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Designing Ethnoscience Learning for Sustainability and Creative Thinking in Elementary Science

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Abstract

Integrating local knowledge into science education can support culturally relevant and sustainability-oriented learning, yet local culture is often used merely as contextual illustration rather than reconstructed into scientific and sustainability reasoning. This study developed and iteratively evaluated a Galendo-based Ethno-Education for Sustainable Development (Ethno-ESD) module for Grade V elementary science and derived design principles from its development. Using Educational Design Research, the study involved six teachers, nine students, five Galendo producers, three experts, a formative trial with 13 students, and an implementation trial with 20 students. Data were collected through interviews, documentary analysis, expert appraisal, questionnaires, classroom observations, and a creative-thinking assessment consisting of 12 multiple-choice and four constructed-response items. Pretest–posttest responses were examined using Rasch stacking and racking. The findings showed that the main instructional challenge was limited integration of local culture, science, sustainability, and creative thinking rather than a lack of learning resources. Expert appraisal ranged from 95.24% to 96.62%, while formative student responses averaged 82.57%. All 20 students showed positive pretest–posttest logit changes, accompanied by observable development in fluency, flexibility, originality, and elaboration. Seven design principles were derived. The findings further suggest that a culturally specific context can remain pedagogically accessible to learners with limited prior familiarity when mediated through scientific reconstruction, multimodal representations, sustainability problems, and project-based learning. These findings provide preliminary support for culturally situated yet potentially transferable elementary science learning.

1 Introduction

Education for Sustainable Development (ESD) emphasizes the role of education in enabling learners to understand interconnected environmental, social, economic, and cultural challenges and to make responsible decisions about the future. The ESD for 2030 framework highlights the importance of connecting sustainability with local action, suggesting that global issues should be made meaningful through learners' engagement with community life, resource use, livelihoods, technology, and culture [1]. This orientation is consistent with sustainability-competency frameworks that emphasize systems thinking, anticipatory thinking, normative and strategic competence, collaboration, and integrated problem solving [2, 3]. Accordingly, sustainability learning should move beyond environmental knowledge alone and connect disciplinary understanding with complex real-life problems [4].

In culturally diverse societies such as Indonesia, local knowledge provides a potentially meaningful resource for such learning. Cross-cultural science education has long conceptualized learning as movement between students' life-worlds and school science [5]. More recent culturally relevant, responsive, and sustaining pedagogies similarly argue that learners' experiences and community practices should function as epistemic resources rather than as decorative cultural additions to the curriculum [6, 7]. A community-based science perspective further recognizes that community experience

and expertise can contribute legitimately to scientific meaning-making when appropriately positioned within instruction [8].

However, integrating local knowledge requires epistemic caution. Cultural practices should not automatically be regarded as scientific or sustainable simply because they are traditional or locally embedded. Research on Indigenous and local knowledge in sustainability education highlights issues of epistemic legitimacy, agency, navigation across knowledge systems, and pedagogical mediation [9]. Local knowledge can enrich science education when it is critically reconstructed and brought into dialogue with scientific knowledge rather than merely celebrated as cultural heritage [10, 11]. In this sense, scientific reconstruction becomes an important pedagogical mechanism through which local practices can be observed, questioned, explained scientifically, and subsequently examined in relation to sustainability.

Studies in Indonesia have demonstrated the potential of this approach. Community knowledge can provide both scientific content and meaningful contexts for sustainability learning [12], while culturally grounded approaches have been shown to connect science learning with cultural sustainability [13]. Ethno-STEM Project-Based Learning has also been associated with critical and creative thinking [14], and Indonesian science-education scholarship has increasingly emphasized the relationship between curriculum reform and local knowledge [15]. Nevertheless, research integrating local knowledge, science, sustainability, and creativity remains comparatively limited at the elementary-school level, and culturally contextualized learning often lacks an explicit pedagogical pathway connecting cultural practice, scientific reconstruction, sustainability reasoning, problem solving, and idea development [16].

Against this background, the present study conceptualizes Ethno-Education for Sustainable Development (Ethno-ESD) not as a universally established standalone theory, but as an integrative pedagogical framework in which community knowledge functions as an epistemic anchor for scientific reconstruction, multidimensional sustainability reasoning, and problem solving. Galendo, a traditional coconut-based food associated with the cultural identity of Ciamis Regency, West Java, Indonesia, was selected as the local context [17]. The cultural and natural resources of Ciamis have also been identified as relevant contexts for contextual science learning within the Indonesian curriculum [18].

Galendo production includes coconut selection, grating, coconut-milk extraction, prolonged heating, oil separation, molding, and pressing. These practices can be connected with scientific concepts such as changes in matter, heat and energy, mixtures and separation, forces, and resource utilization. At the same time, Galendo production is associated with community livelihoods, resource efficiency, the use of production by-products, technological change, and cultural continuity. It can therefore be viewed not merely as a traditional food, but as a community-scale socio-ecological production system. This framing also avoids romanticizing local culture: local practices may contain sustainability-oriented features while simultaneously facing environmental, economic, or intergenerational challenges. Such tensions create opportunities for students to move from asking what scientific concepts are involved? toward

considering how resources are used, what consequences arise, whose interests are affected, and what alternatives might be developed.

These questions are closely related to creative thinking. The OECD [19] defines creative thinking as the capacity to engage productively in generating, evaluating, and improving ideas. Creative performance in education does not need to represent exceptional achievement; the Four-C Model recognizes personally meaningful idea construction during learning as a form of mini-c creativity [20]. At the same time, divergent thinking should be understood as an indicator of creative potential rather than as a complete representation of creativity [21]. The importance of creating such learning opportunities is also reflected in PISA 2022, in which Indonesian 15-year-olds obtained an average creative-thinking score of 19 out of 60 compared with an OECD average of 33 [22]. Although these data cannot be interpreted as direct evidence of elementary-school performance, they indicate a broader need to provide opportunities for generating, evaluating, and refining ideas from earlier stages of education.

Project-Based Learning (PjBL) offers one possible structure for developing such opportunities because it emphasizes authentic problems, investigation, collaboration, product development, communication, and reflection [23, 24]. Research has shown that culturally situated project learning can support creative thinking [14], while a recent meta-analysis reported positive effects of PjBL on creative thinking in science education, although outcomes varied according to instructional design and context [25]. This suggests that projects do not automatically produce creativity; rather, the cognitive demands embedded within project activities determine which forms of creative thinking are afforded.

A further issue concerns cultural familiarity. Place-based and culturally responsive pedagogies often emphasize the value of learners' lived experiences and familiar environments [6, 26]. However, culturally specific contexts may also need to function beyond their immediate communities. Research on epistemic agency suggests that science learning can involve movement across multiple knowledge systems [27]. This raises an important distinction between a context that is culturally familiar and one that is culturally accessible: learners may have limited prior familiarity with a cultural practice yet still engage meaningfully with it when its scientific, cultural, and sustainability meanings are appropriately mediated.

Accordingly, this study addresses four interrelated gaps: the limited representation of elementary education in studies integrating local knowledge, science, sustainability, and creativity; the lack of an explicit integrative architecture connecting cultural knowledge with scientific reconstruction and ESD; limited understanding of how culturally situated project activities afford different dimensions of creative thinking; and insufficient attention to how culturally specific contexts function for learners with limited prior familiarity.

The study was guided by the following research questions:

a. What design principles are required to transform local knowledge embedded in Galendo production into Ethno-ESD-based elementary science learning that integrates scientific reconstruction,

multidimensional sustainability, PjBL, and creative thinking?

b. To what extent does the Galendo-based Ethno-ESD module demonstrate pedagogical feasibility and usability through expert appraisal and iterative classroom implementation?

c. What changes in fluency, flexibility, originality, and elaboration are observed after students participate in the learning intervention?

d. How does the Galendo context function for students with limited prior familiarity with its cultural production environment?

2 Literature Review

2.1 Local and Community Knowledge as an Epistemic Resource in Science Education

Recent scholarship in science education increasingly challenges the treatment of culture merely as a contextual or motivational addition to conventional scientific content. Instead, culturally relevant, responsive, and sustaining pedagogies position students' cultural experiences and community knowledge as legitimate resources for scientific meaning-making [6]. This perspective is reinforced by Tran and Guzey [7], who demonstrate that culturally sustaining STEM learning requires instructional spaces in which diverse ways of knowing can contribute to scientific inquiry rather than being subordinated to a single epistemological framework. Community-based science similarly broadens the notion of expertise by recognizing that community members possess experiential knowledge that can contribute meaningfully to science learning [8].

This development is particularly relevant to the integration of local and Indigenous knowledge. A systematic review by Druker-Ibáñez and Cáceres-Jensen [9] shows that meaningful integration requires attention to epistemic legitimacy, learners' and communities' agency, movement between knowledge systems, and appropriate pedagogical mediation. More recent reviews reinforce this concern. Latip et al. [28] found increasing international attention to local and Indigenous knowledge in science education, while Abas et al. [29], reviewing 65 studies, identified continuing challenges related to tokenism, institutional gatekeeping, unequal epistemic authority, and tensions between scientific and community knowledge systems. These findings imply that local knowledge should neither be romanticized nor simply inserted into science curricula; it requires responsible interpretation and pedagogical reconstruction.

Within this perspective, scientific reconstruction becomes central. Community practices can function as starting points for observing phenomena, identifying patterns, asking questions, constructing causal explanations, and relating experiential knowledge to scientific concepts. This approach preserves the cultural origin of knowledge while allowing learners to examine it scientifically. Consequently, ethnoscience-oriented learning is most educationally productive when culture serves as an epistemic

anchor rather than a decorative context. For the present study, Galendo production is therefore positioned not merely as traditional food knowledge, but as a community practice from which scientific phenomena concerning matter, heat, separation, energy, force, and resource utilization can be reconstructed.

2.2 From Local Knowledge to Sustainability Reasoning

The educational value of local knowledge extends beyond scientific conceptualization when it is connected with Education for Sustainable Development (ESD). Sustainability education at the primary level increasingly emphasizes students' ability to recognize relationships among environmental, social, economic, and cultural dimensions rather than treating sustainability as synonymous with environmental protection. Vesterinen and Ratinen's [30] systematic review shows that sustainability competences in primary education include systems thinking, futures thinking, values thinking, collaboration, and action-oriented competence. Their synthesis also indicates that dialogue, collaboration, imagination, and engagement with everyday environmental issues are important mechanisms through which younger learners begin to develop these competences.

Local and place-based contexts are particularly relevant because they allow sustainability problems to be examined as interconnected socio-ecological issues. Li and Shein [31] showed that place-based Indigenous ESD can strengthen students' understanding of their communities and enable broader reasoning about local sustainability issues. More recently, Ge et al. [32], through a systematic review of 68 K–12 science studies, concluded that place-based learning can support authentic inquiry, integration of local knowledge, understanding of human–environment relationships, and engagement with regional sustainability challenges. However, they also identified difficulties related to curriculum alignment, teacher capacity, students' varying sense of place, and community support.

These findings are important for an Ethno-ESD framework. Local practices should not automatically be labelled "sustainable" simply because they are culturally inherited. Instead, students need opportunities to examine both their sustainability potential and their tensions or trade-offs. In Galendo production, for example, the productive use of coconut by-products may represent resource efficiency, whereas raw-material availability, economic vulnerability, technological change, and declining intergenerational participation represent sustainability challenges. Ethno-ESD can therefore be conceptualized as an integrative pedagogical framework in which local knowledge is reconstructed scientifically and subsequently expanded into multidimensional sustainability reasoning.

2.3 Project-Based Learning and the Development of Creative Thinking

The movement from understanding sustainability problems toward considering alternative responses requires learning environments that allow students to generate, compare, refine, and communicate ideas. Project-Based Learning (PjBL) is relevant because it organizes learning around meaningful problems, inquiry, product development, collaboration, and reflection. Recent quantitative syntheses

generally indicate positive relationships between project-based approaches and higher-order cognitive outcomes, including creativity. Hasibuan et al. [25], using a meta-analysis of science-education studies, found that PjBL supports creative-thinking development, although its outcomes vary according to educational level, subject domain, learning design, and technological support. Pinar et al. [33] similarly reported that project- and problem-based approaches produced comparatively strong effects on scientific creativity across the studies included in their meta-analysis.

Nevertheless, current evidence requires caution. A 2026 umbrella review synthesizing 15 PjBL meta-analyses found a generally positive direction for academic achievement and higher-order thinking, but also substantial heterogeneity and methodological limitations across the existing meta-analytic evidence. In particular, the magnitude of PjBL effects should not be assumed to be uniform across contexts [34]. This reinforces an important pedagogical point: PjBL itself does not automatically generate creativity. What matters is the nature of the cognitive opportunities embedded within project activities.

Accordingly, creative thinking should be intentionally designed. Tasks requiring students to generate several alternatives can afford fluency; examining a problem from environmental, economic, technological, and social perspectives can foster flexibility; proposing uncommon products or solutions can support originality; and explaining mechanisms, evidence, procedures, and design rationales can strengthen elaboration. In this sense, the interaction between sustainability and creativity may be reciprocal: sustainability problems broaden the range of perspectives from which a problem can be viewed, while creative thinking expands the range of possible responses to that problem.

2.4 Culturally Situated Learning and Pedagogical Accessibility

An unresolved issue in culturally grounded science education concerns the degree to which culturally specific knowledge remains meaningful outside its community of origin. Much of culturally responsive and place-based education emphasizes students' lived experiences and familiarity with local contexts [6]. Recent K–12 place-based research likewise shows that learners' sense of place influences how they participate in context-based science learning [32].

However, contemporary research on multiple knowledge systems suggests that cultural familiarity need not be an absolute prerequisite for learning. Tolbert et al. [27] argue that engagement with Indigenous and other knowledge systems involves epistemic agency and navigation among different ways of knowing. Similarly, community-based science emphasizes the importance of maintaining the social and cultural origins of knowledge while making community expertise available for classroom meaning-making [8].

This literature supports a useful distinction between culturally familiar and culturally accessible learning. A culturally familiar context is already embedded in learners' everyday experience, whereas a culturally accessible context may initially be unfamiliar but becomes understandable through deliberate

pedagogical mediation. Visual representations, process diagrams, audiovisual resources, glossaries, community narratives, and explicit links between local practices and scientific concepts can function as such mediation. Consequently, culturally situated learning need not necessarily remain geographically bounded, although cultural knowledge should never be detached from its source or treated as universally interchangeable.

2.5 Educational Design Research and the Emerging Research Gap

The literature therefore points toward a need for instructional designs that integrate these dimensions rather than investigating them independently. Recent reviews show substantial research on local knowledge in science education, sustainability competences, place-based learning, and PjBL, but considerably less evidence concerning an explicit developmental architecture that connects community knowledge → scientific reconstruction → multidimensional sustainability reasoning → project-based problem solving → creative thinking, particularly at the elementary-school level. The systematic review by Rosyidah et al. [16] likewise indicates growing attention to local wisdom and STEM but continued concentration of studies beyond elementary education.

Educational Design Research (EDR) is particularly appropriate for addressing such an integration problem because its contribution lies not only in producing an instructional product but also in generating knowledge about how that product should be designed. Feulner et al. [35], in a scoping review of 425 design-research publications, emphasize the importance of design principles as a bridge between theoretical knowledge and practical intervention. Thus, the contribution of a Galendo-based Ethno-ESD study should extend beyond demonstrating that a module is feasible or associated with positive student responses. Its stronger contribution lies in identifying recontextualizable design principles for transforming culturally embedded community knowledge into science learning, sustainability reasoning, and creative problem solving.

Taken together, current literature supports the conceptual proposition that culturally grounded elementary science learning becomes more generative when community knowledge is treated as an epistemic resource, critically reconstructed into scientific knowledge, expanded through authentic multidimensional sustainability problems, and enacted through activities deliberately designed to afford creative thinking. At the same time, a remaining research problem concerns whether this architecture can remain pedagogically meaningful for learners with limited prior cultural familiarity. This gap provides the theoretical basis for examining Galendo-based Ethno-ESD not only as a locally grounded instructional module, but also as a case for exploring culturally situated yet potentially recontextualizable science learning.

3 Methods

3.1 Research Design

This study employed Educational Design Research (EDR), also commonly referred to as Design-Based Research (DBR), because the study aimed not only to develop an instructional product but also to investigate an educational problem in context, iteratively refine the intervention, and generate design principles. EDR was implemented through four interconnected phases: (1) needs analysis and exploration; (2) design, construction, and expert appraisal; (3) formative evaluation and revision; and (4) classroom implementation, measurement, reflection, and formulation of design principles [36–38].

The study was therefore intended primarily to generate contextually grounded design knowledge rather than statistical generalization.

3.2 Research Context and Participants

The study connected the Galendo-producing community with formal elementary science education. Participants were purposively selected according to their methodological roles within the EDR process.

Table 1
Participants and methodological roles

Research phase	Participants	n	Main role
Needs analysis	Elementary teachers	6	Identify instructional practices and needs related to culture, ESD, and creative thinking
Needs analysis	Students from four elementary schools	9	Explore learning experiences, cultural exposure, sustainability understanding, and creative-thinking experiences
Cultural analysis	Galendo producers	5	Document production knowledge, resource use, cultural values, and sustainability issues
Expert appraisal	Science-content expert	1	Evaluate scientific content
Expert appraisal	Ethno-ESD expert	1	Evaluate culture–science–sustainability integration
Expert appraisal	Instructional-material expert	1	Evaluate presentation, language, graphics, and module quality
Formative trial	Grade V students	13	Examine readability, usability, and revision needs
Implementation trial	Grade V students	20	Examine classroom enactment and observed changes in creative-thinking responses

The 13 students in the formative trial were selected based on teacher recommendations because of their relatively strong academic engagement and ability to provide detailed feedback. They functioned as formative users, rather than as an effectiveness sample.

The implementation trial involved 20 Grade V students with heterogeneous academic achievement. The school was located outside the immediate Galendo-production environment, allowing exploratory

examination of the pedagogical accessibility of the cultural context among students with relatively limited prior familiarity

3.3 Development of the Instructional Intervention

The intervention consisted of a printed module, G-BUSS, integrating Galendo-related local knowledge, elementary science, Ethno-ESD, Project-Based Learning (PjBL), and creative thinking. Science learning outcomes were mapped onto phenomena embedded in Galendo production, including changes in matter, heat and energy, separation processes, force, and natural-resource use. Community knowledge was then reconstructed into scientific phenomena that students could observe, question, interpret, and explain.

The sustainability component addressed environmental, social, economic, and cultural dimensions, including resource use, production by-products, local economic activity, cultural continuity, and product innovation. PjBL provided the instructional structure for problem identification, project planning, alternative generation, product or solution development, presentation, and reflection. Learning activities were explicitly aligned with four creative-thinking dimensions: fluency, flexibility, originality, and elaboration [19, 21].

3.4 Data Sources and Instruments

First, semi-structured interviews were conducted with teachers, students, and Galendo producers. Teacher interviews focused on instructional resources, local-culture integration, ESD, creative-thinking opportunities, constraints, and learning needs. Student interviews explored learning experiences, cultural exposure, sustainability understanding, and opportunities to express ideas. Producer interviews documented Galendo production, resource utilization, cultural knowledge, sustainability challenges, and educational relevance.

Second, documentary analysis examined instructional materials in terms of resource availability, ethnoscience, ESD, creative thinking, and explicit Ethno-ESD integration.

Third, expert-appraisal instruments evaluated science content, Ethno-ESD integration, and instructional-material quality.

Fourth, a student-response questionnaire was administered during the formative trial using a four-point scale covering presentation, content usability, and perceived support for creative thinking.

Fifth, classroom observations documented student engagement and manifestations of fluency, flexibility, originality, and elaboration as process evidence.

Sixth, a researcher-developed creative-thinking assessment was administered before and after implementation. It comprised 12 multiple-choice and four constructed-response items. Each creative-thinking dimension was represented by three multiple-choice items and one constructed-response item. The assessment was contextualized within Galendo-related science and sustainability problems and

was intended as a construct-informed contextual measure rather than a direct adaptation of a standardized creativity test.

3.5 Data Analysis

Qualitative data were analyzed using a framework-based analytical procedure. Data were reduced, categorized, and organized according to domains relevant to the EDR design decisions, consistent with the logic of framework analysis [39].

Expert-appraisal scores and student questionnaire responses were summarized descriptively using percentages and interpreted together with qualitative comments.

Pretest and posttest responses were examined using Rasch stacking and racking procedures [40, 41]. Stacking was used to examine changes in estimated person measures, while racking was used to examine relative changes in item difficulty across administrations.

Because the implementation trial involved only 20 students and did not include a control or comparison group, changes in logit estimates were interpreted as observed pre–post changes, rather than as evidence of causal effects or statistical significance. Rasch results were therefore treated as exploratory and interpreted in conjunction with classroom-observation evidence.

4 Results

4.1 RQ1: Transforming Galendo Knowledge into an Ethno-ESD Learning Design

Documentary analysis showed that instructional materials were readily available (100%), but integration of ethnoscience, ESD, and creative thinking was limited to 50% each, while explicit Ethno-ESD integration was identified in only 25% of the materials. The overall score was 58.33%. Thus, the primary issue was not the absence of learning resources, but the limited integration of cultural knowledge, science, sustainability, and creative thinking.

Teacher interviews supported this pattern. Local culture had been introduced through traditional foods and production practices, but these were rarely connected explicitly to scientific concepts. ESD-related activities were also largely limited to cleanliness, conservation, and material reuse. Similarly, students were familiar with several local foods but rarely encountered them as contexts for science learning, and their understanding of sustainability was predominantly environmental.

Interviews with five Galendo producers identified production knowledge involving coconut selection, grating, coconut-milk extraction, heating, oil separation, molding, and pressing. The process also illustrated resource utilization: coconut shells could be used for charcoal, coconut residue for animal feed, and separated oil for cooking. At the same time, producers reported challenges related to raw-material availability, price fluctuations, and declining interest among younger generations. Galendo

therefore provided not only scientific phenomena but also environmental, economic, social, and cultural sustainability issues.

Evidence across the needs-analysis, design, expert-appraisal, and formative-evaluation phases generated seven design principles.

Table 2
Design principles for Galendo-based Ethno-ESD learning

Design principle	Design implication
Local culture as the primary learning context	Cultural practices remain central throughout the learning sequence
Scientific reconstruction of community knowledge	Local practices are explicitly connected with scientific concepts and explanations
Multidimensional sustainability	Environmental, social, economic, and cultural dimensions are examined together
Multimodal pedagogical mediation	Visuals, infographics, glossaries, and videos support access to the cultural context
Explicit creative-thinking opportunities	Activities deliberately support fluency, flexibility, originality, and elaboration
Explicit culture–science–ESD connections	Relationships among cultural practices, science, and sustainability are made visible
Iterative evaluation and revision	Evidence from experts, students, and observations informs refinement

4.2 RQ2: Pedagogical Feasibility and Usability

Expert appraisal produced consistently high ratings: 96.62% for science content, 95.24% for Ethno-ESD, and 95.56% for instructional-material quality. Within these assessments, contextual relevance received 95.59%, scientific reconstruction 93.75%, content quality 97.92%, presentation 97.50%, language 97.22%, graphical quality 88.89%, and module characteristics 95.00%.

Despite these ratings, experts recommended further revisions, including a glossary, QR-linked video resources, simplified scientific terminology, and more explicit culture–science–sustainability connections.

The formative trial with 13 students yielded an average response of 82.57%, comprising 81.41% for presentation, 81.41% for content usability, and 84.89% for support of creative thinking. Classroom observations identified text-heavy sections and insufficiently explicit culture–science links. Subsequent revisions therefore incorporated infographics, process diagrams, concise key points, and dedicated sections explaining culture–science relationships.

These findings indicate that pedagogical feasibility emerged from the combined evidence of expert appraisal, student response, classroom enactment, and iterative revision rather than from numerical ratings alone.

4.3 RQ3: Observed Changes in Creative Thinking

Rasch stacking showed positive pre–post logit differences for all 20 students. For the multiple-choice assessment, changes ranged from 0.37 to 4.97 logits, while constructed-response changes ranged from 1.00 to 6.34 logits.

Rasch racking showed that all 12 multiple-choice items became relatively easier at posttest, with changes ranging from 0.22 to 5.45 logits. For constructed-response items, the estimated changes were 9.53 logits for elaboration, 1.69 for fluency, 10.40 for originality, and 1.52 for flexibility.

Table 3
Summary of Rasch-based pre–post changes

Data source	Observed change
Multiple-choice stacking	0.37–4.97 logits
Constructed-response stacking	1.00–6.34 logits
Multiple-choice racking	0.22–5.45 logits
Elaborative constructed response	9.53 logits
Fluency constructed response	1.69 logits
Originality constructed response	10.40 logits
Flexibility constructed response	1.52 logits

These values represent descriptive patterns within the study sample and were not interpreted as inferential effect sizes or statistical significance.

Classroom observations provided complementary process evidence. Fluency appeared when students generated multiple uses for coconut by-products, including animal feed, organic fertilizer, planting media, handicrafts, and food ingredients. Flexibility was evident when students considered production problems from different perspectives, including temperature, stirring, raw-material quality, moisture, pressing techniques, and equipment.

Originality was reflected in ideas such as Galendo ice cream, cookies, candy, spice-flavored Galendo, coconut-fiber packaging, and QR codes introducing Galendo history. Elaboration appeared in more detailed causal explanations and project descriptions; for example, students connected continuous stirring with even heat distribution, prevention of burning, and product quality.

Originality and elaboration were especially visible during project activities. However, elaboration remained comparatively demanding and continued to require instructional support.

4.3 RQ4: Pedagogical Accessibility for Students with Limited Prior Cultural Familiarity

The implementation trial was conducted in a school outside the immediate Galendo-production environment. Despite relatively limited prior familiarity, students were able to engage with Galendo as a science and sustainability context. They asked questions about heating and changes in coconut milk, identified issues related to production by-products, considered alternative resource uses, and generated product innovations.

This engagement occurred after the module had been strengthened through images, infographics, a glossary, audiovisual representations, and explicit culture–science connections. The findings therefore do not indicate that cultural familiarity is unimportant. Rather, they suggest that a culturally specific context can become pedagogically accessible when appropriately mediated.

Accordingly, the results provide preliminary evidence of potential pedagogical transferability, but not of universal cultural transferability, because cultural familiarity was not independently measured and no direct comparison was made between high- and low-familiarity groups.

5 Discussion

5.1 From Cultural Context to Epistemic and Sustainability Reconstruction

The findings reveal an important distinction between the presence of culture in instructional materials and the use of culture as an epistemic resource for science learning. Although local cultural content was already present in schools, it was rarely connected systematically with scientific explanation, sustainability reasoning, and creative thinking. This supports the view that culturally relevant science education requires more than adding cultural examples to conventional content [6, 7].

In the present study, Galendo producers contributed experiential community knowledge that was subsequently brought into dialogue with school science. Rather than using Galendo merely as an instructional “hook,” the design maintained it as a continuous epistemic context through which students examined production practices, scientific phenomena, and sustainability-related issues. This approach is consistent with cultural border crossing [5], dialogue between epistemologies [11], and community-based science perspectives that recognize community expertise as a legitimate resource for scientific meaning-making [8].

The findings therefore support the proposition that local knowledge needs to be scientifically reconstructed rather than merely represented. Scholarship on Indigenous and local knowledge similarly

emphasizes the need for epistemic mediation when community knowledge enters formal science education [9, 10]. In this study, Galendo knowledge was treated as local/community knowledge rather than automatically categorized as Indigenous Knowledge.

The Galendo context also functioned as a sustainability problem space. Production practices illustrated resource efficiency through the reuse of coconut by-products, while simultaneously revealing economic and intergenerational challenges. Thus, the module did not present Galendo as inherently sustainable. Instead, students were encouraged to examine both its sustainability potential and its unresolved tensions.

This positioning is consistent with ESD perspectives that emphasize systems relationships, multiple dimensions, and trade-offs rather than prescriptive environmental messages [1–3]. The instructional progression moved from identifying scientific phenomena toward considering causes, consequences, affected stakeholders, and possible alternatives. Such reasoning also aligns with place-based education, in which “place” encompasses ecological, social, cultural, and economic relationships rather than geography alone [26].

Accordingly, the pedagogical value of Galendo did not arise merely from its cultural distinctiveness. It emerged from the density of scientific, social, environmental, economic, and cultural relationships embedded in its production system.

5.2 Creative Thinking Emerged from Activity Affordances

The Rasch findings showed positive pre–post directions for all participating students, but the magnitude of change varied substantially. This variation cautions against interpreting the intervention as producing a uniform effect and highlights the importance of examining how learning activities actually afforded creative thinking.

Classroom observations showed that different tasks supported different dimensions. Fluency emerged when students generated multiple possible uses for coconut by-products. Flexibility was evident when students considered problems from technical, environmental, and economic perspectives. Originality was particularly visible in product and packaging innovations, whereas elaboration appeared in causal explanations and more detailed project designs.

These findings suggest that PjBL should not be treated as an automatic cause of creativity. Rather, its contribution depends on the cognitive and epistemic demands built into project activities. This interpretation is consistent with Kokotsaki et al. [23] and with the meta-analysis by Hasibuan et al. [25], which showed that the effects of PjBL on creative thinking vary across instructional designs and contexts. Similar findings have been reported in culturally situated project learning in Indonesia [14].

The pattern also aligns with contemporary conceptualizations of creative thinking. OECD [19] distinguishes among generating diverse ideas, generating creative ideas, and evaluating or improving ideas, while Runco and Acar [21] caution that divergent thinking represents creative potential rather than

creativity as a whole. Kaufman and Beghetto's [20] concept of mini-c is also relevant because students' ideas represented personally meaningful constructions within learning rather than objectively exceptional innovations.

The prominence of originality can be understood from the frequent opportunities for students to design products and solutions. Elaboration, however, remained comparatively demanding. This indicates that producing a new idea and developing it into a detailed, coherent, and scientifically defensible explanation are distinct cognitive processes.

5.3 Creative Thinking Emerged from Activity Affordances

A further contribution concerns the relationship between ESD and creative thinking. Sustainability did not function simply as additional environmental content. Instead, it expanded the range of perspectives through which students could interpret the same problem.

For example, coconut-processing by-products could be considered simultaneously as waste, potential raw materials, economic resources, environmental concerns, or opportunities for innovation. Sustainability therefore created multiple frames that supported flexibility and idea generation.

The relationship was also reciprocal. Creative thinking helped students move from recognizing sustainability problems toward imagining possible responses. Rather than merely stating that waste should be managed, students generated alternative forms of reuse and product development.

This relationship is consistent with sustainability-competence frameworks that emphasize systems thinking, alternative strategies, and problem solving [2, 3]. It also suggests that creative thinking should not be treated as an additional skill appended to ESD. Within the present design, it functioned as a mechanism through which students explored alternative responses to socio-ecological problems.

5.4 From Culturally Familiar to Culturally Accessible Learning

The findings from students outside the immediate Galendo-production environment provide a further conceptual insight. Culturally responsive and place-based pedagogies frequently emphasize the importance of learners' familiar experiences and environments [6, 26]. However, the present findings suggest that familiarity is not the only condition through which culturally situated learning can become meaningful.

Students with limited prior exposure to Galendo were nevertheless able to engage with its scientific and sustainability dimensions. Importantly, this occurred after the module had been strengthened through visual representations, video resources, a glossary, explanations of the production process, and explicit culture–science connections.

This distinction is consistent with scholarship emphasizing epistemic navigation across multiple knowledge systems [11, 27]. Students do not necessarily need to belong to the originating cultural

community in order to learn from its knowledge, provided that the knowledge is represented responsibly and its cultural, scientific, and sustainability meanings are preserved.

The findings therefore support the cautious proposition that:

A culturally specific science context can become pedagogically accessible beyond its community of origin when community knowledge is responsibly represented, scientifically reconstructed, and connected explicitly to problems that students can investigate.

However, this study did not directly compare high- and low-familiarity groups and did not independently measure cultural familiarity. The findings therefore provide only preliminary evidence of potential pedagogical transferability, not demonstrated cultural transferability.

4.5 Design Principles, Limitations, and Implications

The seven principles generated through the EDR process represent a contribution beyond the development of the G-BUSS module itself. Educational Design Research aims to generate both practical solutions and theoretically informed design knowledge [36–38]. Recent methodological work similarly identifies design principles as an important product of design-based inquiry [35].

The findings can therefore be condensed into the following design proposition:

Culturally grounded elementary science learning becomes more generative when community knowledge is positioned as an epistemic anchor, scientifically reconstructed, expanded through multidimensional sustainability problems, enacted through open project-based activities, mediated through accessible representations, and iteratively refined using evidence from learners, experts, and community knowledge holders.

What may be recontextualized elsewhere is not the Galendo content itself, but this architecture of knowledge transformation. Other local foods, crafts, agricultural practices, or community technologies would require their own community analysis, scientific reconstruction, sustainability analysis, curriculum mapping, and formative evaluation.

Several limitations constrain the interpretation of the findings. The implementation involved only 20 students and no comparison group; consequently, the Rasch results indicate observed pre–post changes rather than causal effects. Trial 1 participants were purposively selected as information-rich formative users and were not representative of the broader Grade V population. The creative-thinking assessment was researcher-developed and context-specific, and fuller reporting of Rasch diagnostics and scoring reliability would strengthen the psychometric evidence. Cultural familiarity was also inferred primarily from school location rather than measured directly, and only one cultural context was examined.

Future research should therefore test the design principles across larger and multiple sites, explicitly measure cultural familiarity, and include comparison conditions. Additional Rasch diagnostics and

multiple raters for constructed responses would also strengthen measurement quality. Particular attention should be given to elaboration through activities involving revision, peer feedback, evidence-based justification, and improvement of initial ideas, consistent with the emphasis on evaluating and improving ideas in creative thinking [19].

For practice, the findings suggest that teachers should move beyond asking whether local culture is present in a lesson. More important questions are whether community knowledge is scientifically reconstructed, whether genuine sustainability tensions are examined, whether students are required to consider multiple perspectives, and whether learning activities deliberately create opportunities for different forms of creative thinking. In this way, local culture can function not as curricular decoration, but as an epistemic resource and a meaningful problem space for elementary science learning.

6 Conclusion

This study developed and iteratively evaluated a Galendo-based Ethno-ESD module through Educational Design Research. The findings indicate that the main instructional challenge was not the absence of learning resources, but the limited integration of local culture, science, sustainability, and creative thinking.

Community knowledge embedded in Galendo production was reconstructed into elementary science learning and extended through sustainability reasoning and project-based problem solving. Expert appraisal and formative evaluation supported the feasibility of the module while also generating revisions to strengthen visual representation, conceptual clarity, and explicit culture–science connections. During implementation, all 20 students showed positive pre–post Rasch logit changes, accompanied by observable manifestations of fluency, flexibility, originality, and elaboration, although the magnitude of change varied and elaboration remained comparatively demanding.

The study generated seven design principles emphasizing local culture as a learning context, scientific reconstruction of community knowledge, multidimensional sustainability, multimodal mediation, explicit creative-thinking opportunities, visible culture–science–sustainability connections, and iterative refinement.

The findings further suggest that a culturally specific context can remain pedagogically accessible to students with limited prior familiarity when appropriately mediated. This provides preliminary support for culturally situated yet potentially transferable science learning, without implying universal transferability or causal effects.

Accordingly, the principal contribution of this study lies not only in the G-BUSS module, but in an architecture of knowledge transformation through which community knowledge can be reconstructed into science, sustainability reasoning, problem solving, and creative agency. This architecture may inform the recontextualization of other local cultural practices in elementary science education.

Declarations

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Author contributions

Conceptualization, G.H., P.H.F., A.W and D.H.; Methodology, G.H. and P.H.F.; Software, A.Y.; Validation, G.H. and A.Y.; Formal analysis, G.H. and N.N.; Investigation, P.H.F.; Resources, A.Y.; Data curation, A.Y. and P.H.F.; Writing—original draft preparation, G.H. and P.H.F.; Writing—review and editing, G.H., P.H.F., A.W and D.H.; Visualization, N.N.; Supervision, A.Y. and G.H.; Project administration, N.N.;. All authors have read and agreed to the published version of the manuscript.

Data availability

The data are currently not publicly available due to participants' privacy, but they are available from the first author upon reasonable request.

Ethics approval

Ethical approval for this study was obtained from the Research Ethics Committee of Universitas Pendidikan Indonesia, Indonesia, under Ethical Approval No. 342/UN40.K/PT.01.01/2026. The study was conducted in accordance with relevant institutional and national ethical guidelines and regulations governing research involving human participants. The research procedures were also conducted in accordance with the ethical principles of the Declaration of Helsinki, as applicable to educational research involving human participants.

Consent for participate

Written informed consent to participate was obtained from all adult participants. For participating elementary school students, written informed consent was obtained from their parents or legal guardians, and assent was obtained from the students prior to participation. Participation was voluntary, and participants were informed about the purpose and procedures of the study as well as their right to withdraw from the research without penalty. Confidentiality and anonymity were maintained throughout the study.

Consent for publication

Not applicable. The manuscript does not contain identifiable personal information, images, or other individual participant data requiring consent for publication.

Competing interests

The authors declare no competing interests.

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