance at the 0.01 level*			

The final stage of the analysis is multiple linear regression testing to determine the relative contribution of each predictor. The regression model shows an R^2 value of 0.482, meaning that Socio-Educational Environment and Paperless Learning simultaneously explain 48.2% of the variance in Eco-Digital Literacy. This value indicates moderate explanatory strength, suggesting that nearly half of students' eco-digital literacy can be predicted by the combined contributions of social and technological learning factors. At the same time, the remaining variance may be influenced by external variables not examined in this study. Socio-Educational Environment was found to be the most dominant predictor, with a beta coefficient ($\beta = 0.52$, $p < 0.001$), compared to Paperless Learning ($\beta = 0.29$, $p < 0.01$). These findings highlight that while technology is important, social support remains the primary driving factor in primary education.

Table 4. Results of multiple linear regression analysis

Model	Unstandardized B	Std. Error	Beta (β)	t	Sig.
(Constant)	1.120	0.315		3.556	0.001
Socio-Educational (X_1)	0.465	0.068	0.520	6.838	0.000
Paperless (X_2)	0.235	0.061	0.290	3.852	0.000
R Square = 0.482; F = 61.45; p < 0.001					

To strengthen the presentation of findings, the statistical relationships among variables can also be visualized through bar charts or conceptual path diagrams showing the relative contribution of each predictor to eco-digital literacy. In addition, future analysis may include subgroup comparisons such as gender differences or school categories to provide richer insight into variations in students' eco-digital literacy development.

The main findings of this study show that both independent variables have a positive and significant relationship with students' eco-digital literacy. This model is proven to be strong at predicting students' literacy skills, with the social environment factor having a greater impact than the intensity of paperless device use.

3.2 Discussion

The findings of this study provide crucial empirical evidence that eco-digital literacy in primary schools does not develop in a technological vacuum; rather, it depends heavily on the social ecosystem surrounding students. The dominance of the socio-educational environment variable over paperless learning indicates that the presence of digital devices will be effective only when supported by instructional teacher guidance and a supportive school culture. This phenomenon can be explained through the lens of social constructivism theory, where ecological knowledge is not merely transferred mechanically through screens but is constructed by students through active interaction. Social support creates a Zone of

Proximal Development (ZPD), where dialogues regarding environmental issues mediated by digital devices allow students to build more complex and meaningful ecological understandings. Primary school students are still at the concrete operational stage of development, where they require real behavioral models from educators and peers to internalize sustainability values in their digital activities [24], [25].

The findings also reinforce the multidimensional nature of eco-digital literacy, integrating digital competence, environmental awareness, ethical responsibility, and a sustainable behavioral orientation. Eco-digital literacy, therefore, cannot be interpreted solely as the ability to operate technology, but also as the capacity to evaluate the ecological consequences of digital activities and use technology responsibly within sustainability contexts. The theoretical integration of these results aligns with social cognitive theory, which emphasizes the importance of observational learning within the educational environment. Eco-digital literacy is not merely a technical skill but a form of digital citizenship involving moral and environmental ethical aspects [26], [27]. These findings support the SDG Goal 4 framework, which asserts that the development of human competencies must accompany digital transformation. Without a strong socio-educational environment, the use of paperless technology risks becoming a mechanical activity that fails to cultivate deep ecological awareness.

Compared to previous research, these results reinforce studies stating that teachers' digital skills are the primary catalyst for student literacy [28], [29]. However, this study extends previous findings by demonstrating that the effectiveness of paperless learning is strongly mediated by social interaction and sustainability-oriented school culture rather than by technology exposure alone. There is an interesting discrepancy in the findings, suggesting that technology (gamification) plays a more central role [30]. This difference is likely due to variations in infrastructure, learning culture, and student independence in developing countries, where the role of authority figures, such as teachers, remains highly influential in directing technology use toward productive and ethical purposes. Therefore, the findings suggest that technological innovation without social reinforcement may produce procedural digital engagement but not necessarily meaningful eco-digital literacy development..

The practical implications of these findings are highly relevant to the development of interactive learning media in primary schools. Instructional designers must not focus solely on technical paperless features; they must also integrate social and ecological dimensions into digital learning environments. For instance, the development of learning applications should include collaborative learning spaces, reflective environmental activities, and contextual sustainability tasks that encourage students to connect digital practices with ecological responsibility. A supportive socio-educational environment demands that learning media function interactively rather than merely as one-way information delivery tools. Since social interaction has proven to be the dominant predictor, digital learning media should facilitate collaboration, discussion, peer feedback, and teacher guidance within sustainable learning contexts [31], [32].

At the same time, the findings indicate that paperless learning may also present several limitations that require critical consideration. Increased dependence on digital devices may indirectly contribute to electronic waste, increased energy consumption, and

unequal access to technology among students. Consequently, paperless learning should not be interpreted as automatically environmentally friendly unless accompanied by responsible digital practices and sustainability-oriented educational narratives. This analytical perspective strengthens the argument that eco-digital literacy development requires a balance between technological efficiency and ecological responsibility.

The novelty of this research lies in the identification that paperless learning does not, by itself, significantly increase students' environmental literacy unless it is accompanied by a consistent ecological narrative within the school's social curriculum. The unique contribution of this study is that students often perceive the transition to paperless learning as merely a change in instructional media rather than a sustainability initiative unless schools actively connect digital learning activities with ecological values and environmental reflection. This finding provides a more critical understanding of how sustainability education should be integrated into digital transformation policies in primary education.

While providing important insights, this study is limited by its cross-sectional design, which cannot capture long-term changes in student behavior. The limited sample size in a single region also limits the generalizability of the results to a national scale. Furthermore, this research has not yet included an experimental intervention to test the model's effectiveness directly. Future research should be directed toward developing interactive learning media specifically designed to enhance eco-digital literacy, as well as exploring moderating variables, such as gender and parents' digital literacy levels, through a longitudinal approach. These findings provide empirical support for the vital role of the socio-educational environment and paperless learning in shaping students' eco-digital literacy. This study lays the foundation for future intervention-based research to cultivate a generation that is digitally intelligent while remaining ecologically conscious.

4. CONCLUSION

This study confirms that eco-digital literacy among primary school students is influenced not only by the use of digital technology but also by the socio-educational environment that supports sustainable learning practices. Teacher support, social interaction, and a sustainability-oriented school culture were found to contribute more strongly to the development of eco-digital literacy than paperless learning practices alone, indicating that technological transformation in education requires integrating ecological values and social guidance to create meaningful digital learning experiences. The findings strengthen social constructivism and social cognitive perspectives by positioning eco-digital literacy as a multidimensional construct involving digital competence, environmental awareness, ethical responsibility, and sustainable behavior. The originality of this study lies in emphasizing that paperless learning does not automatically foster environmental literacy unless supported by consistent ecological narratives within the school environment. In practice, the results have implications for teachers, schools, and instructional designers in developing interactive digital learning environments that integrate collaboration, environmental reflection, and responsible digital citizenship. Nevertheless, this study is limited by its cross-sectional design, geographically restricted sample, and reliance on self-reported student perceptions. Future studies are recommended to apply longitudinal or experimental approaches, involve

broader educational contexts, and examine additional variables to strengthen the development of sustainable digital education systems that prepare environmentally responsible and digitally competent future generations.

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