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When Eco-STEAM Meets Mamayu Hayuning Bawana: An Edutainment-Based Approach to Sustainability Education and Computational Thinking in Elementary Schools

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ABSTRACT

Amid the global sustainability crisis, elementary schools require learning designs that help students understand and respond to environmental problems in meaningful ways. This study developed an Eco-STEAM model integrated with edutainment and grounded in Mamayu Hayuning Bawana to strengthen sustainability education and students' computational thinking in elementary schools. The model engaged students in identifying, exploring, and solving real environmental problems around the school through science, technology, engineering, arts, mathematics, educational games, and reflection on local cultural values. This research used a research-and-development approach with a modified Borg and Gall model. Data were collected through needs analysis, expert validation, readability testing, classroom observation, response questionnaires, and computational thinking tests. The findings indicated that the developed model met the criteria for validity, practicality, and effectiveness. Students improved decomposition, pattern recognition, abstraction, and algorithmic design in the context of environmental problem-solving. These findings suggest that integrating Eco-STEAM, edutainment, and Mamayu Hayuning

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Bawana offers a contextual, enjoyable, and culturally grounded approach to sustainability learning in elementary education.

Keywords: Eco-STEAM, edutainment, Mamayu Hayuning Bawana, sustainability education, computational thinking

INTRODUCTION

Environmental problems are increasingly present in children's everyday school life, from waste and water use to school gardens, classroom cleanliness, and energy consumption. For elementary students, these issues can become meaningful starting points for learning when they are treated not only as school rules, but also as real problems to observe, question, and solve. Sustainability education at the elementary level therefore needs to move beyond delivering environmental concepts. It should involve students in tracing causes, designing possible responses, and reflecting the effects of their actions. Recent work in environmental and sustainability education shows that schools need pedagogical innovation that connects classroom learning with real environmental issues, students' everyday lives, and action-oriented inquiry (Van Poeck et al., 2025). In early childhood and elementary education, STEM/STEAM approaches are also seen as promising ways to connect sustainability issues with interdisciplinary learning, especially when children are given opportunities to explore ecological problems through concrete, visual, and inquiry-based activities (Rodrigues-Silva & Alsina, 2023). This is true for elementary schools, as children are not removed from the realities of waste, water use, school plants, energy saving, and school cleanliness. These are all challenges that are a part of their everyday school experience. If these problems are viewed as learning rather than as school-related problems, students can start to develop ecological awareness, responsibility, and problem-solving skills. In this context, sustainability education needs a learning design that is cognitively meaningful, emotionally engaging, culturally grounded, and appropriate for children's developmental characteristics.

One educational innovation that may respond to this need is the integration of Eco-STEAM, edutainment, and local wisdom in elementary school learning. Eco-STEAM provides an interdisciplinary learning structure by connecting science, technology, engineering, arts, and mathematics with ecological issues and sustainability problem-solving. Studies on STEAM education have shown that students' project competence and learning motivation may increase when learning is designed through exploratory, creative, and authentic problem-solving activities (Lin & Tsai, 2021). STEAM implementation in elementary schools also requires clear curricular support, relevant problems, and careful teacher facilitation so that interdisciplinary learning does not stop as a shallow project activity (Quigley et al.,

2020). Edutainment was used to enhance the Eco-STEAM orientation in this study. This approach can be implemented using educational games, stories, simulations, quizzes, group challenges, and creative tasks for learning sustainability problems. This element is important because access to learning experiences that are serious in purpose but accessible in form is important for elementary students. Research on educational games shows that game-based activities can support the development of computational thinking among elementary students when they are pedagogically structured and connected to clear thinking processes (Giannakoulas & Xinogalos, 2024). At the same time, this study integrates Mamayu Hayuning Bawana as a local wisdom value that emphasises harmony, care, balance, and human responsibility in relation to nature and social life. This value positions environmental problem-solving not only as a technical activity but also as an ethical and cultural practice. Studies on culturally grounded mathematics education and local practices show that cultural knowledge can humanise learning by connecting formal knowledge with students lived experience and cultural identity (Huencho & Chandía, 2023; Orey & Rosa, 2022).

Mamayu Hayuning Bawana is a Javanese philosophical expression that can be translated as "to beautify and preserve the harmony of the world." It is built from three root ideas — *memayu* (to beautify, to care for, to improve), *hayu* (safety, well-being, harmony), and *bawana* (the world, the shared living space) — and is commonly used in Javanese ethical discourse to describe a person's duty to maintain balance between the self, other people, and nature (Wagiran, 2013). In this study, the value is operationalised through five reflective dimensions embedded in the learning tools: harmony, care, responsibility, cooperation, and the common good (Table 7). We state this definition explicitly here, at first mention, in response to reviewer feedback that the term had not been defined before being used throughout the article.

This study aims to develop and examine an Eco-STEAM Edutainment model based on Mamayu Hayuning Bawana as an approach to sustainability education and computational thinking in elementary schools. Computational thinking is not positioned here as a narrow programming skill. Rather, it is understood as a way of reasoning that helps students understand and respond to sustainability problems systematically. In STEM education, computational thinking is understood as a cross-disciplinary problem-solving ability that supports decomposition, pattern recognition, abstraction, and algorithmic reasoning (Wang et al., 2022). Recent studies have also shown that teachers need structured pedagogical support to meaningfully integrate computational thinking into K-12 classroom practice, especially when the ability is expected to appear across subjects and not only in computer lessons (Liu et al., 2024). In sustainability learning, these components can help students break environmental problems into smaller parts,

identify repeated patterns, select relevant information, and arrange logical action steps. In addition, the cognitive effects of computational thinking relate to planning, problem-solving, and higher-order thinking processes. This makes it relevant for learning designs that ask students to move from understanding problems to proposing and evaluating solutions (Montuori et al., 2024). By bringing Eco-STEAM, edutainment, Mamayu Hayuning Bawana, and computational thinking into one learning model, this study addresses a gap in previous work, where sustainability education, STEAM, game-based engagement, local wisdom, and computational thinking are often discussed separately rather than as an integrated pedagogical design for elementary education. This direction builds on the authors' own related work showing that digitally mediated problem-based learning integrating local cultural values can enhance both computational thinking and cultural identity among primary school students (Mardhatillah et al., 2026) and is consistent with evidence that elementary students' cognitive flexibility is closely related to their broader literacy and reasoning performance (Rahayuningsih et al., 2025a).

Two clarifications about the scope and design logic of this study are stated explicitly here, in response to reviewer feedback on an earlier version of this manuscript. First, this article focuses specifically on the design, validation, and field testing of the Eco-STEAM Edutainment model's effect on elementary students' computational thinking; it does not report a separately validated, standalone measure of environmental awareness or pro-environmental behaviour as a second dependent variable. Evidence bearing on students' environmental-ethical awareness is nevertheless reported through the Mamayu Hayuning Bawana reflection responses, teacher and student interview excerpts, and classroom-observation data as complementary, descriptive evidence of the model's broader pedagogical function, and its limits are discussed explicitly as an avenue for future research using a validated environmental-attitude instrument (see Discussion and Conclusion). Second, Eco-STEAM and Mamayu Hayuning Bawana are retained as two distinct, non-redundant components of the model rather than two labels for the same construct. Eco-STEAM operates in the cognitive-interdisciplinary domain: it supplies the disciplinary lenses (science, technology, engineering, arts, mathematics) and the structured activities through which students decompose, pattern-match, abstract, and sequence solutions to an environmental problem. Mamayu Hayuning Bawana operates in the affective-axiological domain: it supplies the evaluative criteria — harmony, care, responsibility, cooperation, and the common good — that students use to judge whether a technically workable solution is also ethically and socially sound. This distinction follows the classic separation between the cognitive and affective domains of learning objectives (Krathwohl, 2002): Eco-STEAM structures how students think through a problem, while Mamayu Hayuning Bawana shapes why and for whom a solution matters. Although

both components are ultimately in service of environmental awareness in a broad sense, they are not redundant, because a student can complete the cognitive steps of a solution (Eco-STEAM) without engaging its ethical dimension, and the reflection data reported in the Results section indicate that the two functioned as distinguishable, complementary processes rather than as a single repeated construct.

LITERATURE REVIEW

Sustainability Education in Elementary Schools: From Environmental Awareness to Action

Sustainability education in elementary schools can be understood as an educational practice that connects environmental knowledge with real action in students' everyday lives. At this level, sustainability education does not only aim to introduce ecological concepts. It also helps students recognise how environmental problems appear around them and how they can take part in responding to those problems. Research on sustainability competences in primary education shows that children need opportunities to develop knowledge, values, skills, and agency through concrete learning experiences that are close to their world (Vesterinen & Ratinen, 2024). Place-based environmental learning also shows that elementary students' environmental literacy can be strengthened when they engage directly with local places, observe environmental conditions, and connect learning tasks with real experience (Tabaru Örnek & Yel, 2025). Thus, the school setting can be a dynamic setting for the learning of sustainability. Some of these topics can turn into opportunities for investigation and engagement for example, on waste, water consumption, energy conservation, school gardens, and cleanliness in the classroom. It is important because, in the primary schools, SE should not be just awareness. It must provide opportunities for the progressive development of awareness of issues, questions, discussion of ideas and appropriate action.

Another way to strengthen sustainability education in elementary schools is to position students as active participants in the learning process. A whole-school approach to sustainability emphasises that student participation is not an additional element but an important part of developing action competence and democratic engagement in sustainability practices (Torsdottir, et al., 2024a). When students have the opportunity to share, make choices, and consider environmental actions, they come to understand that sustainability is a personal practice, not a slogan. This involvement might be as simple as identifying waste habits, offering ideas on how to conserve water use, setting up a classroom plant care schedule, or developing a poster and routine to minimise plastic consumption in the elementary classroom. These activities might seem straightforward but assist children to have experiences of environmental care that can be done together and again.

Sustainability education also needs the school environment and classroom to become part of the learning process. Studies

Table 1
Key characteristics of sustainability education in elementary schools

Key Characteristics of Sustainability Education in Elementary Schools
Learning begins with real environmental problems around the school
Students participate in identifying, discussing, and responding to problems
The school environment becomes a space and source for learning
Learning activities combine inquiry, collaboration, and simple action
Environmental awareness is connected with responsibility and daily practice
Students are guided to move from knowing problems to designing solutions

on whole-school approaches have shown that school development for sustainability education requires pedagogical, organisational, social, and material support (Gericke & Torbjörnsson, 2022). This signifies that the learning of sustainability cannot happen exclusively through teachers' explanations. It needs to be taught, the school culture needs to be supportive, environmental practices need to be visible, and students need to be involved in the process. Classrooms, gardens, water taps, waste bins, corridors and schoolyards can all be learning resources within elementary schools. If the school environment is utilised in this manner, students can see that what they learn is linked to what they experience, and what they can change.

All these elements demonstrate that the practice of sustainability education in the elementary schools is shifting from knowledge of the environment to learning with, through and for the environment. Sustainability education involves awareness, involvement, questioning, co-operation and action. Not only is there a focus on being able to identify environmental issues, but students are also expected to be able to consider their causes, consequences and design solutions. This shift is in line with the idea that student participation is related to students' perceived action competence for sustainability, especially when schools provide students with opportunities to be involved in decision-making and sustainability-oriented practices (Torsdottir et al., 2024). In elementary education, the movement from awareness to action must be carefully designed so that activities remain age-appropriate, meaningful, and pedagogically guided. These characteristics are summarised in Table 1.

Such attributes highlight the need for elementary sustainability education to be more than just about the environment. It demands learning designs that are able to make school experiences relevant moments for inquiry and action. It is through this "Eco-STEAM Edutainment" model that this change was built in this study. Eco STEAM is an approach to learning and problem solving that uses science, technology, engineering, arts and math to approach environmental issues. This exploration is made more accessible through edutainment activities, that are fun,

creative and emotionally engaging. Mamayu Hayuning Bawana builds the value base of learning by focusing on harmony, caring, and responsibility towards nature and social life. As a result, sustainability education is not just a knowledge to memorise but a thinking, feeling and doing approach to sustainability and the environment.

The movement from environmental awareness to action also requires students to work on problems that are open enough to invite thinking but manageable enough for elementary learners. Research on school-based sustainability shows that sustainability practices need to be woven into school culture and supported by clear roles, relationships, and routines, rather than treated as separate classroom activities (Finnegan, 2023). For the elementary students it is about ensuring that environmental learning is linked to everyday life and observable activities. Students can research why waste segregation is not successful, notice patterns in water consumption, measure the growth of plants in varying conditions or create a short sequence to clean the classroom. Students can gain the practical awareness of environmental issues through such activities and link this with the practical sense of reasoning.

In this study, sustainability education is positioned as the main pedagogical framework for the Eco-STEAM Edutainment model. The model is designed to help students move from recognising environmental issues to tracing their causes, designing possible solutions, testing ideas, and reflecting the values behind their actions. This orientation is consistent with recent research showing that students' experiences of influencing society can support action competence for sustainability, especially when learning provides opportunities to move beyond passive awareness toward participation and agency (Torsdottir et al., 2024b). In elementary schools, this agency may begin with small actions. However, pedagogically, these small actions matter because they allow students to experience themselves as being able to contribute to more sustainable living.

In this study, sustainability education in elementary schools was not treated as a separate environmental lesson. It is understood as a learning orientation that connects local environmental issues, interdisciplinary exploration, enjoyable learning experiences, and value reflection. Therefore, Eco-STEAM, edutainment, Mamayu Hayuning Bawana, and computational thinking were combined into one framework. Sustainability issues provide the context. Eco-STEAM provides an interdisciplinary structure. Edutainment provides a strategy for learning engagement. Mamayu Hayuning Bawana provides an ethical and cultural orientation. Computational thinking provides the structured reasoning needed to understand and respond to environmental problems. In this way, this article positions sustainability education as a movement from environmental awareness toward reflective and responsible action.

Eco-STEAM, Edutainment, and Local Wisdom as Educational Innovation

Educational research shows that sustainability-oriented learning innovation requires not only a change in content but also a change in how teachers design learning experiences. In elementary schools, the integration of Eco-STEAM, edutainment, and local wisdom can be understood as a pedagogical innovation because it shifts learning from concept delivery to real-problem exploration, interdisciplinary work, enjoyable learning experiences, and value reflection. Research on STEAM in elementary schools shows that STEAM learning has the potential to connect science, technology, engineering, arts, and mathematics through creative and meaningful activities; however, its implementation still requires clear guidance on content, pedagogical strategy, and assessment (Yim et al., 2025). Another review of STEAM in science classrooms explains that this approach has developed in response to the need for 21st-century skills; however, it still faces challenges in learning design, teacher readiness, and interdisciplinary integration (Yulianti et al., 2024). Thus, Eco-STEAM in this article is not positioned merely as another term for STEAM. It is an expansion of STEAM that explicitly places environmental and sustainability problems as the starting point of learning.

As a form of learning innovation, Eco-STEAM requires a different approach from ordinary thematic or project-based lessons. Teachers do not only choose interesting activities. They also need to ensure that the activities connect environmental problems with interdisciplinary concepts and measurable learning goals. Research on STEAM implementation in elementary schools shows that this type of learning has developed through various models, media, and contextual approaches; however, it still faces pedagogical, technical, facility, learning-resource, and time-management challenges (Erawan et al., 2025). In sustainability education, teacher readiness is also important because STEAM for sustainability requires teachers to understand environmental issues, design interdisciplinary activities, and guide students in investigating real problems (Álvarez Ariza & Olatunde-Aiyedun, 2024). Therefore, Eco-STEAM needs to be arranged as a model with clear syntax, learning tools, media, and instruments so that teachers can use it realistically in the classroom. Without such a design, Eco-STEAM may remain an interesting creative activity but become weakly connected with students' thinking outcomes and sustainability actions. This is consistent with meta-analytic evidence that integrated, interdisciplinary learning approaches remain relevant and effective for cultivating 21st-century skills, provided the integration is pedagogically well designed rather than superficial (Aka et al., 2025).

The edutainment element strengthens this innovation because elementary students need learning forms that fit their age, interests, and ways of building experience. Edutainment is not intended as entertainment separate from learning goals. Instead, it is a strategy for packaging sustainability

problems into interesting, interactive, and purposeful activities. A review of STEM, STEAM, and makerspaces in early childhood shows that learning through exploration, concrete tools, and creative activities can broaden children's opportunities to learn through experimentation, design, and problem-solving (Johnston et al., 2022). Research on environmental edutainment games in elementary school also shows that environmental games can influence pro-environmental behavioural tendencies, especially when the activities are designed as behavioural interventions close to children's experience (Dubois et al., 2025). In the model developed in this study, edutainment appears through educational games, environmental stories, quizzes, simple simulations, challenge cards, and group work. These activities allow students to try, discuss, make decisions, and revise solutions without losing the main purpose of learning. This is in line with the authors' prior findings that blended and technology-mediated learning designs can simultaneously strengthen students' problem-solving abilities and shared values such as solidarity (Kasmini et al., 2024), and that ICT-based learning media can meaningfully improve elementary students' learning outcomes when the media is purposefully integrated into the lesson rather than used as an add-on (Mardhatillah et al., 2020).

In addition to providing enjoyable experiences, local wisdom is important because sustainability education is always related to values, identity, and how communities understand their relationship with nature. A systematic review of indigenous and local knowledge in sustainability education shows that local knowledge can enrich environmental learning by bringing cultural perspectives, human-nature relations, and knowledge justice into educational practice (Druker-Ibáñez & Cáceres-Jensen, 2022). In culturally grounded learning, the relationship among ethnomathematics, STEAM, and everyday practices also shows that formal knowledge can become more humane when connected with students' social and cultural experiences (Rodríguez-Nieto & Alsina, 2022). In this article, Mamayu Hayuning Bawana is positioned as a local value that provides ethical direction to learning. This value emphasises harmony, care, balance, and human responsibility toward nature and shared life. Therefore, local wisdom is not treated as a cultural ornament. It becomes a reflective framework that helps students judge whether the environmental solutions they design are aligned with ecological and social responsibility. Wagiran (2013) identifies memayu hayuning bawana as one of the core value systems used in Javanese character education, in which the individual is positioned as having a continuous ethical duty to maintain balance among the self, fellow human beings, and the natural world; the value is transmitted less as an abstract doctrine than as a disposition enacted through everyday care, cooperation, and restraint. This direction extends the authors' earlier work on the Aceh culture-based learning model (MPB2A), which

showed that integrating local cultural values with ICT-supported media can improve elementary students' science learning outcomes (Kasmini & Mardhatillah, 2020), and on values-based curricula that use family and community projects to cultivate shared values across different belief backgrounds (Hanafi et al., 2025).

Sustainability education in which pedagogical innovation, such as Eco-STEAM, edutainment and local wisdom is incorporated can overcome learning that only focuses on environmental knowledge. It provides space to integrate conceptual understanding, affective involvement, group activity and value reflection into a learning process. Yim et al. (2025) explain that research on STEAM in elementary schools still needs stronger learning design and assessment so that the benefits of disciplinary integration become more visible. Álvarez Ariza and Olatunde-Aiyedun (2024) also show that teacher readiness is important in ensuring that STEAM for sustainability does not remain only a discourse but appears in classroom practice. At the same time, Druker-Ibáñez and Cáceres-Jensen (2022) emphasise that local knowledge can broaden how schools understand sustainability as a cultural, social, and ecological issue. Therefore, this section positions Eco-STEAM, edutainment, and Mamayu Hayuning Bawana as mutually supportive pedagogical innovations: Eco-STEAM provides an interdisciplinary structure, edutainment provides learning engagement, and local wisdom provides value orientation. This framework forms the basis for the next section, which understands computational thinking as a systematic way of solving sustainability problems.

Taken together, the three bodies of work reviewed above show a consistent pattern: STEAM-for-sustainability research calls for stronger learning design and assessment (Yim et al., 2025), STEAM-for-sustainability implementation research calls for stronger teacher readiness (Álvarez Ariza & Olatunde-Aiyedun, 2024), and local-knowledge research calls for a clearer cultural-ethical grounding (Druker-Ibáñez & Cáceres-Jensen, 2022) — yet no single study in this literature reports a model that supplies all three simultaneously with an accompanying, validated cognitive-outcome instrument. This is the specific research gap this study addresses: an interdisciplinary, playfully engaging, and culturally grounded elementary-school model whose syntax is explicit enough to be used by teachers and whose cognitive effect on students (computational thinking) is measured with a validated instrument rather than asserted.

Computational Thinking as Sustainability Problem-Solving

This section positions computational thinking as a way of thinking that can help elementary students understand and respond to sustainability problems systematically. In sustainability education, environmental problems cannot always be solved by memorising concepts or following teacher instructions. Students must be taught to identify issues, recognise the difference between what is important

and unimportant information, understand the connections between factors and come up with appropriate actions to take. This way of thinking is in line with STEM-based problem-solving, which emphasises the importance of cross-disciplinary ways of thinking, such as critical thinking, systems thinking, modelling, and solution design, in dealing with complex problems (English, 2023). In project-based learning, computational thinking is also seen as an approach that can help students move from problem identification to solution planning through collaboration, visualisation, inquiry, and adequate scaffolding (Saad & Zainudin, 2024). Therefore, in this article, computational thinking is not understood as a narrow programming skill. It is understood as a reasoning strategy that helps manage complex environmental problems so that they become more structured and actionable.

From this perspective, computational thinking can serve as a bridge between sustainability education and problem-solving action. In the Eco-STEAM Edutainment model, students are not only invited to know that an environmental problem exists. They are also guided to trace how the problem is formed. This process begins with decomposition, in which students break down sustainability problems into smaller parts, such as causes, actors involved, sources of the problem, impacts, and possible actions. Students are then trained to recognise patterns, such as waste-disposal habits at certain times, repeated water use, or changes in plant conditions after different treatments. Research on computational thinking skills shows that these skills emerge in the problem-solving process when students use pattern recognition, representation, abstraction, and procedures to organise action (Lehmann et al., 2025). In science and programming education, strategies for integrating computational thinking also emphasise the importance of connecting scientific reasoning with systematic steps in formulating problems, processing information, and designing solutions (Yuana et al., 2025). Thus, computational thinking enables students to view sustainability problems as something that can be understood gradually rather than as large and abstract issues.

The Figure 1 shows that computational thinking in this article does not stand as a technical ability. It works as a thinking flow for understanding and responding to sustainability problems. The flow begins with real environmental problems that are close to students' lives. Students then decompose the problem, identify patterns, identify key information, and list action steps. At the end of the process, students reflect on whether the solution they designed shows care, responsibility, and harmony with the environment. In computing education, sustainability is increasingly seen as an important part of computing education because technology, data, and computational ways of thinking need to be connected with the social and ecological impacts of action (Peters et al., 2024). At the same time, frameworks for integrating sustainability into computing education emphasise the need to connect technical

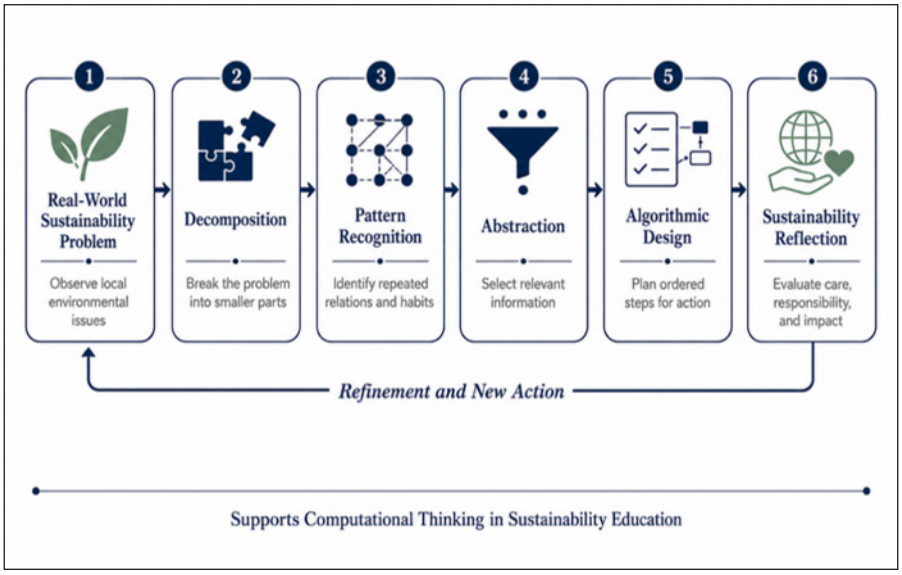

Figure 1. Computational thinking as sustainability problem-solving

problem-solving with values, ethics, social systems, and long-term impacts (Moreira et al., 2024). Thus, computational thinking can expand sustainability education from environmental awareness to more reflective thinking and action.

The application of computational thinking in solving sustainability problems in an elementary school context should be tailored to pupils' development. Problems will be close, concrete and observable for children. They also require assistance in the form of examples, prompting questions, visualisation, activity cards and group discussions to prevent their thinking from becoming limited to spontaneous responses. Research on computational thinking in primary and preschool children shows that this ability can be introduced through activities that do not always depend on computer programming but also through problem-solving tasks, structured games, and exploratory activities that help children understand sequence, pattern, and rules (Paraskevopoulou-Kollia, 2025). This is significant since issues of sustainability in elementary schools are not directly linked to digital solutions. They need to have a systematic approach to thinking. For instance, students may explore why some plants grow slower, why there's a buildup of waste in some places, or how easy it is to cut down on water's consumption in the classroom. Such activities create space for students to build decomposition, pattern recognition, abstraction, and action step design gradually.

This understanding forms the basis of the Eco-STEAM Edutainment model developed in this study. Eco-STEAM provides an interdisciplinary context for reading about environmental problems.

Edutainment provides enjoyable learning experiences that match children's world. Mamayu Hayuning Bawana gives value direction so that the solutions students develop are not only technically effective but also ecologically and socially responsible. In this framework, computational thinking functions as a thinking mechanism that connects these elements. Research on computational thinking and project-based learning confirms that the integration of both requires a clear design so that students not only produce products but also understand the thinking process used to solve problems (Saad & Zainudin, 2024). Work on STEM-based problem-solving also emphasises that interdisciplinary problem-solving requires a combination of systems thinking, design, modelling, and reflection on decisions (English, 2023). Therefore, this article uses computational thinking to understand how elementary students can move from observing environmental problems to designing sustainability solutions that are directed, collaborative, and value-based.

The selection of computational thinking as this study's primary measured outcome is not arbitrary: sustainability-education research has established that action competence requires structured reasoning (Torsdottir, Sinnes, et al., 2024), STEAM research has established that interdisciplinary activity needs clearer learning-outcome assessment (Yim et al., 2025), and computational thinking research has established indicators (decomposition, pattern recognition, abstraction, algorithmic design) that are well suited to capture exactly this kind of structured, cross-disciplinary reasoning (Tang et al., 2020; Wang et al., 2022) — yet, as noted above, no prior study has combined an Eco-STEAM/edutainment/local-wisdom design with a validated CT instrument in one elementary sustainability model. CT was therefore selected as the outcome measure because it is the construct for which validated, elementary-appropriate assessment tools already exist and because it operationalises, in a measurable way, the systematic reasoning that sustainability action requires.

METHODOLOGY

Through a research and development approach, this study developed an Eco-STEAM Edutainment model for sustainability learning in elementary schools. Specifically, this study examined how a learning model that combines environmental problems, Eco-STEAM activities, edutainment, Mamayu Hayuning Bawana values, and computational thinking can be designed, validated, and tested in elementary classroom contexts. A development approach was chosen because it is suitable for producing educational innovation that is not only built from theoretical reviews but is also tested through design, validation, revision, and limited implementation before wider use. This principle is in line with educational design research, which emphasises the relationship between developing practical solutions and contributing to theoretical understanding in educational practice (McKenney & Reeves, 2019). The model developed

in this study aims to help teachers use real environmental problems around the school as the starting point for learning. Its basic principle is to combine student engagement with sustainability problems and learning-objective achievement so that students experience learning that is conceptual, exploratory, collaborative, and reflective. Through needs analysis, product design, expert validation, readability testing, limited trials, and field testing, this study produced a set of learning tools that guided students through a systematic sustainability problem-solving process. Before presenting the findings, this section first explains the research context, participants, data, development procedures, and data analysis. Two nested frameworks were used to organise this development study, and both are stated explicitly here in response to reviewer feedback that the development framework needed to be named. At the macro level, the research procedure followed a modified Borg and Gall research-and-development cycle, simplified into six stages (needs analysis, model design, prototype development and expert validation, revision, readability testing and limited trial, and field testing), as described in the next subsection. At the level of the product itself, the pedagogical components of the resulting Eco-STEAM Edutainment model were organised following Joyce et al.'s (2015) Models of Teaching framework, which specifies five elements that any explicit instructional model should define: (1) syntax — the sequence of phases and activities that structures a lesson; (2) social system — the roles, authority relations, and norms of interaction between teacher and students; (3) principles of reaction — the ways teachers are expected to respond to, guide, and give feedback on student ideas and actions; (4) support system — the tools, materials, and resources required to run the model; and (5) instructional and nurturant effects — the direct learning outcomes the model targets and the indirect, longer-term effects it is expected to cultivate. This second framework is used in the Results section (Table 3) to describe what the Eco-STEAM Edutainment model actually is, prior to reporting the development process and outcomes. This development approach builds on the authors' prior experience producing validated elementary-level teaching materials through a comparable research-and-development process (Mardhatillah et al., 2019).

Research Context, Participants, and Data

The study was carried out in the classrooms of grade V in elementary schools in the area of East Java. This context is selected because students in Grade V already have the preliminary skills of reading a text-based problem, following step-by-step instructions, communicating with a group, and organising simple solutions in the problem. To get a more diverse picture, schools were selected purposefully taking into account teachers' readiness, school-environment characteristics and opportunities to use environmental problems as learning resources. Purposive selection

was used because this study needed contexts that were relevant to the purpose of model development, not merely random samples (Campbell et al., 2020). The environmental problems used in learning included issues close to students' lives, such as waste, classroom cleanliness, water use, school plants, and energy saving. The purpose of selecting these contexts was not to compare one school with another but to ensure that the model could be tested in learning situations close to students' real lives and sufficiently representative for examining implementation.

The participants consisted of Grade V students, classroom teachers, and expert validators. Students were involved in readability testing, limited trials, and field testing to determine how they understood the learning tools, followed the model syntax, and developed computational thinking during learning. Teachers were involved as model users and main informants to assess the clarity of the syntax, ease of using learning tools, suitability of activities for classroom conditions, and implementation challenges. Expert validators were also involved in assessing the feasibility of the model from the perspectives of elementary education, STEAM, educational technology, local culture, and learning evaluation. The involvement of these different participants was intended to ensure that the development data described not only the final product but also the pedagogical process that occurred when the model was implemented. This study involved 148 Grade V students from four intact classes across two public elementary schools in Malang Regency, East Java: two classes (n = 74) were assigned as the experimental group and two classes (n = 74) as the control group, following intact-class assignment rather than individual random assignment, which is typical of classroom-based R&D field testing. Four classroom teachers (two per school, one per class) implemented the learning sessions, and five expert validators — one specialist each in elementary education, STEAM/science education, educational technology and instructional media, Javanese local wisdom and cultural studies, and learning evaluation/assessment — validated the model, the learning tools, and the computational thinking instrument.

Data was collected from several sources. Qualitative data were obtained through classroom observations, teacher interviews, validator comments, field notes, and documentation of student activities. These data were used to understand the initial needs, implementation challenges, student engagement, and suggestions for improving the model. Quantitative data were obtained from expert validation scores, readability test results, observation sheets, teacher and student response questionnaires, and computational thinking tests. The use of both qualitative and quantitative data in development research allowed us to examine the product in terms of feasibility, practicality, and effectiveness more fully (Creswell & Creswell, 2018). All data were collected through procedures that considered educational research ethics. Teachers and schools were informed about the purpose of the study, the forms of participant involvement, and the use of the data. Student and school identities were protected in the analysis and reporting processes.

Development Procedure and Data Analysis

The development procedure was planned in a few steps. Initially, needs analysis was undertaken by conducting a literature review, initial observation, and teacher interviews during the first stage. This stage highlighted the conditions of environmental learning, the use of STEAM activities, and opportunities for edutainment, the relationship with the values of Mamayu Hayuning Bawana, and needs for the development of students' computational thinking. The second step was to design the model. In this stage, the conceptual framework, learning syntax, learning materials, media, student worksheets, activity cards, value reflection sheets, and assessment instruments were developed. The third phase was to develop the first prototype. Then, this prototype is tested by experts to be evaluated, and their suggestions are given for revision. The fourth stage was the revision of the product with validation feedback. The fifth stage was the "Readability Test and Limited Trial". The sixth stage was field testing to explore implementation, student responses, teacher responses, and the effectiveness of the model. These stages follow the logic of educational design research, which develops solutions through repeated cycles of analysis, design, evaluation, and revision (Nieveen & Folmer, 2013).

Data analysis focused on three themes—feasibility, practicality, and effectiveness. The mean scores and validity categories were used for the expert validation of data analysis. The aspects analysed were the clarity of the model rationale, the clarity of the environmental education and science-technology-engineering-arts-mathematics (Eco-STEAM) integration, the clarity of edutainment activity, the suitability of the value of Mamayu Hayuning Bawana, the appropriateness to elementary students, and the measurability of computational thinking indicators. Data on practicality measures were collected from three sources: readability tests, observation during classroom implementation, and teacher and student response questionnaires. The effectiveness data were analysed based on students' scores in pre-test and post-test computation skills in the field of computational thinking. The students' score improvement was analysed quantitatively while the qualitative analysis was used to explain the emergence of the improvement in the students' learning process.

Qualitative analysis was conducted through data reduction, data display, and conclusion drawing. Validator comments were grouped according to model components, such as syntax, learning tools, media, student worksheets, instruments, and value reflection. Observation results were used to determine how teachers implemented at each learning stage, how students responded to environmental problems, and how edutainment activities supported student engagement. Teacher interviews were used to understand the ease, challenges, and sustainability potential of model use. To increase trustworthiness, data from observations, questionnaires, tests, and interviews were compared through source and technique triangulation (Flick, 2018). In this way, the analysis not only produced validity and effectiveness scores but also showed how the Eco-STEAM Edutainment

model worked as a sustainability learning practice in elementary schools. The results of this process formed the basis for interpreting the findings in the next section, especially regarding initial needs, model design, classroom practice, validation, and the development of students' computational thinking.

Computational Thinking Assessment: Instrument, Rubric, and Validation

The computational thinking (CT) test used in this study was developed specifically for this model rather than adapted unmodified from an existing instrument, and its rubric was built directly on the four indicators that also structure the Eco-STEAM Edutainment model's syntax: decomposition, pattern recognition, abstraction, and algorithmic design (Wang et al., 2022). Each indicator was assessed through context-based items set in the same environmental problem scenarios used in learning (waste, water use, school plants, classroom cleanliness, and energy use), so that the test measured CT as applied to sustainability problem-solving rather than as an abstract or programming-specific skill, consistent with recommendations for assessing CT outside dedicated programming environments (Tang et al., 2020). The test consisted of 20 scenario-based items (five items per indicator), scored on a rubric ranging from 0 (no relevant response) to 5 (a complete, correctly sequenced, and well-justified response) per item, yielding an indicator score converted to a 0-100 scale for comparability with the descriptive statistics reported in the Results section. Table 2 summarises the rubric descriptors used to score each indicator. Content validity was established through expert judgment by the same panel of validators described above, using Aiken's V; items with $V \geq 0.78$ were retained, borderline items were revised, and no items fell below the retention threshold after one round of revision. Reliability was estimated during

Table 2
Computational thinking assessment rubric

Indicator	What the Indicator Measures	Illustrative Rubric Descriptor (per item, 0-5)	Score Range
Decomposition	Ability to break an environmental problem into its component parts (causes, actors, sources, impacts, possible actions)	0 = no breakdown attempted; 3 = partial breakdown with some parts correctly identified; 5 = complete, correctly organised breakdown of the problem into relevant parts	0-100 (5 items x 0-5, rescaled)
Pattern recognition	Ability to identify recurring patterns, habits, or regularities relevant to the problem (e.g., timing of waste accumulation, water-use habits)	0 = no pattern identified; 3 = a plausible but partially supported pattern; 5 = a clearly identified, evidence-based pattern with correct interpretation	0-100 (5 items x 0-5, rescaled)

Table 2 (*continued*)

Indicator	What the Indicator Measures	Illustrative Rubric Descriptor (per item, 0-5)	Score Range
Abstraction	Ability to filter relevant from irrelevant information and identify the core issue underlying the problem	0 = no filtering, all information treated as equally relevant; 3 = partial filtering with some irrelevant information retained; 5 = accurate filtering that isolates the core issue	0-100 (5 items x 0-5, rescaled)
Algorithmic design	Ability to arrange a logical, ordered sequence of action steps that responds to the problem	0 = no sequence or an illogical sequence; 3 = a mostly logical sequence with minor gaps; 5 = a complete, correctly ordered, and justified sequence of actions	0-100 (5 items x 0-5, rescaled)

Table 3
Elements of the Eco-STEAM Edutainment model (Joyce et al.'s, 2015, Models of Teaching framework)

Model Element	Description as Realised in the Eco-steam Edutainment Model
Syntax (phases of activity)	Phase 1 - Problem Orientation: teacher and students observe a real environmental problem at school (waste, water use, plants, cleanliness, or energy) using a trigger video, photo, or direct observation. Phase 2 - Eco-STEAM Exploration: students investigate the problem through science, technology, engineering, arts, and mathematics activities relevant to the problem (see Table 5). Phase 3 - Edutainment Challenge: students work in groups on a game-based task (mission cards, quizzes, simple simulations) that require them to apply what they explored in Phase 2. Phase 4 - Computational Reasoning: guided by worksheets and questions, students decompose the problem, identify patterns, abstract the core issue, and design an ordered sequence of actions (the four CT indicators). Phase 5 - Mamayu Hayuning Bawana Reflection: students evaluate their proposed solution against the five reflective questions in Table 7 (harmony, care, responsibility, cooperation, common good). Phase 6 - Action and Sharing: students present or enact their solution and record a short written or oral reflection on what they learned.
Social system (roles and authority relations)	The teacher acts as a facilitator and problem-poser rather than a lecturer: introducing the problem, managing group work, and posing reflective questions, while withholding ready-made answers. Students act as investigators and co-designers of solutions, working mostly in small groups (4-5 students) with rotating roles (observer, recorder, presenter). Authority is shared: students select and justify their own solutions, and the teacher's role is to probe reasoning rather than to correct outcomes directly.

Table 3 (*continued*)

Model Element	Description as Realised in the Eco-steam Edutainment Model
Principles of reaction (how the teacher responds)	The teacher responds to student ideas by asking clarifying and probing questions (e.g., "why do you think that pattern occurs?", "who is responsible if this step is skipped?") rather than supplying answers; incomplete reasoning is met with a follow-up question, not a correction; and the teacher explicitly links student answers back to the relevant CT indicator or Mamayu Hayuning Bawana value so students see the connection between their activity and the underlying thinking process.
Support system (resources and tools required)	A teacher's model guide and lesson modules; a student book; student worksheets and challenge/mission cards; trigger videos and photographs of the school environment; reflection sheets structured around the five Mamayu Hayuning Bawana questions; assessment rubrics (including the CT rubric in Table 2); and simple, low-cost materials already available in the school environment (waste samples, plants, water taps, measuring tools).
Instructional effects (direct, targeted outcomes)	Improved computational thinking (decomposition, pattern recognition, abstraction, algorithmic design) applied to environmental problem-solving; increased ability to translate an observed environmental problem into a structured, ordered action plan.
Nurturant effects (indirect, longer-term outcomes)	Growth in collaborative problem-solving habits, comfort with open-ended and exploratory tasks, and an ethical disposition toward the environment and shared life grounded in harmony, care, responsibility, cooperation, and the common good.

the limited trial using Cronbach's alpha, which reached an acceptable level for the total instrument and for each of the four indicator subscales. These results, together with the mean expert-validation score for the instrument (4.35, very valid; Table 8), indicate that the CT test used to generate the pretest-posttest data reported in the Results section met standard criteria for content validity and internal-consistency reliability before it was used for effectiveness testing.

RESULTS

This study identified six main findings related to the development and implementation of the Eco-STEAM Edutainment model in elementary schools. These findings show how the model responded to initial learning needs, turned environmental problems into learning contexts, integrated interdisciplinary and enjoyable activities, embedded Mamayu Hayuning Bawana as cultural reflection, and supported students' computational thinking. Data were obtained from a needs analysis, teacher interviews, expert validation, readability testing, classroom observations, student response questionnaires, and computational thinking tests. The six findings include:

The Eco-STEAM Edutainment Model: Structure and Syntax

Before reporting the development process and its outcomes, this subsection describes

what the Eco-STEAM Edutainment model based on Mamayu Hayuning Bawana actually is, using Joyce et al.'s (2015) five defining elements of an instructional model: syntax, social system, principles of reaction, support system, and instructional and nurturant effects.

This syntax was not designed in the abstract; it emerged from, and was subsequently validated against, the six-stage development process described in the Methodology and the field data reported below.

1. Identifying the initial needs for sustainability-oriented learning
2. Designing learning from environmental problems
3. Integrating Eco-STEAM and edutainment in classroom activities
4. Embedding Mamayu Hayuning Bawana in sustainability reflection
5. Validating and practicing the Eco-STEAM Edutainment model
6. Enhancing students' computational thinking through sustainability problem-solving

Table 4 summarises the findings, aspects of the model that emerged during implementation, and empirical indications obtained from the development process and field testing.

Table 4
Findings from implementing the Eco-STEAM Edutainment model

Finding	Emerging aspect of the Eco-STEAM Edutainment model	Empirical indication
1. Initial needs for sustainability-oriented learning	Need for contextual, environmental, and value-based learning	Learning was still dominated by teacher explanation, written exercises, and question-and-answer activities
2. Designing learning from environmental problems	Real environmental issues as the starting point of learning	Waste, water use, school plants, classroom cleanliness, and energy saving were used as learning contexts
3. Integrating Eco-STEAM and edutainment in classroom activities	Interdisciplinary exploration and enjoyable learning experiences	Students engaged in observation, group challenges, quizzes, solution design, and collaborative activities
4. Embedding Mamayu Hayuning Bawana in sustainability reflection	Local wisdom as ethical and cultural reflection	Students reflected on harmony, responsibility, cooperation, and environmental care
5. Validating and practicing the model	Expert validation, readability, practicality, and classroom implementation	Model validation = 4.48; tools = 4.44; readability = 89.27%; positive student response = 95.65%
6. Enhancing students' computational thinking	Sustainability problem-solving through decomposition, pattern recognition, abstraction, and algorithmic design	The experimental group increased from 52.68 to 82.41; N-Gain = 0.63; p = 0.000

Initial Needs for Sustainability-Oriented Learning

The first finding shows a need for learning that is more contextual, environmental, and oriented toward sustainability problem-solving. Initial observations showed that Grade V learning was still dominated by teacher explanations, examples, written exercises, and question-and-answer activities. Students were not consistently involved in identifying problems, collecting information, discussing causes, designing solutions, or reflecting the effects of their proposed ideas. Although teachers had used several learning media, these had not been specifically directed toward developing sustainability education and computational thinking.

This was supported by teacher interviews. Teachers were aware of the significance of environmental learning, application of technology in class, creativity, and local values. However, these ideas were difficult to translate into classroom practice without a clear model. Teachers needed learning syntax, ready-to-use teaching materials, structured student worksheets, supporting media, and assessment instruments that could guide them in implementing sustainability-oriented learning.

One teacher explained:

> *" Children are easily interested when learning is connected with the school environment, such as waste or plants. But we still need clear examples of learning steps, because when we only use an environmental theme, the lesson often returns to explanation and written exercises."*

Another teacher added:

> *"We understand that computational thinking is important; however, it is not easy to teach. Teachers need concrete activity examples, especially those suitable for elementary school students."*

This finding shows that the development of the Eco-STEAM Edutainment model started with real school needs. The model was not designed as a new learning label. It was designed as a structured response to teachers' needs to connect environmental problems, interdisciplinary exploration, enjoyable learning experiences, local wisdom, and computational thinking.

Designing Learning from Environmental Problems

The second finding concerns the use of environmental problems as the starting point of learning. In this model, learning did not begin with abstract definitions or textbook explanations, but with environmental issues that students could directly observe at school. The issues included waste accumulation, classroom cleanliness, water use, school-plant care, and energy saving.

At the design stage, these environmental problems were translated into teaching modules, student books, student worksheets, challenge cards, trigger videos, interactive quizzes, assessment rubrics, and reflection sheets. Each medium was designed to guide students from observation to analysis and

from analysis to solution design. Thus, the school environment did not only become the background of learning. It became an active learning resource.

Designing learning from environmental problems helped students connect sustainability issues with their thinking processes. For example, when students observed classroom waste, they were guided to break the problem down into sources of waste, locations, habits, impacts, and possible solutions. When students observed water use, they were guided to identify repeated patterns and arrange clear water-saving steps.

A teacher stated:

"The environmental problems selected were close to the students. The children did not need to imagine distant problems. They could directly see the trash bin, plants, and water taps at school."

This finding shows that environmental problems can become meaningful entry points for developing computational thinking when they are addressed through clear learning activities. The model helped students transition from simply noticing a problem to analysing it and designing a possible response.

Integrating Eco-STEAM and Edutainment in Classroom Activities

The third finding shows that the integration of Eco-STEAM and edutainment supported students' engagement in active and

Table 5
Environmental problems and learning design orientation

Environmental Problem	Learning Activity	Eco-STEAM Connection	Computational Thinking Focus
Waste in the classroom and schoolyard	Students observe types of waste and discuss their causes	Science: waste classification; Mathematics: counting waste frequency; Art: campaign poster	Decomposition and pattern recognition
Inefficient water use	Students identify water-use habits and propose saving steps	Science: water use; Technology: simple monitoring; Engineering: water-saving routines	Pattern recognition and algorithmic design
Poorly maintained school plants	Students compare plant conditions and arrange care schedules	Science: plant growth; Mathematics: observation table; Art: visual plant journal	Abstraction and algorithmic design
Classroom cleanliness	Students identify sources of untidiness and design classroom routines	Engineering: routine design; Social collaboration; Art: classroom-rules poster	Decomposition and algorithmic design
Energy use in the classroom	Students observe the use of lights/fans and create saving procedures	Science: energy; Technology: simple reminders; Mathematics: usage estimation	Pattern recognition and abstraction

meaningful learning. Eco-STEAM provides an interdisciplinary structure through science, technology, engineering, arts, and mathematics. Edutainment made the activities more accessible to elementary students through games, stories, quizzes, simple simulations, mission cards, and group challenges.

Observation data showed positive changes in student activity over five meetings. Problem-solving and solution-design activities increased from 30.24% in the first meeting to 38.12% in the fifth meeting. Discussions with peers and teachers increased from 22.18% to 25.72%. In contrast, irrelevant behaviour decreased from 4.85% to 0.57% (Table 6).

The change in activity patterns showed that students gradually became more involved in learning tasks that required exploration, discussion, and solution design. In the first meeting, the students still needed considerable teacher guidance. In later meetings, they were more able to read environmental problems, divide group tasks, formulate strategies, and connect solutions with sustainability values.

One student stated in reflection:

"I liked it because learning felt like a challenge. We saw problems in the classroom and then looked for ways to make the class cleaner."

Another student added:

"Usually, environmental learning is only reading, but this time we made a plan and discussed it with friends."

With the responses it is clear that edutainment did not serve as additional entertainment. It turned into a pedagogical approach to engage students in more complex thinking processes. Student challenges, missions, and visual media were used to encourage them to observe, discuss, and refine solutions

Embedding Mamayu Hayuning Bawana in Sustainability Reflection

The fourth finding concerns the embedding of Mamayu Hayuning Bawana in sustainability reflection. In this model, Mamayu Hayuning Bawana was not treated as a standalone

Table 6
Percentage of student activities during learning

Student Activity	Meeting 1	Meeting 2	Meeting 3	Meeting 4	Meeting 5
Paying attention to the teacher or peers	17.85	15.42	13.16	11.74	10.68
Reading and understanding environmental problems	11.36	12.58	13.27	13.94	14.10
Solving problems and designing solutions	30.24	33.76	35.81	37.25	38.12
Discussing with peers and the teacher	22.18	23.45	24.36	25.08	25.72
Drawing conclusions and reflecting on local values	13.52	12.96	11.89	11.03	10.81
Irrelevant behaviour	4.85	1.83	1.51	0.96	0.57

cultural topic. It was used as a reflective framework that guided students to assess whether the solutions they designed reflected harmony, care, responsibility, cooperation, and balance in the relationship between humans and the environment.

This value was conveyed through reflection sheets, teacher questions, and discussions after solution design activities. After the students arranged their solutions, they were invited to consider several questions: Does this solution help protect the environment? Does it involve cooperation? Does it benefit others? Does it show responsibility for shared life? Through this reflection process, sustainability learning became not only technical but also ethical and cultural.

Students' positive responses to Mamayu Hayuning Bawana's reflection reached 91.89%. This indicates that most students understand the relationship between environmental problem-solving and the values of harmony, responsibility, and care.

A teacher explained:

"The value of Mamayu Hayuning Bawana helped students understand that environmental solutions are not only about right or wrong, but also about maintaining balance and taking shared responsibility."

A student wrote in the reflection sheet,

"If we take care of plants and do not throw waste carelessly, the school becomes more comfortable, and all friends feel the benefits."

This finding shows that local wisdom can function as a reflective framework for sustainability education. Mamayu Hayuning Bawana gives cultural meaning to environmental problem-solving and helps students evaluate solutions using ethical and social considerations.

Validating and Practicing the Eco-STEAM Edutainment Model

The fifth finding concerns the model's validity and practicality. Expert validation showed that the learning model obtained an

Table 7
Embedding Mamayu Hayuning Bawana in learning reflection

Value Dimension	Classroom Reflection Question	Expected Student Response
Harmony	Will this solution help create a better relationship between humans and nature?	Students consider environmental balance
Care	Does this solution care for the school environment?	Students connect action with environmental care
Responsibility	Who is responsible for implementing this solution?	Students recognise shared responsibility
Cooperation	Can this solution be implemented alone, or does it require cooperation?	Students understand the importance of group action
Common good	Who benefits from this solution?	Students consider social and environmental impact

average score of 4.48, which was categorised as very valid. The highest score was found in the integration of Mamayu Hayuning Bawana, which was 4.62. This result shows that the cultural value component was clearly represented in the model.

Learning tool validation and computational thinking test validation received average scores of 4.44, and 4.35, respectively. Both were in very valid category. The readability test was obtained with a score of 89.27% which indicates that the student book, student worksheet, visual instructions, and the flow of activity could be understood by students and teachers.

Teachers' ability to manage learning increased across meetings. The average score increased from 3.91 in the first meeting to 4.70 in the fifth meeting (Table 9). This shows that teachers became more able to manage environmental problem orientation, Eco-STEAM exploration, edutainment challenges, computational thinking guidance, and Mamayu Hayuning Bawana reflection.

The student response questionnaire showed that students responded positively to the learning implementation (Table 10). The highest responses were in the classroom atmosphere and edutainment challenges,

Table 8
Summary of model validation and practicality results

Aspect	Result	Category
Learning model validation	4.48	Very valid
Learning-tool validation	4.44	Very valid
Computational thinking test validation	4.35	Very valid
Readability test	89.27%	Very good
Positive student response	95.65%	Very good
Teacher classroom management	4.37	Very good
N-Gain of experimental group	0.63	Moderate
Paired sample t-test	p = 0.000	Significant
Independent sample t-test	p = 0.000	Significant

Table 9
Teacher's ability to manage learning

Observed aspect	M1	M2	M3	M4	M5
Communicating learning objectives	4.10	4.30	4.50	4.60	4.70
Motivating students	4.00	4.35	4.45	4.65	4.75
Orienting students to Eco-STEAM problems	3.95	4.25	4.55	4.70	4.80
Managing edutainment activities	3.80	4.15	4.35	4.55	4.65
Guiding computational thinking	3.85	4.20	4.48	4.68	4.76
Integrating Mamayu Hayuning Bawana	3.90	4.22	4.44	4.61	4.72
Managing learning time	3.70	4.05	4.25	4.40	4.55
Conducting evaluation and reflection	3.95	4.25	4.50	4.63	4.70
Mean	**3.91**	**4.22**	**4.44**	**4.60**	4.70

Table 10
Student responses to learning implementation

Assessed Aspect	Positive Rresponse	Negative Response
Learning material	95.95%	4.05%
Student book	94.59%	5.41%
Student worksheets	97.30%	2.70%
Classroom atmosphere	98.65%	1.35%
Teacher's way of teaching	95.95%	4.05%
Eco-STEAM activities	94.59%	5.41%
Edutainment challenges	98.65%	1.35%
Mamayu Hayuning Bawana reflection	91.89%	8.11%
Interest in similar learning activities	97.30%	2.70%

Table 11
Descriptive statistics of computational thinking scores

Group	N	Test	Minimum	Maximum	Mean	SD
Experimental	74	Pretest	38	69	52.68	7.14
Experimental	74	Posttest	67	96	82.41	6.83
Control	74	Pretest	37	68	51.94	7.28
Control	74	Posttest	55	84	68.17	7.06

both reaching 98.65%. The lowest positive response was in the reflection on Mamayu Hayuning Bawana, which reached 91.89%, but it was still in the very good category.

These results show that the model was not only conceptually valid but also practical for use in the classroom. Teachers might use the learning syntax with only minor adaptations such as providing more examples of expected responses, making the instructions easier on student's worksheet, and adding examples of expected responses.

Enhancing Students' Computational Thinking through Sustainability Problem-Solving

The sixth finding concerns students' CT results. The computational thinking test was administered before and after the learning sessions. The test measured four indicators: decomposition, pattern recognition, abstraction, and algorithmic design.

Descriptive statistics showed that the experimental group increased from 52.68 in the pre-test to 82.41 in the post-test (Table 11). The control group also increased, but at a lower level, from 51.94 to 68.17. The experimental group increased by 29.73 points, whereas the control group increased by 16.23 points. This result shows that the Eco-STEAM Edutainment model produced a stronger improvement than regular instruction.

Indicator analysis showed improvement in all computational thinking components (Table 12). Decomposition increased from 53.10% to 84.02%. Pattern recognition increased from 52.34% to 82.76%.

Abstraction increased from 50.85% to 79.88%. Algorithmic design increased from 54.43% to 83.01%. Among the four indicators, abstraction obtained the lowest post-test score. This suggests that selecting important information remains challenging for elementary students.

The effectiveness test strengthened this finding. The paired sample t-test showed a significant difference between the pretest and posttest scores in the experimental group ($p = 0.000$). The independent sample t-test also showed a significant difference between the experimental and control groups' posttest scores ($p = 0.000$). The N-gain score of the experimental group was 0.63, while that of the control group was 0.34.

One teacher reflected:

> *"The children understood the steps for solving problems more easily when the problems were visible to them. They did not only answer questions; they tried to arrange the sequence of actions."*

One student also explained the following:

> *"When the problem was too big, we broke it down first. For example, with waste in the classroom, we looked at where it came from, when it was most common, and then made group rules."*

This finding shows that computational thinking can be meaningfully developed through sustainability problem-solving. The model helped students transition from observing environmental problems to breaking down problems, recognising patterns, selecting important information, and designing ordered action steps. In this context, computational thinking is not viewed as a separate technical skill. Rather, it has become a thinking tool in sustainability learning.

Table 12
Mean scores of computational thinking indicators in the experimental group

Indicator	Pretest	Posttest	Gain
Decomposition	53.10	84.02	30.92
Pattern recognition	52.34	82.76	30.42
Abstraction	50.85	79.88	29.03
Algorithmic design	54.43	83.01	28.58
Total mean	**52.68**	**82.41**	29.73

Overall, the results indicate that the Eco-STEAM Edutainment model was effective, which occurred via three interconnected pathways. First, the model puts environmental issues at the start of learning. Secondly, it facilitated interdisciplinary exploration via fun and cooperative activities. Thirdly, it helped students to reflect on solutions using Mamayu Hayuning Bawana. These pathways enabled students to enhance their computational thinking skills and also gain awareness of the nature of environmental issues as ones that need knowledge, action, care, and a sense of responsibility

DISCUSSION AND CONCLUSION

Based on the results of this study, the Eco-STEAM Edutainment model can be explained as a pedagogical innovation that combines the concepts of sustainability education, interdisciplinary learning, and fun learning experiences with the local

wisdom and computational thinking in one learning model in elementary school. It is important to note that this model is not meant to supplant the current classroom practices of teachers in their entirety. It is important to note that this model is not a quick way to completely replace teachers' current classroom practices. Instead, it is seen as providing a structure that guides teachers to move from the dominant teaching approach of providing explanations and written assignments to more contextual, exploratory, and reflective learning experiences. In this study, environmental problems close to students' lives became a starting point that helped teachers connect learning with real experience. This finding is in line with research on sustainability education, which emphasises that the success of ESD implementation is not determined only by the content taught, but also by teacher readiness, pedagogical design, and learning experiences that allow students to understand sustainability issues as part of their lives (Dittrich et al., 2024). The model also indicates that the concept of environmental learning in elementary schools should be conceived as a process of learning, of something more than just concept delivery. Therefore, the first contribution of this study is to demonstrate the implementation of the learning that provides students with opportunities to observe, question, design solutions and reflect on their responsibility for the environment.

The results also indicate that the combination of the concepts of Eco-STEAM and edutainment can enhance students' involvement in sustainability learning. The amount of student activities connected to problem-solving and solution design was higher in the fifth meeting than in the first meeting, and the amount of irrelevant behaviour decreased in each meeting. This implies that students can learn with real problems in their environment, interdisciplinary activities, and fun challenges to keep them busy in more advanced thinking. This is significant because sustainability learning can be challenging when environmental material is introduced in a normative manner, such as by offering suggestions on what to do to make the classroom sustainable. In Eco-STEAM Edutainment, students were not only requested to “learn” good behaviour, they also were asked to know the reasons for a problem occurring, to learn how patterns of problems would manifest, and to know what steps might be taken. Research on sustainability education and learning processes shows that learning that connects concepts, connections, creativity, and community can strengthen the quality of students' learning experiences (Brandt et al., 2021). In this article, edutainment provided a learning form that matched children's world, while Eco-STEAM provided an interdisciplinary structure so that learning still had a clear academic direction. The combination made learning more engaging without losing its orientation toward understanding and sustainability of action. This is consistent with the authors' earlier findings that a well-implemented internet-based learning strategy can strengthen

students' engagement with course content (Ananda et al., 2023), and that students' emotional engagement is itself associated with better learning outcomes, including in mathematics (Jalaluddin et al., 2020).

The results further show that Mamayu Hayuning Bawana served as a bridge between environmental problem-solving and value formation. This value helped students assess solutions not only based on technical feasibility but also on care, cooperation, responsibility, and harmony with the environment. This point is important because sustainability education cannot be separated from ethical and social dimensions. If students are only asked to design environmental solutions without reflecting the values behind their actions, learning can become too technical and lose its meaning. In this study, Mamayu Hayuning Bawana reflection gave students space to ask whether their proposed actions were beneficial for the environment and shared life. This finding is consistent with research on local wisdom integration in environmental education, which shows that cultural knowledge and values can strengthen the connection among learning, social identity, and sustainability behaviour (Sihombing et al., 2025). Therefore, the model shows that local wisdom does not need to be positioned as a cultural ornament. It can become a source of reflection in sustainability education. The principle of Mamayu Hayuning Bawana also has transferability because harmony, care, and ecological responsibility can be found in many other cultures, even if the terms and practices differ. This finding is also the study's main evidence bearing on the question of environmental-ethical awareness raised in the Introduction. The 91.89% positive response rate to the Mamayu Hayuning Bawana reflection (Table 7), together with the qualitative excerpts above, shows that students were not only completing the cognitive steps of Eco-STEAM exploration; they were also engaging, and largely agreeing with, the value-based questions used to evaluate their own solutions. Because this was measured through a response questionnaire and reflection-sheet coding rather than a standardised, validated environmental-attitude or pro-environmental-behaviour scale, it is reported here as descriptive, complementary evidence of the model's function rather than as a confirmatory test of environmental-awareness gain; a validated instrument for that specific construct is identified as a direction for future research below. What the data do allow us to say with more confidence is the point raised in the Introduction about redundancy: the results on student activity (Table 6) show students becoming more capable at the cognitive-interdisciplinary steps of a solution through Eco-STEAM, while this finding shows students separately engaging an evaluative, values-based judgment about that same solution through Mamayu Hayuning Bawana — two distinguishable processes operating on the same problem, not one process measured twice.

From a computational thinking perspective, this study shows that students'

abilities improved after learning through the Eco-STEAM Edutainment model. Improvement occurred in decomposition, pattern recognition, abstraction, and algorithmic design. This result shows that computational thinking can be developed through sustainability problems, not only through programming or coding lessons. When students observed classroom waste, water use, plant care, or energy saving, they were actually learning to break down problems, recognise patterns, select important information, and arrange action steps. This finding supports the view that computational thinking at the elementary level can be developed through unplugged, visual, and problem-based activities that are close to students' lives (Curi et al., 2025). However, our findings also show that abstraction received the lowest score compared with the other indicators. This is understandable because abstraction requires students to filter information, set priorities, and distinguish the core problem from additional information. Future implementation therefore needs stronger learning support, such as information maps, guiding questions, visual organisers, and gradual examples. Thus, the second contribution of this study is to broaden the understanding of computational thinking as a way of thinking for responding to sustainability problems systematically and responsibly. Abstraction receiving the lowest post-test score among the four indicators (79.88, against 82-84 for the others; Table 12) is worth discussing its own terms rather than only noting in passing. Abstraction, in this test, required students to filter relevant from irrelevant information and isolate the core issue — a demand that is cognitively heavier than decomposing a problem into parts or sequencing already-identified steps, and one that other elementary CT research has also found to be the most difficult of the standard CT indicators for this age group. This suggests that the gap is a feature of the construct's developmental difficulty rather than a defect specific to the model's Phase 4 (Computational Reasoning) activities (Table 3). This is consistent with the authors' own findings on natural number bias among Indonesian elementary students, which show that young learners' abstraction and generalisation processes are systematically constrained by their existing conceptual schemas and therefore require deliberate instructional support to overcome (Rahayuningsih et al., 2025b).

Practically, this study shows that the success of the model was strongly influenced by teachers' readiness to manage learning syntax, group activities, edutainment, and value reflection. The increase in teachers' ability to manage learning from the first to the fifth meeting shows that this model can be learned and practiced gradually. However, this increase also shows that teachers need time to adapt. Teachers do not only need to understand the steps of the model. They also need to become familiar with managing learning that is more open, collaborative, and problem-based. This is in line with research on teacher development for computational thinking, which emphasises the importance of teacher development

programs that connect content knowledge, pedagogy, technology, and classroom practice (Kong, 2023). In the context of Eco-STEAM edutainment, support for teachers needs to include examples of teaching materials, guiding questions, activity scenarios, assessment rubrics, and examples of value reflection. With this kind of support, the model has the potential to be implemented not only in one theme or one school but also in other learning contexts that use local environmental problems as the starting point. The steady increase in teachers' classroom-management scores across five meetings (Table 9) also indicates that the model's syntax (Table 3) is learnable through practice rather than dependent on specialised prior training. Practically, this suggests that the model's success is contingent on giving teachers structured support — the guide, modules, and rubrics listed as the support system in Table 3 — during an adjustment period, rather than assuming the syntax can be implemented correctly from a single reading.

Although this study showed positive results, several limitations must be addressed. First, the model was tested in Grade V elementary school contexts. Its application in lower grades, secondary schools, or areas with different environmental characteristics requires adjustment. Second, Mamayu Hayuning Bawana originated from a specific local cultural context; therefore, its implementation in other regions must be aligned with local values in those communities. Third, this study emphasised short-term outcomes, including validity, practicality, student responses, and improvements in computational thinking. Further research should examine the long-term effects of the model on students' environmental behaviour. Fourth, abstraction still requires stronger support in activity design. These limitations do not reduce the contribution of the model; however, they show that Eco-STEAM Edutainment development should be viewed as a process that can continue to be refined. Research on computational thinking assessment also emphasises that measuring this ability requires instruments that are clear, reliable, and sensitive to different learning contexts (Tang et al., 2020). Therefore, future research can expand field testing, strengthen assessment, and develop more adaptive supporting tools. Fifth, this study measured validity, practicality, student and teacher responses, and CT effectiveness using an experimental-control field test; it did not employ a separately validated environmental-awareness or pro-environmental-behaviour scale, and its evidence on environmental-ethical awareness (discussed above) is therefore descriptive rather than confirmatory. Future studies should incorporate such a validated instrument alongside the CT test so that the model's effect on ecological attitudes and behaviour can be measured directly rather than inferred from reflection responses.

Overall, this study concludes that the Eco-STEAM Edutainment model grounded in Mamayu Hayuning Bawana is feasible as a sustainability learning approach in elementary schools. The model

showed high validity, classroom practicality, positive student responses, and effectiveness in improving computational thinking. The main contribution of this study is the integration of four elements that are often discussed separately: sustainability education, Eco-STEAM, edutainment, and local wisdom. The model shows that school environmental problems can become rich learning spaces, that enjoyable activities can still be directed toward serious thinking goals, and that local values can provide ethical depth to problem-solving. The implication is that elementary teachers can use simple environmental problems as a starting point for interdisciplinary learning. Schools can also support the implementation of the model by providing space, time, and a school culture that strengthens sustainability practices. Further studies are recommended to test this model in other cultural contexts, develop digital or hybrid versions, and evaluate its impact on sustainability competence, collaboration, creativity, and students' ecological behaviour. The main contribution of this study is therefore twofold. Theoretically, it integrates four elements that are often discussed separately in the literature — sustainability education, Eco-STEAM, edutainment, and local wisdom — into one explicit, replicable instructional model, described through its syntax, social system, principles of reaction, support system, and instructional and nurturant effects (Table 3), rather than only through the process used to produce it. Practically, it demonstrates that a specific local value system can provide ethical depth to problem-solving without duplicating the cognitive work already carried out through Eco-STEAM.

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