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Research article

Reconstruction of the Engineering Design Project (EDPj) Learning Model based on Ethno-ESD to Actualize Students' Sustainable Environmental Literacy

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Abstract: The research aims to reconstruct the Ethno-ESD-Based Engineering Design Project Learning Model and analyze its effectiveness in actualizing students' sustainable environmental literacy in higher education. This study uses the ADDIE model's instructional development design, which consists of two main phases: the model development phase (analysis, design, develop) and the model effectiveness testing phase (implementation and evaluation). The instrument validity test was carried out using SmartPLS 3.0 software, namely Convergent Validity in the form of Outer Loadings (Loading Factor) and Average Variance Extracted (AVE) as well as Discriminant Validity in the form of Fornell-Larker Criterion and Cross Loading. The model's effectiveness was tested through a quasi-experiment with Posttest-Only Design with Nonequivalent Groups design, involving 105 students with independent sample t-test and Effect Size analysis techniques. The reconstruction of the EDPj learning model based on Ethno-ESD can produce individuals who not only have engineering expertise but also have a strong understanding of the complexity of environmental issues and their impact on local culture. The results of the t-test showed that the experimental group had significantly higher scores than the control group in Sustainability Knowledge ($t = -5{,}828$, $p < 0.001$), Sustainability Attitude ($t = -6{,}013$, $p < 0.001$), and Self-report Sustainable Behavior ($t = -4{,}619$, $p < 0.001$). The effect size test showed a high impact on knowledge (0.88) and attitude (0.87), as well as a moderate impact on behavior (0.81). These findings indicate that learning interventions are significantly able to actualize students' sustainability literacy.

Keywords: EDP; Project Learning; Ethnoscience; ESD; Environmental Literacy; Sustainability

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1 Introduction

Environmental education is pivotal in cultivating students' awareness and concern for environmental issues (Putra, 2022). One of the key courses relevant to this context is Environmental Chemistry. To enhance the effectiveness of learning in Environmental Chemistry courses, adopting a learning model that effectively integrates aspects of ethnoscience

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and Education for Sustainable Development (ESD) is essential. The primary challenge in teaching Environmental Chemistry lies in introducing complex scientific concepts and ensuring that students comprehend their practical implications within the context of environmental sustainability. The integration between environmental chemistry courses and local wisdom creates a deeper understanding of the impact of chemistry on the environment and how local communities can play a role in sustainable solutions. Students can see that the application of chemistry can align with local wisdom, create solutions that preserve the local cultural and natural richness and develop an appreciation for local knowledge and sustainability values passed down from generation to generation (Izzah et al., 2020). This integration can motivate students to incorporate the principles of local wisdom in their approach to chemical research and practice.

The reorientation of sustainability education confirms that program developers need to balance looking ahead for a more sustainable society by looking back at traditional ecological or cultural knowledge (Zidny et al., 2021). The quality of learning can be achieved by integrating local culture into science learning (ethnoscience) (Sudarmin et al., 2020; Sumarni et al., 2021). Local culture can be a learning stimulus to motivate and assist students in constructing knowledge (Sudarmin et al., 2020; Sudarmin et al., 2023). Understanding how chemicals are used in environmental chemistry studies and their impact on local ecosystems can come from traditional community practices (Febrianty et al., 2023). Sustainability values embedded in local wisdom can inspire conservation efforts and sustainable environmental management (Li et al., 2016). Environmental chemistry studies can identify chemical activities' positive or negative impacts on the local environment. Local wisdom can offer insights into how local communities develop sustainable economic activities (Sulaiman et al., 2022). In environmental chemistry study materials, this economic activity can include developing environmentally friendly production or processing methods of chemicals.

The field study found that local communities adapted their culture to manage the environment and live harmoniously with nature (Batoro et al., 2017). Ethnoscience-based learning has a strategic role in preserving indigenous knowledge, which is included in the Educational for Sustainable Development (ESD) category. With these characteristics, ESD has long grown and developed in the environment of local communities that have always consistently preserved the environment and nature (Erman et al., 2023). The concept of ESD includes ecological awareness, environmental literacy, the relationship between humans and nature, the interaction between science and social sciences, and the exploration of environmental social issues (Juntunen & Aksela, 2014). Judging from the ESD concept, ethnoscience-based learning is very relevant to ESD, which focuses on mastering learning materials and the environment and social life. The context in ESD is then elaborated with ethnoscience to become an Ethno-ESD learning approach. Thus, Ethno-ESD is a learning approach that involves various scientific or transdisciplinary disciplines, including economic, environmental, social, and cultural aspects.

The urgent need to create a learning environment that can actualize sustainable environmental literacy presents the main issue. The Engineering Design Process (EDP) learning approach has been selected for its capacity to stimulate creativity and problem-solving through an action-oriented methodology (Denayer et al., 2003; Winarno et al., 2020). Integrating ethnoscience and ESD can deepen understanding of the interconnections between chemical knowledge and current environmental issues by reinforcing ethical values and local wisdom. Ethnoscience approaches are crucial in this context, as they involve recognizing and respecting local knowledge, cultural values, and traditional wisdom in the learning process (Sumarni et al., 2021; Sudarmin et al., 2023). The integration of ESD enhances the ethnoscience aspect by aligning learning objectives with the principles of sustainable development. Through this approach, students gain an understanding of environmental chemistry phenomena and develop sustainable solutions that can be implemented within their communities.

The Engineering Design Process (EDP) model is a systematic approach to developing products or systems (Mangold & Robinson, 2013; Syukri et al., 2018). This process encompasses steps intended to efficiently design, develop, and test products or systems (Berland et al., 2018). The EDP model typically consists of several phases or stages that aid development teams in comprehending and resolving design challenges within project-based learning environments (Baxter et al., 2007). Project-based learning is an educational methodology that emphasizes applying knowledge and skills in actual projects (Guo et al., 2020).

Project-based learning allows students to apply concepts acquired in real contexts (Shpeizer, 2019). The EDP model aids in structuring systematic steps for applying this knowledge within projects (Mangold & Robinson, 2013). Integrating the EDP model into project-based learning (Engineering Design Project) can make education more contextual and relevant, enabling students to develop robust design skills, problem-solving abilities, and team collaboration.

The Engineering Design Project (EDPj) model is a pedagogical approach centered on developing design and problem-solving skills and applying academic concepts within actual project contexts (Yu et al., 2020). The EDP learning model facilitates the practical application of knowledge, allowing students to learn through hands-on experience. The Engineering Design Project (EDPj) Learning Model Based on Ethno-ESD is a promising tool for achieving sustainable education goals, as it not only imparts chemical concepts but also promotes active student involvement in creating practical solutions to environmental challenges faced by their communities. This research significantly contributes to the development of innovative learning strategies aimed at producing graduates who possess a profound understanding of environmental chemistry and a strong commitment to sustainable practices in their daily lives. This approach is intended to cultivate students as environmentally conscious and responsible agents of change capable of addressing global environmental challenges.

The primary objective of the research is to enhance students' comprehension of environmental chemistry concepts while simultaneously fostering sustainable attitudes and behaviors. The Engineering Design Project (EDPj) Learning Model Based on Ethno-ESD is anticipated to positively impact the development of sustainable environmental literacy among students, aligning with the growing emphasis on sustainability and environmental preservation in contemporary society. The critical importance of this research lies in its comprehensive understanding of the nexus between environmental literacy and sustainable development. By emphasizing sustainable knowledge, attitudes, and behaviors, the research findings contribute substantially to shaping students as environmentally conscious change agents who can actively participate in sustainable development. Through this holistic perspective, it is expected that students will emerge as future leaders with a heightened awareness of their actions' environmental impacts, enabling them to make informed and sustainable decisions for the planet's well-being.

Education for Sustainable Development (ESD) embodies a transformative vision of education, empowering individuals of all ages to take responsibility for creating a sustainable future (Biasutti et al., 2018). ESD facilitates the acquisition of knowledge, skills, attitudes, and values essential for shaping a sustainable future (Yoon et al., 2014). Education is pivotal in achieving sustainable development by laying the foundation for transforming human perceptions, attitudes, and behaviors (Ferguson & Roofe, 2020). ESD establishes a framework for education to prepare students with the requisite knowledge, skills, attitudes, and values to shape a sustainable future (Lysgaard & Simovska, 2016). By prioritizing sustainability, education can integrate the multidimensional aspects of development, including economic equilibrium, environmental protection, and social justice (Kioupi & Voulvoulis, 2019). Through sustainable education, individuals can become change agents, contributing to sustainable development and fostering an environmentally conscious society that embraces sustainability values (Pavlova, 2013).

Integrating project-based learning with the Engineering Design Process (EDP) model results in an innovative Engineering Design Project (EDPj) model, which provides a holistic and systematic approach to developing students' technical skills and creativity. This concept combines two educational models: project-based learning, which emphasizes practical application and hands-on experience (Lucas et al., 2022), and the EDP model, which focuses on a structured and iterative engineering process (Winarno et al., 2020). The EDPj model, integrated with the Ethno-ESD approach, reinforces the alignment of the engineering process with local wisdom and sustainability values (Mangold & Robinson, 2013). Integrating Ethno-ESD within the EDPj model creates a learning environment that respects and leverages local cultural wisdom while demonstrating the relationship between technology and sustainability (McFadden & Roehrig, 2019). This approach emphasizes the empowerment of local communities and the utilization of traditional knowledge in designing technical solutions that are culturally and environmentally relevant. The rationale for developing the innovative EDPj model with Ethno-ESD lies in its capacity to foster creative thinking and sustainable solutions, considering ethnic, cultural, and environmental factors at every project design and implementation stage. The EDPj model with Ethno-ESD produces effective technical products or solutions and considers the positive social and environmental impacts consistent with the sustainability principles promoted by Ethno-ESD. Furthermore, the integration of Ethno-ESD within the EDPj model enriches students' learning experiences by immersing them in the local cultural context, exploring the potential of traditional knowledge, and creating solutions that are more attuned to the local community's needs.

This research is based on the importance of environmental education in shaping students' awareness and concern for environmental issues, as expressed by Yeşilyurt et al. (2020) and Handoyo et al. (2025). The Environmental Chemistry course was chosen because of its relevance in connecting complex scientific concepts with practical implications for sustainability, in line with Sudarmin et al. (2023, 2024), who emphasized the importance of integrating ethnosciences in learning. The EDPj model, as described by Mangold and Robinson (2013) and Syuk-ri et al. (2018), effectively stimulates creativity and problem-solving skills. By integrating ethnoscience and ESD principles, this model provides a holistic approach to building students' deep understanding of global and local environmental issues while developing sustainable attitudes and behaviors, as recommended by Denayer et al. (2003) and Winarno et al. (2020). Therefore, this research contributes to innovative learning strategies to improve students' sustainable environmental literacy, which is an urgent need in facing sustainable development challenges.

The rationale behind the EDPj learning model with Ethno-ESD is to create a learning environment that reflects cultural richness and supports sustainable development through engineering integrated with local and global values. This model offers a systematic and structured approach to designing and developing technical solutions for complex problems. The EDPj learning model incorporates a methodical approach to designing and developing products or solutions (Becker & Mentzer, 2015). The EDPj learning model mirrors the engineering work cycle in the real world, from problem identification to solution implementation, which enables students and professionals to grasp the full context of a project, integrating theoretical knowledge with actual practice. The EDPj model aids in developing technical design skills, including the capacity to design, develop prototypes, and optimize solutions. It fosters creative and innovative thinking skills, crucial in addressing technological changes and societal needs.

2 Materials and Methods

This research employs the ADDIE instructional design model (Dick & Carey, 2001), which encompasses the stages of analysis, design, development, implementation, and evaluation. These stages are divided into two main phases: the model development phase and the model effectiveness testing phase. The model development phase includes analysis, design, and development stages, whereas the model testing phase comprises the implementation and evaluation stages. Each stage of the ADDIE model involves specific activities evaluated under the research objectives, needs, and future expectations. The results of these evaluations are utilized to assess the extent of goal achievement. Progression from one phase to the next is contingent upon the outcomes of these evaluations.

2.1 Data Sources and Research Subjects

The data sources for this research encompass all materials or information the researcher utilizes to acquire relevant data aligned with the research objectives. Data sources include interviews, observations, tests, and questionnaires. The research subjects are students enrolled in the Environmental Chemistry course in the Chemistry Education study program for the 2022/2023 academic year. The method used in the EDPj learning model user trial based on Ethno-ESD is a quasi-experiment with a one-shot case study design. The subjects involved in the trial of the model are 26 students. The research design in the implementation stage uses the Posttest-Only Design with Nonequivalent Groups design experiment. The grouping of samples in this study was carried out using the purposive sampling technique, where samples were selected based on specific criteria relevant to the research objectives. The sample consisted of 5th-semester Chemistry Education students who were taking Environmental Chemistry courses, with a total of 105 students.

This sample was divided into three classes: one control class that did not get the EDPj learning model based on Ethno-ESD and two experimental classes that applied the learning model. Class grouping is carried out based on the division of administrative classes of the study program without considering the student's achievement or academic ability to avoid selection bias. The homogeneity between the control group and the experiment was examined through the distribution of student characteristics, such as average GPA and pretest results. Several strategic steps are implemented to control the potential for response bias or authoritative bias that may arise because students follow courses taught by researchers. Researchers limit their role as teachers in experimental classes to reduce the influence of authority on students. In addition, learning outcomes are assessed through an objective test (posttest) designed by an independent research team to ensure that the evaluation is not influenced by subjectivity. Observation is also carried out by third parties, such as collaborating lecturers, to maintain the objectivity of the learning process. With this procedure, research is expected to minimize bias and produce valid and trustworthy data.

2.1 Instruments and Data Analysis Techniques

The instruments utilized for the effectiveness test include the Assessment Sustainable Environmental Literacy (ASEL) set, which comprises test questions and questionnaires addressing student attitudes and behaviors. A significant innovation in this research is the development of the ASEL based on the NAAEE Framework, a set of digital assessment tools designed to measure students' sustainable environmental literacy, thereby contributing to conservation education goals within the context of local wisdom in a sustainable manner.

The research instruments were constructed based on the NAAEE framework, consisting of test and non-test items focusing on Sustainability Knowledge, Sustainability Attitude, and Self-Report Sustainable Behavior. The instrument development process is part of the design phase, which begins with creating an instrument blueprint, including analyzing the environmental chemistry lesson plan and deconstructing the indicators of environmental literacy and ESD. Validity testing of the instruments was carried out in several stages using SmartPLS 3.0 software, including Convergent Validity assessed through Outer Loadings (Loading Factor) and Average Variance Extracted (AVE), and Discriminant Validity evaluated using the Fornell-Larcker Criterion and Cross Loadings. In the Convergent Validity test results, some Outer Loading and AVE values did not meet the threshold of 0.5 or higher (Hair Jr. et al., 2017). To further assess Discriminant Validity, the Cross Loading test was employed. This test determines whether the Outer Loading values of a constructed variable are more significant for its variable than other variables. Reliability testing in this research was conducted using Composite Reliability and Cronbach's Alpha values, which were required to be above 0.6. The validity and reliability analysis model using SmartPLS was executed through the outer model test.

2.3 Analysis of the Reconstruction and Effectiveness of the Engineering Design Project (EDPj) Learning Model Based on Ethno-ESD

Data analysis in the reconstruction of the EDPj learning model based on Ethno-ESD employs a Grounded Theory approach involving a series of systematic qualitative steps. The process begins with data collection, including interviews, observations, and field notes, encompassing Ethno-ESD and environmental sustainability. The researcher works independently to prevent bias, starting with open coding/categorization to identify concepts or themes without prior conceptual limitations. In developing main categories, emphasis is placed on aspects most relevant to developing the EDPj learning model based on Ethno-ESD. Core concepts emerging from the data form the basis of the main theory, which includes relationships and processes underlying the model's development. Theory verification is conducted through data triangulation, and the results are interpreted. This comprehensive process allows for a deep understanding of how the development of the EDPj model can integrate ethnoscience and environmental sustainability aspects, enabling iteration and reflection to enhance understanding.

The interviews in this study involved participants from lecturers and students at three universities. The interview instruments were prepared systematically using interview sheets validated by five experts in instruments, chemistry education, and the environment. The validation process is carried out to ensure that the questions used are relevant, clear, and able to dig up the information needed following the research objectives. Any expert input is used to refine the instrument before it is applied in the field. This validation aims to improve the reliability and credibility of the data obtained so that the interview results can accurately represent the participants' perspectives in developing an EDPj learning model based on Ethno-ESD. **Source triangulation** was carried out by comparing the results of the interviews with data from observation and analysis of related documents. The information obtained from the interviews is consistent with data from other sources, thus strengthening the validity of the findings. **The triangulation**

method combined in-depth interviews, focus group discussions, and field record analysis to see if the interview results aligned with other methods. This approach helps identify gaps or inconsistencies in the data.

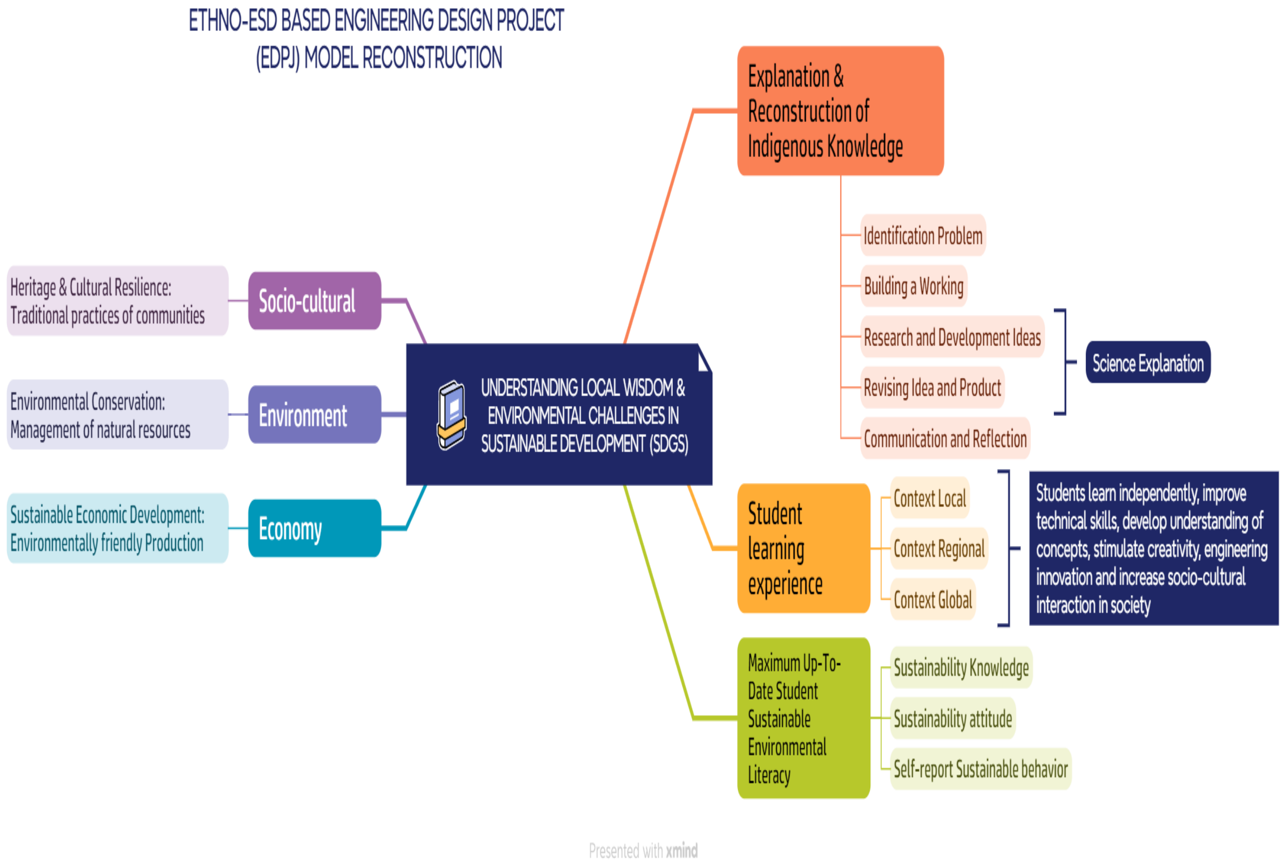
The effectiveness test data is evaluated semi-summatively to conclude whether the intervention meets predetermined specifications. The effectiveness test in this study is conducted using a quasi-experimental design, specifically the Posttest-Only Design with Nonequivalent Groups, and involves testing research prerequisites. An independent sample t-test is performed to determine if there are significant differences in sustainable environmental literacy between students implementing the EDPj learning model based on Ethno-ESD and those applying the Project-Based Learning model. The decision criterion for the independent sample t-test is that if the significance value is less than 0.05, H0 is rejected, and H1 is accepted. Additionally, the effectiveness level of the EDPj learning model based on Ethno-ESD is determined by calculating the effect size and R-Square.

3 Result

3.1 Reconstruction Results of the EDPj Learning Model Based on Ethno-ESD

Research on the EDPj learning model reconstruction based on Ethno-ESD was carried out to improve students' sustainable environmental literacy. Previous learning models generally relied on conventional approaches focused on theory and practice-based teaching that did not integrate aspects of local culture and sustainability in engineering learning. In the old model, although there was learning related to the environment, it did not pay enough attention to the relationship between engineering practices, local wisdom, and environmental sustainability issues that are increasingly relevant in today's world of higher education. The reconstruction of this model is necessary to adapt learning to current needs, where students need to not only master engineering skills but also understand the complexity of environmental problems affecting local communities, as well as how they can contribute to sustainable solutions. An Ethno-ESD-based approach that integrates local cultural values and environmental sustainability can bridge the gap. By developing this model, students are technically skilled and have a greater awareness of their work's environmental impact and the ability to design solutions based on local wisdom and sustainability principles. The preliminary model design of this study is presented in Figure 1.

Figure 1. The Preliminary EDPj Learning Model Based on Ethno-ESD Design



Constructing a learning model involves designing and developing a comprehensive framework or lesson plan that directs the teaching and learning process. The primary objective is creating an effective and structured learning environment that achieves the educational goals. The reconstruction of the EDPj learning model based on Ethno-ESD aims to provide a profound learning experience pertinent to real-life situations, fostering critical and innovative thinking that can be applied within the context of sustainable culture and environment. This stage of research activities is carried out based on a research plan following the stages of the Research and Development (R&D) research model of ADDIE's design: Analysis, Design, Development, Implementation, and Evaluation. The final goal of this development phase is to obtain an EDPj learning model based on Ethno-ESD that is ready to be implemented in environmental chemistry learning. These stages are grouped into two main phases, namely the model development phase and the model effectiveness testing phase. The model development phase consists of analysis, design, and development. Each stage has a primary goal that will be obtained through various activities, as described below.

3.1.1 Results of the Analysis Stage

This stage is a needs analysis to build a rationale for developing an EDPj learning model based on Ethno-ESD in the form of a feasibility analysis. The initial needs analysis in the Environmental Chemistry course learning aims to comprehensively understand the learning outcomes, course learning outcomes, and the structure of the semester learning plan. The learning outcomes designed include continuous awareness and concern for the environment, in-depth knowledge of the impact of chemicals on the environment and human health, and engineering design and communication skills based on local cultural approaches. The learning outcomes of the course focus on students' ability to analyze and design solutions based on the concept of conservation of local wisdom and sustainable development, including the study of global and local environmental issues, as well as sustainable management of soil, water, and air using the principles of Green Chemistry. Semester learning plans support project-based learning or case studies, which are integrated with aspects of local wisdom and the environment.

Integrating environmental aspects and local wisdom in Environmental Chemistry learning is carried out thoroughly to ensure that students understand the impact of chemical practices on the environment and can design innovative solutions. Traditional knowledge, values, and practices of local communities are important elements in managing natural resources and the environment. This approach allows students to be actively involved in solving environmental problems through learning methods relevant to the local cultural context. Thus, this needs analysis process results in a solid Semester Learning Plan and can prepare students to face environmental challenges with integrated skills and understanding. The following needs analysis of interview data with the environmental chemistry course lecturers revealed a positive view of the learning process, especially appreciation of students' enthusiasm for environmental and sustainability issues. However, challenges such as limited resources, differences in student backgrounds, and administrative obstacles are the main obstacles. The Ethno-ESD-based EDP learning model has the potential to help by integrating local values, ethnic wisdom, and relevant practical approaches to overcome these barriers. In addition, lecturers showed readiness to adapt to new, more contextual, and relevant teaching methods to increase learning effectiveness.

The approaches that lecturers have taken include combining traditional methods, using technology, and collaborative projects involving students. The potential for integrating the EDPj learning model based on Ethno-ESD principles is significant, especially in enriching group discussions, utilizing technology for intercultural collaboration, and instilling local values in teaching. Lecturers also show an openness to collaboration with fellow lecturers, students, and external parties, such as local communities and environmental institutions, to create a holistic learning experience. This collaboration can strengthen learning sustainability by connecting theory and practice, increasing student participation, and supporting environmental awareness and responsibility. This analysis provides a foundation for designing a more responsive, sustainable learning model implementation strategy.

Literature studies at the analysis stage show that learning materials about the environment and environmentally friendly behavior have been taught from schools to universities, but their impact on Indonesian society has not been significant. Although environmental awareness has long been the focus of education, research shows low public support for environmental conservation. At the university level, students' experiences dealing with environmental issues are an interesting context to integrate into learning. By utilizing new knowledge, students can be empowered to solve local, regional, and global environmental problems, making learning more relevant and applicable.

In an era of high environmental awareness and the urgent need for sustainable development, environmental literacy has become an important factor in shaping decision-making, policy formulation, and community action (Calikusu et al., 2022; Papadopoulou et al., 2022). Environmental literacy is important in promoting sustainable development and fostering a deeper understanding of the interconnection between human and environmental activities (Hamid et al., 2017; Hassan et al., 2010). Environmental literacy equips individuals with the knowledge, skills, and attitudes necessary to make informed decisions and take responsible action to address pressing environmental challenges (Alm et al., 2022; Radwan & Khalil, 2021; Sekhar & Raina, 2021). As sustainable development continues to gain global recognition as an important path to a more resilient and equitable future, the importance of environmental literacy is becoming increasingly clear and urgent.

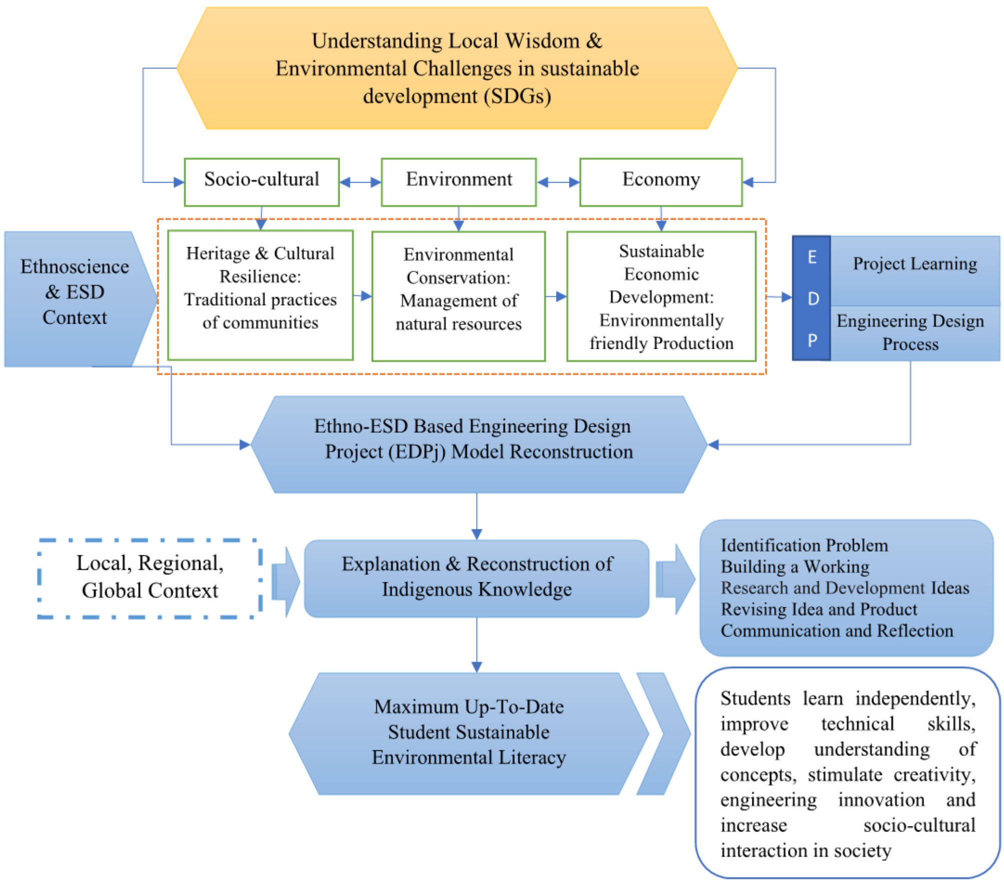
Based on the needs analysis, the development of this model is vital because there is a gap between conventional learning methods that have not been deeply integrated with local wisdom values and the concept of sustainability with the needs of students who have a high interest in environmental issues but have not been supported by relevant and applicable learning strategies. In addition, challenges such as limited resources, differences in student backgrounds, and administrative constraints require a more contextual and collaborative approach to learning. The results of interviews with lecturers also show a need to develop learning models that are not only theory-based but also project-based and collaborative with local communities to provide a more holistic learning experience. The EDPj learning model based on Ethno-ESD principles can improve students' understanding of environmental issues in a more practical and contextual way and prepare them to face sustainability challenges with a more interdisciplinary and local culture-based approach.

3.1.2 Results of the Design Stage

The design stage of the Ethno-ESD-based EDP learning model involves various strategic steps to design the model and its components. First, identifying learning objectives that align with the principles of Ethno-ESD, including understanding culture, environment, and sustainable development, by designing a learning structure that supports the integration of these concepts into learning activities according to the characteristics of students and their cultural and environmental contexts. A sustainable environmental literacy evaluation tool was developed to assess students' understanding and application of Ethno-ESD concepts. This evaluation instrument is designed to reflect the impact of learning on critical and innovative thinking skills in cultural and environmental contexts.

Overall, the design process aims to create a learning model following the cultural, in-depth, and relevant context to improve students' sustainable environmental literacy. The Ethno-ESD-based EDP reconstruction model aims to produce individuals who have engineering expertise and a strong understanding of the complexity of environmental issues and their impact on local culture. Thus, students can actualize sustainable environmental literacy holistically, gaining a deeper understanding of the interconnection between engineering, culture, and sustainability in an increasingly complex global context. The reconstruction of the Ethno-ESD-based EDPj learning model is a continuous and responsive process to changes in student needs, scientific developments, and local environmental dynamics presented in Figure 2.

Figure 2. Design of EDPj Learning Model Based on Ethno-ESD



The EDPj learning model based on Ethno-ESD aims to produce individuals who have engineering expertise and a strong understanding of the complexity of environmental issues and their impact on local cultures. Thus, students can actualize sustainable environmental literacy holistically, gaining a deeper understanding of the interconnection between engineering, culture, and sustainability in an increasingly complex global context. The EDPj learning model based on Ethno-ESD is applied by following the syntax developed from the EDP model from Jolly (2015) and PjBL from Lucas and Goodman (2015), which consists of: 1) identification problem, 2) building a working model/prototype, 3) research and development ideas, 4) revising ideas and products, 5) communication and reflection. The integration of local wisdom values is contained in the content/content of environmental chemistry study materials. The Ethno-ESD-Based EDPj learning model prioritizes improving the ability of Sustainability Knowledge, Sustainability attitude, and self-report sustainable behavior, which is a valid, practical, and effective learning model. The syntax of the Ethno-ESD-based EDPj learning model is presented in Figure 3.

Figure 3. The Syntax of the EDPj Learning Model Based on Ethno-ESD

Efforts to actualize sustainable environmental literacy through the reconstruction of the EDPj learning model based on Ethno-ESD primarily focus on enriching students' learning experiences by integrating cultural values and sustainability principles into every stage of the learning process. The EDPj learning model based on Ethno-ESD aims to foster a deep understanding of the environmental challenges faced by specific local communities by designing innovative and sustainable engineering solutions. Following the determination of the components of the EDPj learning model based on Ethno-ESD, supporting tools and evaluation instruments are specified, and the initial design of the learning model is constructed.

3.1.3 Results of the Develop Stage

The main activity in developing an Ethno-ESD-based EDP learning model was conducting a limited trial to implement the design that had been made previously. The method used in the EDPj learning model user trial based on Ethno-ESD is a quasi-experiment with The One Shoot Case Study design. The subjects involved in the model trial are 26 students of Chemistry Education in the 5th semester. The next step is to test the validity and implementation of the model. Validity tests are conducted to ensure that all model components reflect the principles of Ethno-ESD and follow the learning objectives. This process involves an assessment by education experts, instrument experts, and practitioners. In addition to the validity test, this stage also involves a feasibility test to ensure that the learning model can be implemented effectively in the actual learning environment. Lecturers provide feedback based on their practical experience applying the EDPj learning model based on Ethno-ESD in the trial class. This evaluation includes an assessment of the extent to which the model can be well integrated into the curriculum and the extent to which students respond positively to the proposed learning approach.

The validity testing in this research was conducted through several stages using SmartPLS 3.0 software. This included Convergent Validity, assessed through Outer Loadings (Loading Factor) and Average Variance Extracted (AVE), and Discriminant Validity, evaluated using the Fornell-Larcker Criterion and Cross Loadings. The results of the Convergent Validity test indicated that several Outer Loading and AVE values did not meet the standard threshold of 0.5. The initial AVE values are presented in Table 1.

Table 1. AVE Values for Sustainable Environmental Literacy

	Cronbach's Alpha	**rho_A**	**Composite Reliability**	**AVE**
Sustainability Knowledge	0.870	0.871	0.802	0.606
Sustainability Attitude	0.802	0.873	0.894	0.617
Self-report Sustainable Behavior	0.752	0.797	0.875	0.532

Table 1 illustrates that all variables have met the AVE criteria, with values ≥0.5, indicating that the Convergent Validity test is acceptable. The results of the Convergent Validity test presented in Table 1 show that the AVE values for the three dimensions of Sustainable Environmental Literacy (Sustainability Knowledge, Sustainability Attitude, and Self-report Sustainable Behavior) are above the minimum accepted threshold of 0.5. The AVE values for each dimension are as follows: Sustainability Knowledge (0.606), Sustainability Attitude (0.617), and Self-report Sustainable Behavior (0.532). This result shows that all indicators on each construct have sufficient convergent validity, as the AVE value is more significant than 0.5, meaning that the construct can account for more than 50% of the indicators' variance. Thus, these results support the validity of good constructs in the research model.

The reliability in this study was analyzed using Cronbach's Alpha, rho_A, and Composite Reliability (CR). Based on Table 1, all constructs have a Cronbach's Alpha value above 0.7, which indicates that the instrument has a good level of internal consistency. rho_A values that are close to or higher than Cronbach's Alpha also indicate reliability stability in each variable. In addition, the CR value for all variables is above 0.7, which means that the construct has strong reliability. CR is superior to Cronbach's Alpha in measuring reliability because it considers indicators with different weights in the measurement model. Furthermore, the validity of the research was continued with the Discriminant Validity test through the Fornell-Larcker Criterion and Cross Loading tests. The Fornell-Larcker Criterion test is carried out by comparing the value of AVE with other latent variables. The concept that must be fulfilled is that the correlation value of one AVE with its own variable construct must be greater than that of other variable constructs. The diagonal and vertical directions can see this of each variable column. The Fornell-Larker Criterion values are presented in Table 2.

Table 2. Fornell-Larcker Criterion Values

	Sustainability Knowledge	**Sustainability Attitude**	**Self-report Sustainable Behavior**
Sustainability Knowledge	0.805		
Sustainability attitude	0.717	0.808	
Self-report Sustainable Behavior	0.700	0.802	0.764

Table 2 indicates that the AVE value for Latent Variable 1 - Sustainability Knowledge with itself is 0.805. This signifies that the AVE value of Latent Variable 1 with itself is higher than its correlation with other variables. Similarly, the AVE value for Latent Variable 2 - Sustainability Attitude is 0.808, and for Latent Variable 3 - Self-report Sustainable Behavior, it is 0.764. A reliable instrument consistently produces the same data when used repeatedly to measure the same object. The validity and reliability assessments using the Measurement Model indicate that the data collection instruments employed in this study are valid and reliable. These findings demonstrate that the research instruments possess dependable consistency.

3.2 Effectiveness of the EDPj Learning Model Based on Ethno-ESD on Sustainable Environmental Literacy

The objective of the effectiveness testing phase for the EDPj learning model based on Ethno-ESD is to provide a comprehensive assessment of the model's effectiveness in fostering students' sustainable environmental literacy. This phase comprises the implementation and evaluation stages.

3.2.1 Results of the Implementation Stage

The research in this implementation stage uses the Posttest-Only Design with Nonequivalent Groups design experiment. The model was implemented in 16 meetings in August-December 2023 with the application of the syntax of the Ethno-ESD-based EDP learning model in the environmental chemistry course.

Table 3. Implementation Results of the EDPj Learning Model based on Ethno-ESD

Syntax Model	**Student Activities**
Identification Problem	Students concentrate on identifying aspects of the natural and environmental carrying capacity. This activity encompasses understanding ecological conditions, the sustainability of natural resources, and the impact of tourism activities on the local ecosystem. Additionally, students investigate the cultural carrying capacity and local wisdom within their respective areas. This involves comprehending cultural values, traditions, and community participation in environmental development.
Building a Working	Students engage actively in the design of models or prototypes aimed at addressing the previously identified environmental issues. This process offers practical experience applying environmental chemistry concepts and devising sustainable solutions.
Research and Development Ideas	The instructional activities emphasize collecting information to substantiate the proposed design concept. This involves the analysis of literature, environmental data, and the investigation of current technologies that can be incorporated into the proposed solution.
Revising Idea and Product	Students underscore the significance of ongoing evaluation and refinement. They are prompted to reflect on the efficacy of their solutions, receive feedback, and implement necessary revisions to improve the effectiveness and sustainability of their approaches. This stage is vital for ensuring that the solutions meet current demands, contribute positively and sustainably to the environment, and respect local wisdom.
Communication and Reflection	Students must present their ideas and solutions to their peers and the community. The reflection process is also conducted to evaluate the environmental and social impacts of the proposed solutions.

3.2.2 Results of the Evaluation Stage

In general, the evaluation stage is aimed at obtaining an overview of the extent to which the Ethno-ESD-based EDPj learning model developed can actualize sustainable environmental literacy, obtaining an overview of the ease and difficulties (strengths and limitations) during the implementation of the model. An independent sample t-test was conducted to see if there was a significant difference between the sustainable environmental literacy of students who applied the Ethno-ESD-based EDP learning model and those who applied the Project-based Learning model. The basis for decision-making in the independent sample t-test is that if the significance value < 0.05, H_0 is rejected, and H_1 is accepted. The prerequisite test was carried out to test the normality of the data presented in Table 4.

Table 4. Test of Normality (Shapiro-Wilk)

		W	p
Sustainability Knowledge	Control	0.852	0.076
	Experiment	0.987	0.146
Sustainability attitude	Control	0.887	0.083
	Experiment	0.954	0.056
Self-report sustainable behavior	Control	0.897	0.083
	Experiment	0.923	0.056

Note. Significant results suggest a deviation from normality.

The normality test results showed that all variables, both in the control group and the experiment, had a W value closer to 1 and a p-value greater than 0.05. The W value in the Shapiro-Wilk test indicates how close the data distribution is to the normal distribution, where a value close to 1 indicates that the data is more likely to be normal. In more detail, for the Sustainability Knowledge variable, the W value in the control group was 0.852 (p = 0.076), while in the experimental group, it was 0.987 (p = 0.146). This value showed no significant deviation from normality in either group. On the Sustainability Attitude variable, the control group had a W = 0.887 (p = 0.083), while the experimental group W = 0.954 (p = 0.056), which also showed that the data could be considered normal. Furthermore, in the Self-report Sustainable Behavior variable, the W value in the control group was 0.897 (p = 0.083), and in the experimental group was 0.923 (p = 0.056), which means that the data still met the normality assumption. Based on these results, since all p-values are greater than 0.05, the null hypothesis (H_0) is accepted, which states that the data are normally distributed.

Thus, the parametric statistical analysis method can be used for further analysis without transforming the data. This ensures that the analysis results are more valid and can be interpreted properly. The following prerequisite is the homogeneity test, with Levene's test in Table 5.

Table 5. Test of Equality of Variances (Levene's)

	F	df1	df2	p
Sustainability Knowledge	0.819	1	103	0.176
Sustainability attitude	0.185	1	103	0.283
Self-report sustainable behavior	0.133	1	103	0.756

The results of Levene's Test for Equality of Variances presented in Table 6 show that the variances between groups (Control and Experiment) for the three variables tested are homogeneous or not significantly different. Since the p-value of all three variables is greater than the commonly used significance level of 0.05, we fail to reject the null hypothesis. This means there is not enough evidence to show a difference in variance between the Control and Experiment groups. In other words, the assumption of variance homogeneity has been fulfilled for these three variables. Since the results of Levene's test show that the variance between the groups does not differ significantly, a standard independent sample t-test can be performed, which assumes the equivalence of variance between the groups. The results of the T-test analysis on Sustainability Knowledge, Sustainability Attitude, and Self-Report Sustainable Behavior were calculated using SPSS 26 software and are summarized in Table 6.

Table 6. T-Test Results for Sustainability Knowledge, Sustainability Attitude, and Self-Report Sustainable Behavior

Dimensi Sustainable Environmental Literacy	**Group**	**Mean**	**SD**	**t**	**Sig.(2-Tailed)**
Sustainability Knowledge	Control	71.448	5.272	-5.828	< .001
	Experiment	79.737	7.980		
Sustainability attitude	Control	122.725	16.024	-6.013	< .001
	Experiment	132.215	24.011		
Self-report sustainable behavior	Control	74.875	11.930	-4.619	< .001
	Experiment	76.369	12.136		

The t-test results for the comparison between the Control and Experiment groups on the three dimensions of Sustainable Environmental Literacy (Sustainability Knowledge, Sustainability Attitude, and Self-report Sustainable Behavior) showed significant differences between the two groups in each variable tested. In the Sustainability Knowledge dimension, the Control group has an average score of 71,448 (SD = 5.272), while the Experiment group has an average score of 79.737 (SD = 7.980). The t-test produced a t(103) = -5.828 value, with a $p < 0.001$, which showed a significant difference between the two groups. The Experiment group had significantly higher scores compared to the Control group. For the Sustainability Attitude dimension, the Control group had an average of 122,725 (SD = 16.024), while the Experiment group had an average of 132.215 (SD = 24.011). The t-test showed t(103) = -6.013, with a $p < 0.001$, indicating a significant difference between the two groups. The Experiment group showed a more positive attitude towards sustainability than the Control group. In the Self-report Sustainable Behavior dimension, the Control group had an average of 74.875 (SD = 11.930), while the Experiment group had an average of 76.369 (SD = 12.136). The t-test produced a value of t (103) = -4.619, with a $p < 0.001$, which indicates a significant difference. The average difference between the Control and Experiment groups was less significant than in the dimensions of Sustainability Knowledge and Attitude.

The t-test results showed that the Experiment group had higher scores on all sustainability dimensions (knowledge, attitudes, and behaviors) than the Control group, with statistically significant differences in each variable. These results show that the treatment or intervention applied to the Experiment group positively affects students' knowledge, attitudes, and sustainable behavior. Furthermore, an effect size test was carried out to measure the effectiveness of the Ethno-ESD-based EDPj learning model on sustainability knowledge, sustainability attitude, and Self-reporting of the sustainable behavior of students, which is presented in Table 7.

Table 7. Effect Size Test Results for Sustainability Knowledge, Sustainability Attitude, and Self-Report Sustainable Behavior

Dimensions of Sustainable Environmental Literacy	Effect Size	Interpretation
Sustainability Knowledge	0.88	High
Sustainability attitude	0.87	High
Self-report sustainable behavior	0.81	Moderate

The effect size test results, which recorded high scores for Sustainability Knowledge (0.88) and Sustainability Attitude (0.87), indicate a significant impact on knowledge and attitudes towards sustainability within the context of this study. The high effect size values for these two variables suggest that changes in participants' knowledge and attitudes strongly influence sustainability. Conversely, the moderate effect size for Self-Report Sustainable Behavior (0.81) signifies a more moderate impact on the sustainable behaviors reported by respondents. Although the effect is not as pronounced as that for knowledge and attitude, it still indicates a substantial relationship between these factors and sustainable behavior. These findings suggest that efforts to enhance knowledge and attitudes toward sustainability can positively influence the implementation of sustainable behaviors in daily practice.

Subsequent testing involved analyzing the Standardized Root Mean Square Residual (SRMR) values from the sustainable environmental literacy test for environmental chemistry students, which was 0.089, less than 0.10, indicating a model fit category. The model fit output for the inner model of sustainable environmental literacy using SmartPLS 3 is presented in Table 8.

Table 8. Output Model Fit Test

	Saturated Model	Estimated Model	Model-Fit Criteria
SRMS	0.089	0.089	SRMS<0.08
d_ULS	1.760	1.760	d_ULS > 2.000
d_G	1.301	1.301	d_G > 0,900
Chi-Square	745.723	745.723	
NFI	0.945	0.945	NFI>0.9

The SRMS (Standardized Root Mean Square), GFI (Goodness of Fit Index), and d_G values for the learning model in actualizing sustainable environmental literacy meet the model-fit criteria. This indicates that the model's fit metrics from the descriptive data are acceptable and well-suited. The NFI (Normed Fit Index) value exceeds the standard threshold, indicating high significance. The Analysis of Variance (R^2) or Determination Test assesses the influence or contribution of the independent variables on the dependent variable, as represented by the R-Square coefficient in the Outer Model testing. An R-Square value of 0.691 indicates the proportion of variability in the dependent variable explained by the independent variables within the model. In this context, the dependent variable is the EDPj learning model based on Ethno-ESD, while the independent variables are Sustainability Knowledge, Sustainability Attitude, and Self-Report Sustainable Behavior. The Adjusted R-Square value of 0.685 is a refined version that accounts for the number of independent variables and the sample size. An R-Square value of 0.691 demonstrates that Sustainability Knowledge, Sustainability Attitude, and Self-Report Sustainable Behavior explain 69% of the variability in the EDPj learning model based on the Ethno-ESD construct. Therefore, it can be concluded that 69% of the variance in the sustainable environmental literacy construct is attributable to the development of the EDPj learning model based on Ethno-ESD.

4. Discussion and Conclusion

The EDPj learning model based on Ethno-ESD significantly impacts the actualization of sustainable environmental literacy. By integrating local values, culture, and environmental considerations into engineering projects, students comprehensively understand technology's interconnections with social and environmental contexts (Yu et al., 2020). This approach encourages students to develop a deeper understanding of environmental issues and heighten their awareness of the technological impacts on sustainability (Mangold & Robinson, 2013). Implementing the social system within the EDPj learning model based on Ethno-ESD is evident through the interactions between lecturers and students. These interactions are reciprocal, occurring both between lecturers-students and among students themselves. Such social interactions foster a dynamic and inclusive learning environment where the understanding of sustainability is rooted not only in scientific knowledge, cultural experiences, and local values (Barth & Michelsen, 2013; Raymond et al., 2010). Through this process, students transition from mere knowledge recipients to agents of change, capable of contributing to sustainable development within their cultural contexts.

The EDPj learning model based on Ethno-ESD is centered around the student, aligning with social constructivist perspectives that emphasize the importance of activities and practical engagement in the learning process (Smit et al., 2014; Hynes, 2017). Lecturers are facilitators (Keiler, 2018), guides, motivators, and managers (Garrett, 2008). Collaborative learning environments shape student interaction patterns, fostering communication, cooperation, the exchange of ideas, and mutual respect (Robinson et al., 2017; Yücel & Usluel, 2016). The norms adhered to during the learning process reflect the prevailing societal norms of Indonesia, such as politeness, religious adherence, respect, responsibility, and discipline (Hayati et al., 2020; Munawir, 2024). These norms are mirrored in the character development of the students.

The role of lecturers in implementing the EDPj learning model based on Ethno-ESD encompasses functions as facilitators (Purnama, 2015; Allen & Blythe, 2018) and motivators (Johnson, 2017; Kade et al., 2022). As motivators, lecturers can stimulate students' desire to learn. The motivation provided can involve various student environments, including social and cultural potentials. This aligns with student projects linking motivation to local wisdom, such as eco-friendly chemical batik, demonstrating the direct relevance between learning material and local wisdom, which increases student engagement in learning. Additionally, lecturers serve as managers (Banasiak & Karczmarzyk, 2018; Gujjar et al., 2009; Ngaziah et al., 2021) and guides (Al-Maali & Siddiek, 2022). In implementing learning, lecturers facilitate the creation of a constructive learning environment (Triantafyllou, 2022). This is exemplified in the identification problem syntax, where lecturers assist students in extensively seeking information and analyzing concepts related to the movement system material.

Lecturers, as motivators, can significantly enhance students' learning motivation. They can also encourage students to complete projects within the predetermined schedule. Elvianasti et al. (2022) suggest that students with high learning motivation will likely achieve higher learning outcomes. This is evident in building a working model syntax of the EDPj learning model based on Ethno-ESD, where lecturers provide motivation and feedback on the progress of students' projects. Feedback from lecturers in their roles as facilitators, motivators, managers, and guides is crucial when implementing the EDPj learning model based on Ethno-ESD.

The stages of this research adhered to the preliminary research framework, which aims to identify field needs by analyzing lecturers' understanding of the Merdeka curriculum implemented in teaching. The Merdeka curriculum includes project-based learning strategies and themes of local wisdom that can be integrated into instruction (Festiyed et al., 2022), as well as the use of technology in education (Azimi, 2013) to support sustainable education (Sung et al., 2021; Al-Mudabri & Tayfour, 2021; Baena-Morales et al., 2020) and quality education (Haleem et al., 2022), and to achieve teaching and learning objectives (Almufarreh & Arshad, 2023). Therefore, the development of this instructional design serves as the current needs analysis. Needs assessment is employed to identify present requirements in developing an instructional strategy (Nugraha et al., 2018). The instructional design developed incorporates aspects of ethnoscience, ESD, and EDP derived from project-based learning models as a technology in education, aligning with government policies on the applied curriculum. Integrating technology provides opportunities for students to engage directly and interactively, enabling them to create and innovate within projects to develop additional technology-based learning media.

Further analysis of the evaluation results indicates that the EDPj learning model based on Ethno-ESD design positively impacts three main aspects: Sustainability Knowledge, Sustainability Attitude, and Self-Reported Sustainable Behavior among students. The increase in Sustainability Knowledge is evident from the students' understanding of sustainability concepts applied in the context of sustainability projects, such as the eco-friendly natural batik project (Ariyatun et al., 2022). This outcome reflects the success of the EDP learning design in effectively transferring sustainability knowledge to students. The change in Sustainability Attitude illustrates a significant shift in students' perspectives on environmental and sustainability issues. The EDPj learning model based on Ethno-ESD design has effectively created an environment conducive to developing positive attitudes towards sustainability, incorporating ethnographic elements, such as the creation of biopesticides from black turmeric leaves, to explore local and cultural values that support sustainability. Enhancing Self-Reported Sustainable Behavior indicates that the EDP learning design not only imparts knowledge and influences attitudes but also encourages students to undertake tangible, sustainable actions (Horvath et al., 2013). Students' ability to report their sustainable behaviors underscores the integration of sustainability values into their daily practices.

The Ethno-ESD-based EDPj learning design is crucial in influencing students' perspectives on sustainability. The change in Sustainability Attitude shows how students' values have evolved to include the value of environmental conservation. As evidenced by their growing understanding of sustainability issues, including waste reduction, the use of eco-friendly materials, and the preservation of local culture in their daily activities, students are becoming increasingly concerned about the impact of their actions on the environment. This shift can be explained in ethnographic teaching methods, which encourage students to understand the importance of local values and expose them to scientific data (Baptista & Molina-Andrade, 2023). For example, a project involving converting black turmeric leaves into biopesticides gives students a first-hand view of how local knowledge can be integrated into modern sustainability solutions. This reinforces a positive attitude towards sustainability and connects abstract concepts with real contexts, thus encouraging the internalization of these values.

In the aspect of sustainable behavior, students showed an increase in real behavior that supported their aspirations in sustainable behavior. This is shown by the proactive application of environmentally friendly methods in daily life and learning initiatives. The ability of students to report behaviors that eliminate their cravings, such as using organic materials in daily activities or reducing the use of plastic, shows how the values of cravings are refined and integrated into their worldview. It is impossible to separate the development of these behaviors from teaching practices that encourage the active involvement of students as agents of change. This strategy is consistent with Triana et al. (2020), highlighting how project-based learning can motivate students to act in ways that advance their goals. Overall, the EDPj learning model based on Ethno-ESD has succeeded in creating a learning environment that fosters sustainability awareness and motivates students to implement real actions. This transformation of attitudes and behaviors proves that sustainability-based education has great potential to form a more responsible generation for the environment and culture.

The EDPj learning model based on Ethno-ESD provides students opportunities to collaborate with local communities, enhancing community engagement in educational projects. As a result, students can directly observe the impact of the technological innovations they design within a sustainability context, which can stimulate positive changes in attitudes and actions toward the environment (Winarno et al., 2020). Consequently, the EDPj learning model based on Ethno-ESD develops students' technical skills and fosters deep and sustainable environmental literacy. Research findings indicate that the EDPj learning model based on Ethno-ESD addresses the local sociocultural context. By incorporating these aspects, the learning process becomes more relevant and capable of addressing specific environmental issues pertinent to the local community. This relevance is crucial for imparting a more significant positive impact on students and the community.

The environmental literacy of prospective teachers improves after participating in the EDPj learning model based on Ethno-ESD. The EDPj learning approach employs strategies to foster environmental literacy in prospective teachers through environmental education (Saribas et al., 2014). This learning model is essential for building environmental literacy in the next generation, offering solutions to environmental problems (Shamuganathan & Karpudewan, 2015). Moreover, this model can enhance environmental literacy through effective education (Ozsoy et al., 2012). The project activities support achieving sustainable development competencies in higher education through project- and problem-based pedagogy (Lozano et al., 2017).

Developing environmental literacy in prospective teachers will instill confidence and competence, enabling them to deliver environmental education to their students effectively (Dada et al., 2017). This educational model enhances teachers' confidence in implementing environmental education by leveraging their learning experiences during coursework (Tuncer et al., 2009). Consequently, sustainable development education in higher education necessitates pedagogies that align with the desired competencies (Lozano et al., 2017). Integrating the context of environmental education practices derived from cultural heritage can significantly enhance environmental literacy. The implementation of ESD in Norway exemplifies this approach through experiential learning pedagogies and sociocultural learning theories (Jegstad et al., 2018).

The reconstruction of the EDPj learning model based on Ethno-ESD can produce individuals with engineering expertise and a strong understanding of the complexity of environmental issues and their impact on local culture. The EDPj learning model based on Ethno-ESD meets the validity criteria and effectively actualizes students' sustainable environmental literacy. The results of the independent sample T-test, with a significance level of less than 0.05, indicate a significant difference between the experimental and control classes. The Effect Size test result of 0.8 signifies a high level of effectiveness. This research concludes that the EDPj learning model based on Ethno-ESD was successfully developed with five syntaxes, demonstrating both feasibility and effectiveness in actualizing students' sustainable environmental literacy.

Research Ethics

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author Contributions

A: conceptualization, investigation, methodology, project administration, validation, visualization, writing—original draft preparation, writing—review and editing.
S: formal analysis, writing—review and editing
A.R: data curation, funding acquisition

W: writing—review and editing.

TW: supervision

All authors have read and agreed to the published version of the manuscript.

Artificial Intelligence

SMART-PLS (Simultaneous Multi-group Analysis and Response-based PLS) and VOSviewer is a software tool for constructing and visualizing bibliometric networks.

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References

Alm, K., Beery, T. H., Eiblmeier, D., & Fahmy, T. (2022). Students' learning sustainability – implicit, explicit or non-existent: a case study approach on students' key competencies addressing the SDGs in HEI program. *International Journal of Sustainability in Higher Education*, *23*(8), 60–84. https://doi.org/10.1108/IJSHE-12-2020-0484

Baptista, G. C. S., & Molina-Andrade, A. (2023). Science Teachers' Conceptions About the Importance of Teaching and How to Teach Western Science to Students from Traditional Communities. *Human Arenas*, *6*(4), 704–731. https://doi.org/10.1007/s42087-021-00257-4

Barth, M., & Michelsen, G. (2013). Learning for change: An educational contribution to sustainability science. *Sustainability Science*, *8*(1), 103–119. https://doi.org/10.1007/s11625-012-0181-5

Batoro, J., Indriyani, S., & Yanuwiadi, B. (2017). Ethno-ecology of Komplangan Field of the Bromo, Tengger, and Semeru Area in East Java:A Qualitative Approach. *Biosaintifika: Journal of Biology & Biology Education*, *9*(1), 41. https://doi.org/10.15294/biosaintifika.v9i1.9193

Baxter, D., Gao, J., Case, K., Harding, J., Young, B., Cochrane, S., & Dani, S. (2007). An engineering design knowledge reuse methodology using process modelling. *Research in Engineering Design*, *18*(1), 37–48. https://doi.org/10.1007/s00163-007-0028-8

Becker, K., & Mentzer, N. (2015). Engineering Design Thinking : High School. *Proceedings of 2015 International Conference on Interactive Collaborative Learning (ICL), September*, 5–12.

Berland, L., Steingut, R., & Ko, P. (2018). High School Student Perceptions of the Utility of the Engineering Design Process: Creating Opportunities to Engage in Engineering Practices and Apply Math and Science Content. *Journal of Science Education and Technology*, *23*(6), 705–720. https://doi.org/10.1007/s10956-014-9498-4

Biasutti, M., Makrakis, V., Concina, E., & Frate, S. (2018). Educating academic staff to reorient curricula in ESD. *International Journal of Sustainability in Higher Education*, *19*(1), 179–196. https://doi.org/10.1108/IJSHE-11-2016-0214

Calikusu, A. N., Cakmakli, A. B., & Gursel Dino, I. (2022). The impact of architectural design studio education on perceptions of sustainability. *International Journal of Architectural Research: Archnet-IJAR*. https://doi.org/10.1108/ARCH-09-2021-0251

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE Publications Inc.

Denayer, I., Thaels, K., Vander Sloten, J., & Gobin, R. (2003). Teaching a structured approach to the design process for undergraduate engineering students by problem-based education. *European Journal of Engineering Education*, *28*(2), 203–214. https://doi.org/10.1080/0304379031000079031

Dick, W., & Carey, L. (2001). *The systematic design of instruction (5th)*. New York: Longmann.

Erman, Suyatno, & Wakhidah, N. (2023). An expert judgment of textbook draft of local wisdom-based learning of science: A preliminary study. *The 1st International Conference on Science Education and Science*.

Fasasi, R. A. (2017). Effects of ethnoscience instruction, school location, and parental educational status on learners' attitude towards science. *International Journal of Science Education*. https://doi.org/10.1080/09500693.2017.1296599

Febrianty, Y., Rohaedi, E., Hosnah, A. U., & Wijaya, M. M. (2023). the Local Government Concept To Protect the Value of Community Cultural Traditions (Pariaman West Sumatra) in Regional Regulations. *Journal of Law and Sustainable Development*, *11*(3), 1–14. https://doi.org/10.55908/sdgs.v11i3.434

Ferguson, T., & Roofe, C. G. (2020). SDG 4 in higher education: challenges and opportunities. *International Journal of Sustainability in Higher Education*, *21*(5), 959–975. https://doi.org/10.1108/IJSHE-12-2019-0353

Garrett, T. (2008). Student-Centered and Teacher-Centered Classroom Management : A Case Study of Three Elementary Teachers. *Journal of Classroom Interaction*, *43*(2004), 34–47.

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*(May), 101586. https://doi.org/10.1016/j.ijer.2020.101586

Hair Jr., J. F., Matthews, L. M., Matthews, R. L., & Sarstedt, M. (2017). PLS-SEM or CB-SEM: UpdatedUpdated guidelines on which method to use. *International Journal of Multivariate Data Analysis*, *1*(2), 107.

Hamid, S., Ijab, M. T., Sulaiman, H., Md. Anwar, R., & Norman, A. A. (2017). Social media for environmental sustainability awareness in higher education. *International Journal of Sustainability in Higher Education*, *18*(4), 474–491. https://doi.org/10.1108/IJSHE-01-2015-0010

Handoyo, E., Ariyatun, A., Syaifuddin, Winarto, W., Saputro, S. D., Anwar, E. D., Reffiane, F., & Kenayathulia, H. B. (2025). Integration of the global attitudes of prospective teachers in encouraging a culture of environmental conservation for sustainable development in higher education. *Multidisciplinary Review*, *8*(4).

Hardy, J. G., Sdepanian, S., Stowell, A. F., Aljohani, A. D., Allen, M. J., Anwar, A., Barton, D., Baum, J. V., Bird, D., Blaney, A., Brewster, L., Cheneler, D., Efremova, O., Entwistle, M., Esfahani, R. N., Firlak, M., Foito, A., Forciniti, L., Geissler, S. A., … Wright, K. L. (2021). Potential for Chemistry in Multidisciplinary, Interdisciplinary, and Transdisciplinary Teaching Activities in Higher Education. *Journal of Chemical Education*, *98*(4), 1124–1145. https://doi.org/10.1021/acs.jchemed.0c01363

Hassan, A., Noordin, T. A., & Sulaiman, S. (2010). The status on the level of environmental awareness in the concept of sustainable development amongst secondary school students. *Procedia - Social and Behavioral Sciences*, *2*(2), 1276–1280. https://doi.org/10.1016/j.sbspro.2010.03.187

Hastuti, P. W., Setianingsih, W., & Widodo, E. (2019). Integrating inquiry based learning and Ethnoscience to enhance students' scientific skills and science literacy. In *Journal of Physics: Conference Series* (Vol. 1387, No. 1, p. 012059). IOP Publishing. https://iopscience.iop.org/article/10.1088/1742-6596/1387/1/012059/meta

Hayati, F. N., Suyatno, S., & Susatya, E. (2020). Strengthening of Religious Character Education Based on School Culture in the Indonesian Secondary School. *The European Educational Researcher*, *3*(3), 87–100. https://doi.org/10.31757/euer.331

Horvath, N., Stewart, M., & Shea, M. (2013). Toward Instruments of Assessing Sustainability Knowledge: Assessment Development, Process, and Results From A Pilot Survey At The University of Maryland. *Journal of Sustainability Education*, *5*(May). https://www.susted.com/wordpress/content/toward-instruments-of-assessing-sustainability-knowledge-assessment-development-process-and-results-from-a-pilot-survey-at-the-university-of-maryland_2013_06/

Hynes, M. (2017). Students-as-producers: Developing valuable student-centered research and learning opportunities. *International Journal of Research Studies in Education*, *7*(4). https://doi.org/10.5861/ijrse.2017.1858

Izzah, S. N., Sudarmin, S., & Prasetyo, A. P. B. (2020). Identification of the indigenous science concepts in the batik-manufacturing process to develop STEM integrated ethnoscience learning. *Journal of Physics: Conference Series.* vol. 1567, no. 4, p. 042032. https://iopscience.iop.org/article/10.1088/1742-6596/1567/4/042032/meta

Juntunen, M. K., & Aksela. (2014). Education for sustainable development in chemistry – Challenges, possibilities and pedagogical models in Finland and elsewhere. *Chemistry Education Research and Practice*, *15*, 488–500. https://doi.org/10.1039/x0xx00000x

Keiler, L. S. (2018). Teachers' roles and identities in student-centered classrooms. *International Journal of STEM Education*, *5*(34). https://doi.org/https://doi.org/10.1186/s40594-018-0131-6

Kioupi, V., & Voulvoulis, N. (2019). Education for Sustainable Development : A Systemic Framework for Connecting the SDGs to Educational Outcomes. *Sustainability*, *11*.

Li, Y., Cheng, H., Beeton, R. J. S., Sigler, T., & Halog, A. (2016). Sustainability from a Chinese cultural perspective: the implications of harmonious development in environmental management. *Environment, Development and Sustainability*, *18*(3), 679–696. https://doi.org/10.1007/s10668-015-9671-9

Lucas, H.-D. L. C., Martinez-Rodrigo, F., De Pablo, S., Ramirez-Prieto, D., & Rey-Boue, A. B. (2022). Procedure for the Determination of the Student Workload and the Learning Environment Created in the Power Electronics Course Taught Through Project-Based Learning. *IEEE Transactions on Education*, *65*(3), 428–439. https://doi.org/10.1109/TE.2021.3126694

Lysgaard, J. A., & Simovska, V. (2016). The significance of 'participation' as an educational ideal in education for sustainable development and health education in schools. *Environmental Education Research*, *22*(5), 517–534. https://doi.org/10.1080/13504622.2015.1029875

Mangold, J., & Robinson, S. (2013). The engineering design process as a problem-solving and learning tool in K-12 classrooms. *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--22581

Marfai, M. A. (2019). *Pengantar Etika Lingkungan dan Kearifan Lokal*. Yogyakarta: Gadjah Mada University Press.

McFadden, J., & Roehrig, G. (2019). Engineering design in the elementary science classroom: supporting student discourse during an engineering design challenge. In *International Journal of Technology and Design Education* (Vol. 29, Issue 2). Springer Netherlands. https://doi.org/10.1007/s10798-018-9444-5

Munawir, A. (2024). Harmonizing Local Wisdom with Islamic Values : A Guide to Character Education Development. *International Journal of Asian Education*, *5*(1), 63–75.

Papadopoulou, M., Papasolomou, I., & Thrassou, A. (2022). Exploring the level of sustainability awareness among consumers within the fast-fashion clothing industry: a dual business and consumer perspective. *Competitiveness Review*, *32*(3), 350–375. https://doi.org/10.1108/CR-04-2021-0061

Pavlova, M. (2013). Teaching and learning for sustainable development: ESD research in technology education. *International journal of technology and design education*, *23*, 733–748. https://doi.org/10.1007/s10798-012-9213-9

Putra, N. S. (2022). Profile of Students' Environmental Literacy: A Hypotetic Model to Perform Effective Environmental Education. *Natural Science*, *8*(1), 50–56. https://doi.org/10.15548/nsc.v8i1.3695

Radwan, A. F., & Khalil, E. M. A. S. (2021). Knowledge, attitude and practice toward sustainability among university students in UAE. *International Journal of Sustainability in Higher Education*, *22*(5), 964–981. https://doi.org/10.1108/IJSHE-06-2020-0229

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management*, *91*(8), 1766–1777. https://doi.org/10.1016/j.jenvman.2010.03.023

Robinson, H. A., Kilgore, W., & Warren, S. J. (2017). Care, communication, learner support: Designing meaningful online collaborative learning. *Online Learning Journal*, *21*(4), 29–51. https://doi.org/10.24059/olj.v21i4.1240

Sekhar, C., & Raina, R. (2021). Towards more sustainable future: assessment of sustainability literacy among the future managers in India. *Environment, Development and Sustainability*, *23*(11), 15830–15856. https://doi.org/10.1007/s10668-021-01316-0

Shpeizer, R. (2019). Towards a successful integration of project-based learning in higher education: Challenges, technologies and methods of implementation. *Universal Journal of Educational Research*, *7*(8), 1765–1771. https://doi.org/10.13189/ujer.2019.070815

Smit, K., de Brabander, C. J., & Martens, R. L. (2014). Student-centred and teacher-centred learning environment in pre-vocational secondary education: Psychological needs, and motivation. *Scandinavian Journal of Educational Research*, *58*(6), 695–712. https://doi.org/10.1080/00313831.2013.821090

Strachan, S., Logan, L., Willison, D., Bain, R., Roberts, J., Mitchell, I., & Yarr, R. (2021). Reflections on developing a collaborative multi-disciplinary approach to embedding education for sustainable development into higher education curricula. *Emerald Open Research*, *3*, 24. https://doi.org/10.35241/emeraldopenres.14303.1

Sudarmin, Pujiastuti, S. E., Rayandra, A., Prasetya, A. T., Diliarosta, S., & Ariyatun. (2023). Chemistry project-based learning for secondary metabolite course with ethno-STEM approach to improve students' conservation and entrepreneurial character in the 21st century. *Journal of Technology and Science Education*, *13*(1), 393–409,.

Sudarmin, S., Diliarosta, S., Pujiastuti, S. E., Jumini, & Prasetya, A. (2020). The instructional design of ethnoscience-based inquiry learning for scientific explanation about Taxus sumatrana as cancer medication. *Journal for the Education of Gifted Young Scientists* 8, no. 4. 1493-1507. https://dergipark.org.tr/en/pub/jegys/article/792830

Sudarmin, S., Mursiti, S., & Asih, A. G. (2018). The use of scientific direct instruction model with video learning of ethnoscience to improve students' critical thinking skills. *Journal of Physics: Conference series*. https://iopscience.iop.org/article/10.1088/1742-6596/1006/1/012011/meta

Sudarmin, S., Pujiastuti, R. S. E., Asyhar, R., Tri Prasetya, A., Diliarosta, S., & Ariyatun, A. (2023). Chemistry project-based learning for secondary metabolite course with ethno-STEM approach to improve students' conservation and entrepreneurial character in the 21st century. *Journal of Technology and Science Education*, *13*(1), 393. https://doi.org/10.3926/jotse.1792

Sudarmin, S., Savitri, E. N., Pujiastuti, R. S. E., Yamtinah, S., Zain Mohd, H. N. ., & Ariyatun, A. (2024). Reconstruction of Ethno-STEM Integrated Project Learning Models for Explanation of Scientific Knowledge Regarding Aroma Compounds of Indonesian and World Herbal Teas. *Jurnal Pendidikan IPA Indonesia*, *13*(2), 195–208. https://doi.org/10.15294/jpii.v13i2.4556

Sudarmin, Sumarni, W., Mursiti, S., & Sumarti, S. S. (2020). Students' innovative and creative thinking skill profile in designing chemical batik after experiencing ethnoscience integrated science technology engineering mathematic integrated ethnoscience (ethno-stem) learnings. *Journal of Physics: Conference Series*, *1567*(2). https://doi.org/10.1088/1742-6596/1567/2/022037

Sulaiman, A. I., Masrukin, M., & Putri, D. D. (2022). Community Empowerment Program Based on Green Economy in Preserving Herbs as Local Wisdom. *Sustainable Development Research*, *4*(2), p14. https://doi.org/10.30560/sdr.v4n2p14

Sumarni, W. (2018). The influence of ethnoscience-based learning on chemistry to the chemistry's literacy rate of the prospective teachers. *Unnes Science Education Journal*. https://journal.unnes.ac.id/sju/index.php/usej/article/view/23722

Sumarni, W., Sudarmin, S., Sumarti, S. S., & Kadarwati, S. (2021). Indigenous knowledge of Indonesian traditional medicines in science teaching and learning using a science–technology–engineering–mathematics (STEM) approach. In *Cultural Studies of Science Education* (Issue 0123456789). Springer Netherlands. https://doi.org/10.1007/s11422-021-10067-3

Syukri, M., Soewarno, S., Halim, L., & Mohtar, L. E. (2018). The impact of engineering design process in teaching and learning to enhance students' science problem-solving skills. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 66–75. https://doi.org/10.15294/jpii.v7i1.12297

Triana, D., Anggraito, Y. U., & Ridlo, S. (2020). Effectiveness of Environmental Change Learning Tools Based on STEM-PjBL Towards 4C Skills of Students. *Jise*, *9*(2), 181–187. http://journal.unnes.ac.id/sju/index.php/jise

Wibowo, T., & Ariyatun. (2020). Analysis of Attitute towards Chemistry Profile of Students in Senior High School. *Journal of Physics: Conference Series*, *1594*(1). https://doi.org/10.1088/1742-6596/1594/1/012019

Winarno, N., Rusdiana, D., Samsudin, A., Fitria, D., Husaeni, A., Bayu, A., & Nandiyanto, D. (2020). The steps of the Engineering Design Process (EDP) in science education: A systematic literature review. *Journal for the Education of Gifted Young Scientists*, *8*(4), 1345-1360. https://dergipark.org.tr/en/pub/jegys/article/766201

Yeşilyurt, M., Balakoğlu, M. Ö., & Erol, M. (2020). The impact of environmental education activities on primary school students' environmental awareness and visual expressions. *Qualitative Research in Education*, *9*(2), 188–216. https://doi.org/10.17583/qre.2020.5115

Yoon, S. Y., Dyehouse, M., Lucietto, A. M., Diefes-Dux, H. A., & Capobianco, B. M. (2014). The Effects of Integrated Science, Technology, and Engineering Education on Elementary Students' Knowledge and Identity Development. *School Science and Mathematics*, *114*(8), 380–391. https://doi.org/10.1111/ssm.12090

Yu, K. C., Wu, P. H., & Fan, S. C. (2020). Structural Relationships among High School Students' Scientific Knowledge, Critical Thinking, Engineering Design Process, and Design Product. *International Journal of Science and Mathematics Education*, *18*(6), 1001–1022. https://doi.org/10.1007/s10763-019-10007-2

Yücel, Ü. A. I., & Usluel, Y. K. (2016). Knowledge building and the quantity, content and quality of the interaction and participation of students in an online collaborative learning environment. *Computers and Education*, *97*, 31–48. https://doi.org/10.1016/j.compedu.2016.02.015

Zidny, R., Solfarina, S., Aisyah, R. S. S., & Eilks, I. (2021). Exploring indigenous science to identify contents and contexts for science learning in order to promote education for sustainable development. *Education Sciences*, *11*(3). https://doi.org/10.3390/educsci11030114