Students' Engagement in STEAM PjBL-Design Thinking for Environmental Literacy

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ABSTRACT

Aim. The aim of this study was to investigate Indonesian students' engagement in STEAM Project-Based Learning (PjBL), integrated with design thinking, to enhance their environmental literacy.

Methods. A survey was conducted with a sample of 156 eleventh-grade students from five classrooms in three secondary schools in Jakarta, Indonesia. The study used The Environmental Literacy Scale (ELS) to measure cognitive, affective, and behavioural elements of environmental literacy, and an interview was conducted to evaluate students' views. A paired t-test and thematic analysis were used to analyse the data.

Results. The study revealed that students exhibited moderate cognitive, affective, and behavioural elements of environmental literacy. Contextual learning through STEAM PjBL-design thinking effectively enhanced students' knowledge and behaviour and their positive attitude toward environmental issues. Female students were found to generally outperform male students in cognitive and affective elements, while both genders demonstrated similar environmental behaviour.

Conclusion. In conclusion, integrating STEAM-PjBL with design thinking can positively impact students' environmental literacy and their engagement in chemistry. The findings suggest practical implications for enhancing interdisciplinary learning in chemistry education to promote environmental sustainability.
Keywords: design thinking, environmental literacy, project-based learning, STEAM education

Introduction

The environment plays a crucial role in meeting the requirements of human existence. Currently, the exponential population growth and the concurrent rise in human demands have an impact on the sustainability of the environment, especially in Indonesia. Intricate and nonlinear connections between humans and the environment give rise to this problem (Kioupi & Voulvoulis, 2019). The sustainability is fundamentally rooted in human behavioural patterns. Excessive exploitation of natural resources, justified by the assertion of meeting individual and societal needs, disrupts the current environmental balance (Leff, 2021). Surveys and research undertaken by the World Economic Forum indicate that environmental concerns are emerging as a worldwide menace that leads to economic inequality, social division, and the escalation of environmental risks in the next few decades (World Economic Forum, 2017). The 2022 Environmental Performance Index (EPI) data places Indonesia in the 164th position out of 180 countries, with a score of 28.20. This indicates that Indonesia's environmental sustainability remains inadequate (Wolf et al., 2022). Indonesia faces socio-scientific challenges, including waste pollution (Lestari & Trihadiningrum, 2019; Sulaeman et al., 2018), environmental degradation caused by illicit mining (Muslihudin et al., 2018), and forest and land fires (Adrianto et al., 2019).

Indonesia is a vast archipelago comprising some 17,500 islands and 90 distinct types of ecosystems. Indonesia is ranked 17th out of 139 countries in terms of natural resource competitiveness. The tropical forests of Indonesia rank as the third largest internationally, followed by Brazil and the Congo. Approximately 59% of Indonesia's average land area consists of tropical forests, equivalent to 10% of the global forest area or around 126 million hectares (Kementerian Lingkungan Hidup dan Kehutanan, 2021). A substantial deforestation rate of around 1.08 million hectares annually has emerged as a significant obstacle to forest conservation in Indonesia (Forest Watch Indonesia, 2015). Deforestation in Indonesia is widespread throughout many islands, including Sumatra, Java, Bali, Nusa Tenggara, Kalimantan, Sulawesi, Maluku, and Papua (Kementerian Lingkungan Hidup dan Kehutanan, 2020). Improving the management of Indonesia's declining forest cover is critical to mitigating deforestation. Deforestation and forest degradation result in elevated greenhouse gas emissions and heighten the vulnerability of Indonesia's plant and animal species, leading to extinction. Therefore, it is necessary to make efforts to improve changes in human views, beliefs, attitudes, and behaviour toward environmental use (Scoones et al., 2020). Education has a crucial role in transforming perspectives and principles that have the potential to address obstacles by upholding environmental sustainability (Glavič, 2020; Kioupi & Voulvoulis, 2019; Kopnina, 2020; Pacis & VanWynsberghe, 2020).

Chemistry is a scientific discipline concerned with understanding the composition, characteristics, actions, and transformations of matter (Mahaffy et al., 2019). It supports two essential endeavours in environmental sustainability: comprehending and implementing specific measures to address urgent sustainability issues and providing feasible solutions to guarantee long-term sustainability (Wissinger et al., 2021). Chemistry teachers are faced with the task of creating a curriculum that offers practical learning experiences, and incorporates environmental sustainability, while ensuring that students also engage with complex chemical and interdisciplinary concepts (Mahaffy et al., 2018). The purpose of chemistry education focused on environmental sustainability is to develop students' skills through pedagogical methods that engage the cognitive, affective, and psychomotor domains, thus promoting their active participation as catalysts for change (Monte & Reis, 2021). By doing so, chemistry education contributes to enhancing students' environmental literacy and their capacity to address, reduce, and resolve environmental issues (Liang et al., 2018). Environmental literacy enables students to make informed choices and behave ethically by acknowledging the interdependent connection between humans and the environment, guided by the concepts of sustainable environmental management (Klein et al., 2021).

Traditional instructional approaches that emphasise rote memorisation of information and theoretical understanding may not be enough to develop the analytical thinking and problem-solving abilities required to tackle environmental challenges (Lord, 1999; Snyder & Snyder, 2008). STEAM (Science, Technology, Engineering, Arts, and Mathematics) education provides an alternative approach by promoting learning across many disciplines, emphasising the practical application of knowledge. The integration of scientific concepts with creative and imaginative thinking in STEAM education enables students to develop a comprehensive understanding of environmental challenges (Gavari-Starkie et al., 2022; Hadinugrahaningsih et al., 2017). This methodology not only enhances students' academic performance but also equips them with the necessary skills to become conscientious members of society who can contribute to the development of enduring solutions (Rahmawati et al., 2022). By integrating environmental education into the STEAM framework, educators can equip students with the necessary skills to navigate the complex aspects of a contemporary world and actively contribute to environmental conservation (Rahmawati & Mardiah, 2022; Videla et al., 2021).

Student projects using the STEAM method employ design thinking, a problem-solving process that provides a framework to deliver STEAM-based learning material. (Graham, 2020). The process also facilitates cross-disciplinary learning experiences to identify solutions that can be implemented in the environment (Cook & Bush, 2018). Incorporating design thinking with STEM-based learning has the potential to broaden the traditional limitations of each discipline, enabling students to comprehend and articulate their knowledge through problem-solving (Rolling, 2016). Design thinking involves the use of creative and analytical approaches to develop ideas through collaborative brainstorming, sketching, and evaluation activities to determine a solution focused on human needs (Lin et al., 2020; Wrigley & Straker, 2017). When incorporating design thinking into the learning process, the teacher assumes the role of a facilitator. They design projects for students to investigate and address environmental issues. This approach aims to foster the development of environmental literacy (Farida et al., 2017) as well as 21st-century skills that include creativity, communication, critical thinking, and collaboration (Rusmann & Ejsing-Duun, 2022).

Therefore, this study investigated the influence of design thinking-STEAM-Project-Based Learning (PjBL) on environmental literacy among secondary school chemistry students in Indonesia. The objective of the study was to assess the impact of this novel educational methodology on students' understanding of environmental issues, their views on sustainability, and their level of involvement in the learning tasks. The significance of the study is multifaceted. It promotes a deeper understanding of a methodology utilised in chemistry learning by integrating environmental values. Empirical evidence demonstrates that design thinking-STEAM PjBL can successfully enhance the acquisition of knowledge about nature by secondary school students, and it has the capacity to transform lesson preparation in schools and instructional delivery methods. This framework offers novel approaches for instructors to actively involve students in environmental education and cultivate behaviors that promote sustainable living.

Background

STEAM Education

STEAM education has emerged as a fundamental teaching approach in the 21st century (Hadinugrahaningsih et al., 2017; Kangas et al., 2022; Martinez, 2017). Initially, the emphasis was on STEM (science, technology, engineering, and mathematics) education. This facilitated students' acquisition of technical skills and knowledge, allowing them to succeed in these domains. In response to the evolving world, educators and governments recognised the necessity of incorporating the arts. This resulted in a transition from STEM to STEAM methodologies. The inclusion of arts in STEM was prompted by the recognition that creativity, design thinking, and novel concepts have a significant impact on problem-solving and the practical application of knowledge (Aguilera & Ortiz-Revilla, 2021; Razi & Zhou, 2022). This shift demonstrates that sophisticated technical abilities alone are insufficient to address intricate global challenges. Instead, STEAM education fosters a harmonious integration of analytical and creative thinking that equips students with a comprehensive range of skills. The evolution of STEAM exemplifies a broader transformation in the field of education (Harris & de Bruin, 2018; Rahmawati & Mardiah, 2022) where schools encourage students to explore the connections between various disciplines. This results in a more comprehensive learning experience that adapts to novel challenges (Cassidy & Puttick, 2022; Rennie et al., 2018).

Within the current educational environment, STEAM has become increasingly significant as a way of cultivating a diverse set of abilities in students that transcend conventional academic disciplines. Integrating art into STEM education improves students' cognitive abilities and essential competencies in a rapidly evolving society (Aguilera & Ortiz-Revilla, 2021; Razi & Zhou, 2022). The STEAM approach engages students in practical, project-oriented tasks that stimulate innovative thinking and collaboration. The methodology helps students understand and apply complex concepts, thereby preparing them for future employment that demands adaptability and broad expertise across various domains (Bertrand & Namukasa, 2020; Mardiah et al., 2022).

Furthermore, the emphasis on creativity and design in STEAM cultivates problem-solving abilities that are crucial for addressing significant challenges such as environmental conservation and technological advancement (de Vries, 2021; Guyotte et al., 2014). As organisations increasingly seek employees who can integrate knowledge from many fields and think innovatively, STEAM education plays a vital role in equipping students with the necessary skills to thrive in a challenging global labour market (Zou, 2021). STEAM education equips students with professional trajectories and the ability to think creatively and solve problems in any discipline (Bertrand & Namukasa, 2020).

Project-Based Learning (PjBL) in STEAM Education

Project-Based Learning (PjBL) is an interactive pedagogical approach that expands upon constructivism and experiential learning. It emphasises the essentiality of practical experiences (Sukackė et al., 2022; Wijnia et al., 2024). Unlike conventional teaching, project-based learning (PjBL) empowers students to take ownership of their own learning by engaging them in purposeful initiatives that stimulate critical thinking, analytical problem-solving, and collaborative teamwork (Almulla, 2020; Putri et al., 2021). PjBL aligns with the concept that we construct knowledge by actively engaging with the environment, rather than solely relying on didactic instruction. Furthermore, it aligns with the perspective that the most effective learning occurs through first-hand experience and reflection on past actions (Jumaat et al., 2017). Through engaging in practical projects, students deepen their understanding and retention of concepts. This approach facilitates the acquisition of factual knowledge by students (Wurdinger, 2009) as well as fostering a sense of ownership and accountability towards their education. The Project-based Learning (PjBL) approach in STEAM education effectively integrates Science, Technology, Engineering, Arts, and Mathematics. It enables interconnections between various disciplines and how students might apply them to address significant real-world problems (Lou et al., 2017; Rahmawati et al., 2021).

Project-Based Learning within the STEAM framework significantly enhances student engagement, enthusiasm, and academic performance (Ananda et al., 2024; Chistyakov et al., 2023; Rahmawati et al., 2021). Using the STEAM PjBL framework, students engage in cross-subject projects that challenge them to apply their knowledge from several STEAM disciplines to generate, construct, and demonstrate solutions to practical challenges. For example, in a successful STEAM PjBL project students created a model of a green city system (Ruiz Vicente et al., 2020) which necessitated the integration of engineering principles, earth science, and creative aptitude, while simultaneously applying technology and mathematics to construct a functional prototype. Projects of this nature enhance students' understanding of certain topics and cultivate essential abilities for functioning in the contemporary world, skills such as collaboration, oral communication, and critical thinking (Rahmawati et al., 2019).

Research indicates that students who participate in STEAM PjBL exhibit higher levels of motivation and involvement in their learning compared to those in traditional classrooms (Blackley et al., 2018) because the practical and inquiry-oriented approach of PjBL enhances the relevance and enjoyment of the learning process. Project-based Learning (PjBL) has been associated with improved academic performance as students tend to retain information and comprehend the content when they actively participate in the learning process (Chen & Yang, 2019; Karaçalli & Korur, 2014). Therefore, incorporating PjBL with STEAM education not only enhances academic development but also prepares students to become innovative thinkers and problem-solvers capable of tackling challenging challenges in our contemporary society.

Design Thinking as a Pedagogical Tool

Design thinking exerts its effect on education as a pedagogical instrument (Mardiah et al., 2023). Human-centred problem-solving is a methodology that prioritises people and continuously explores novel approaches. This concept originated in the domain of design and innovation (Brown, 2008; Veerasinghan et al., 2021) where understanding user requirements through empathy is essential. This approach facilitates a thorough exploration of issues from the perspective of the individuals it impacts (Liedtka, 2015). The core principles of design thinking are empathy, defining, ideation, prototyping, and testing (Köppen & Meinel, 2015). Empathy refers to the act of placing oneself in the shoes of the user to identify their requirements and challenges, that inform subsequent decisions in the design process (Kouprie & Visser, 2009). The generation of ideas stimulates students to generate numerous solutions, thereby encouraging them to think big, think creatively, and present novel ideas (Carlgren et al., 2016). Developing prototypes involves constructing tangible manifestations of theoretical concepts, allowing for experimentation, input from others, and incremental improvement (Carlgren et al., 2016; Micheli et al., 2019). The process synergistically contributes to fostering a mentality of curiosity, productive collaboration, and perseverance (Cook & Bush, 2018; Oberer & Erkollar, 2024). The design thinking process ensures students acquire the ability to approach difficulties with a new perspective and be ready to persist in refining their thoughts. Within educational institutions, design thinking transforms the traditional teaching approach by empowering students to assume control as they address tangible issues that are relevant and directly interconnected with their world (Rusmann & Ejsing-Duun, 2022; Welsh & Dehler, 2013).

The integration of design thinking with STEAM project-based learning (PjBL) influences the learning process and academic performance of students (Ananda et al., 2023). Design thinking enhances PjBL by providing a transparent yet flexible approach to addressing complex challenges, compelling students to consider issues from many perspectives and generate diverse solutions (Henriksen et al., 2017). Using design thinking in STEAM education enables students to apply knowledge from several disciplines as they progress through the stages of comprehending others' ideas, creating models, and critically evaluating them in their projects (Cook & Bush, 2018; Mardiah et al., 2022). Consider a STEAM project in which students are required to create a sustainable consumer product to address an environmental issue. Students would initially endeavour to comprehend the individuals impacted by the environmental problem, generate several potential remedies, and then develop and evaluate prototypes through the application of design thinking. This iterative approach not only enhances students' comprehension of STEAM concepts but also cultivates crucial abilities such as creativity, collaboration, and resilience in the face of obstacles (Ananda et al., 2023; Mardiah et al., 2022). Evidence indicates that teachers who integrate design thinking with STEAM PjBL increase student engagement and enthusiasm for the learning process. This phenomenon occurs because the practical and sequential procedural structure in STEAM PjBL enhances student engagement and interest in the learning process (Cooke, 2022). Moreover, the emphasis on creating for users fosters a sense of connection among students toward their work and enhancing their understanding of its purpose. This, in turn, generates further interest and enhances their academic learning experience. Students take responsibility for their own learning when they apply design thinking. They assume the role of proactive problem-solvers and cultivate the necessary abilities to generate novel solutions that adapt to an increasingly intricate society (Scheer et al., 2011; Wrigley & Straker, 2017).

Environmental Literacy in Education

Environmental literacy refers to the relationship between humans and the natural world (Fang et al., 2023). It encompasses the comprehension of ecological processes, environmental issues, and the impact of human activities on nature (Fang, 2020). Environmental literacy involves learning about the environment and its challenges, engaging in conservation, and taking actions that benefit the ecosphere (McBride et al., 2013; McClaren, 2019). It goes beyond the acquisition of factual knowledge and involves a sense of responsibility and contemplation of environmental issues. Individuals with sound environmental literacy skills make informed decisions and implement measures to address environmental issues (Klein et al., 2021; Lloyd-Strovas et al., 2018). Shih-Wu Liang et al. (2018) define environmental literacy as comprising three components: cognitive (pertaining to understanding of nature, environmental concerns, and suitable action strategies), affective (pertaining to awareness and sensitivity towards the environment, environmental values, and decision-making attitudes about environmental issues), and behaviour (encompassing the inclination to take action, strategies and skills for environmental action, and involvement in environmentally responsible behaviour).

Education plays a crucial role in fostering environmental consciousness by equipping individuals with the necessary abilities to comprehend and actively engage in environmental matters (Glavič, 2020; Kioupi & Voulvoulis, 2019; Kopnina, 2020; Pacis & VanWynsberghe, 2020). Educational institutions impart fundamental knowledge to pupils regarding ecosystems, biodiversity, climate change, and other significant environmental subjects. Effective environmental education goes beyond the mere dissemination of information; it provides educational opportunities that compel students to critically consider their impact on the environment and cultivate a sense of responsibility towards it (Kopnina, 2020; Monroe et al., 2019). Educational programmes that incorporate experiential learning, such as outdoor courses, community service, and practical exercises, effectively foster environmental consciousness (Gaffney & O'Neil, 2019). These techniques facilitate the connection between abstract concepts and practical applications, therefore enhancing the authenticity and effectiveness of the learning process. Educational initiatives that foster environmental consciousness not only prepare students to be knowledgeable members of society but also empower them to become catalysts for change in their localities, capable of addressing environmental challenges through intelligent decision-making and conscientious behaviours (Monte & Reis, 2021).

Methodology

Research Design

The research was conducted in five secondary school chemistry classrooms in Jakarta, Indonesia by implementing STEAM PjBL-Design Thinking for learning the colloid topics. Each classroom implemented the five stages of design thinking in STEAM PjBL. The learning activities and data collection were conducted in Indonesian and subsequently translated into English by the authors. This study employed the design thinking approach established by David Kelley and Tim Brown (2018), where students work through the stages of empathising, defining, ideating, prototyping, and testing (see Figure 1).

Design Thinking-STEAM PjBL was implemented in the classroom during six chemistry lessons after which a survey was conducted to explore the students' perceptions of the lesson. A survey is useful for identifying relationships between variables and forming generalisations based on survey findings (Cohen et al. 2007). The Environmental Literacy Questionnaire (ELQ), adapted from Liang et al. (2018), was used to survey environmental literacy in the cognitive, affective, and behavioural domains. After students completed the closed-ended questionnaire, they completed open-ended questions regarding three dimensions of environmental literacy.

Participants

156 eleventh-grade students from five classrooms in three different secondary schools, in Jakarta, Indonesia, participated in the survey. The participants were 55.8% (n=87) female ranging in age from 16 to 19 years, with an average age of 17.03 years and a standard deviation of 0.62. All participants were informed about the purpose of the study and signed consent forms. Participation in this study was voluntary.

Instrument

To assess environmental literacy after participating in the Design Thinking-STEAM PjBL activities, the adapted Environmental Literacy Questionnaire (ELQ; Liang et al., 2018) was utilized. The ELQ contains three questions related to the participants' demographic data (gender, grade level, and age), followed by 70 statements regarding elements of environmental literacy: cognitive (n=16; alpha = 0.42), affective (n=23; alpha = 0.97), and behavioral (n=31; alpha = 0.98). The low reliability of the cognitive element in the present study has also been reported by Liang et al. (2018). According to Liang et al. (2018), this is likely due to the nature of dichotomous and multiple-choice questions, as well as an insufficient number of items, which prevents the elimination of non-representative items. The items were first translated from English to Indonesian and then reviewed by an Indonesian language expert to refine the questionnaire. To evaluate the cognitive element, nine true-false questions and seven multiple-choice questions with four options were used. For ease of administration and analysis, and to facilitate quick responses, participants were expected to choose their answers from the options provided in closed-ended questions (Liang et al., 2018). To enable easy and objective quantification of the data, participants' responses to the affective element were collected anonymously on a five-point Likert scale ranging from Strongly Disagree (score: 1) to Strongly Agree (5) for each statement. Scores were adjusted when items were presented negatively. To investigate the behavioural element, which focused on students' environmentally responsible actions, 31 questions were used, a five-point frequency scale (from never to always). Students took approximately 40–45 minutes to complete the questionnaire.

Data collection

Prior to data collection, participants were asked to read an explanatory statement and sign an agreement to participate in the study with an opt-out option at any time during the process. Researchers explained to the students in each class why they were being asked to participate, how to respond to the questionnaire, and how much time would be required. Participants were also informed that their data would be used anonymously. The survey was administered in person at three public high schools in Jakarta, the capital region of Indonesia. The survey was distributed through an anonymous link with the help of chemistry teachers. A total of 156 participants provided consent and completed the entire survey. Participants had access to the questions only if they confirmed consent; otherwise, the questionnaire remained hidden. With the cooperation of teachers, students were asked to carefully complete the questionnaire within one school hour to maximise response rates. The self-reported questionnaire was developed using Google Forms to ensure ease of access and completion. During the data collection period, researchers were available to answer any questions from students. Based on participants' responses, cognitive, affective, and behavioural scores were calculated. The higher the score, the higher the student's environmental literacy. The open-ended questions at the end of the questionnaire provided opportunities for students to explore their views on their environmental literacy.

Data analysis

The data were coded and entered into SPSS, where further statistical analysis was conducted. To determine the distribution of participants' background variables and environmental literacy, descriptive statistics, including means and standard deviations (SD), were adopted. Given that the sample size exceeded 50, the Kolmogorov-Smirnov test was chosen to assess normality. Since large significance values ($p>0.05$) were obtained from the Kolmogorov-Smirnov test, the distribution was found to be normal. Therefore, parametric statistics were used to analyse the variables further. In this study, a t-test with a significance level set at $p < 0.05$ was used to determine whether there were differences in environmental literacy scores between male and female students. IBM SPSS Statistics v25 was used for the analysis. Students' answers to open questions were put on each dimension.

Results and Discussions

Descriptive Statistics

Environmental Literacy: Cognitive Element

According to the results (see Figure 2), knowledge about biodiversity (Question K1), the ecological balance of river systems (K4), and the use of herbal medicines (K11) showed high correct response rates, while knowledge about environmentally friendly power generation (K6) and environmental labeling (K16) showed very low correct response rates. In general, students demonstrated a better understanding of certain environmental issues but lacked comprehensive knowledge in specific areas like greenhouse gases and appropriate environmental action strategies. The high correct response rates for questions related to biodiversity, river systems, and herbal medicines may be linked to the strong cultural and traditional connections many Indonesian students have with their natural environment. Indonesia's rich biodiversity and the widespread use of herbal medicines in traditional practices could contribute to students' familiarity and understanding of these topics. In the literature, cultural and indigenous knowledge play a role in shaping environmental literacy, particularly in regions with deep-rooted traditions related to nature (Ens et al., 2011). The Indonesian education system may also place greater emphasis on certain environmental topics, particularly those that are more relevant or visible in the local context, such as biodiversity and river ecosystems. By contrast, less focus may be given to global environmental issues like greenhouse gases and renewable energy, which could explain the lower correct response rates in those areas. In earlier studies (Drake et al., 2023; Li et al., 2024), the content of educational curricula significantly influences students' environmental literacy, with disparities in knowledge often reflecting the emphasis on specific topics within the curriculum. Topics like greenhouse gases, renewable energy, and environmental labelling are inherently complex and abstract requiring a deeper understanding of scientific principles and global environmental policies. Students may find these topics more challenging due to their abstract nature and the need for higher cognitive skills to grasp the underlying concepts. Some researchers argue that the complexity of environmental issues, particularly those related to global phenomena and scientific processes, can be a significant barrier to student understanding (Chang & Pascua, 2015; McNeill & Vaughn, 2012).

The survey results in the form of open-ended questions explored students' environmental literacy in the cognitive element. Contextual learning implemented through the use of design thinking in STEAM-PjBL enabled students to see the relevance of colloidal content l to real life, especially in relation to the environment. The responses of students 30 and 38 from school A reflected good cognitive aspects in understanding the content and strategic actions that can be taken related to environmental pollution that occurs:

> Colloids play an important role in the context of environmental pollution, especially in water and air pollution. In water pollution, colloidal particles such as silt and suspended organic matter cause water to become cloudy and undrinkable, while harmful chemicals bound to colloids spread through water, contaminating water sources. In the air, pollutants in aerosol form such as smoke and dust produce smog that adversely affects respiratory health, and colloidal particles in the atmosphere, such as volcanic dust and sea salt, affect the climate by reflecting or absorbing sunlight. Sewage treatment using coagulation and flocculation techniques is important to remove colloidal particles, thereby ridding water of contaminants (Response of Student 30, School A)

> Colloids have an important role in environmental pollution, especially in air, water, and soil. Colloidal particles, such as dust and smoke in the air, can trigger health problems such as respiratory disorders. In water, colloidal pollutants, such as oil and chemicals from industrial waste, are difficult to break down, requiring special treatment techniques such as coagulation and filtration. In soil, colloids from pesticides and agricultural chemicals can spread pollutants to groundwater sources. Understanding colloidal properties also helps the development of pollution control technologies, such as the use of activated carbon and zeolite to absorb colloidal pollutants. (Response of Student 38, School A)

The research findings demonstrate that contextual learning applied through design thinking in STEAM-PjBL supports students' environmental literacy, especially in cognitive aspects related to colloid content and environmental pollution. This approach prioritises multidisciplinary problem-solving, enabling students to confront authentic environmental issues through the application of scientific and technological expertise, hence enhancing cognitive engagement. In chemistry classrooms, STEAM-PjBL has enhanced scientific literacy by linking abstract topics such as colloids and pollution to tangible environmental challenges (reference?). These relationships enable students to cultivate critical thinking skills by applying the stages of design thinking (empathise, define, ideate, prototype, and test) to investigate solutions to pollution issues, thus augmenting their comprehension and cognitive abilities pertaining to the subject matter (Mardiah et al., 2022; Winarni et al., 2024)

Students in School A showed a deep understanding of the role of colloids in water, air, and soil pollution. Student 30 identified how colloidal particles such as silt and organic matter in water cause cloudiness and contamination, and how colloidal aerosols in the air affect respiratory health and climate. Student 38 extended this understanding by mentioning the impact of colloids from dust, smoke, and industrial chemicals on water and soil quality, as well as the importance of treatment techniques such as coagulation, filtration, and the use of sorbents such as activated carbon and zeolite. These examples confirm the effectiveness of the STEAM PjBL-design thinking in linking theoretical learning with practical applications in an environmental context, allowing students to relate colloid concepts to real pollution challenges and possible technological solutions.

The survey results from Schools B and C also indicated that the contextual learning approach in STEAM-PjBL was effective in improving students' environmental literacy. The findings in all three schools showed that students demonstrated a similar cognitive understanding of the role of colloids in environmental pollution and the application of treatment techniques to address the problem.

> Colloids play an important role in environmental pollution, whether in water, air or soil. Pollutants such as heavy metals and oil are often in colloidal form, so coagulation and flocculation processes are used in sewage treatment to remove them. In the air, aerosols that are gaseous colloids contribute to air pollution and health problems. In soil, colloidal particles

> such as heavy metals and pesticides affect the mobility of pollutants. Colloidal technologies, including the use of activated carbon and nanotechnology, are being applied to monitor and control pollution more effectively. (Response of Student 13, School B)
>
> Colloids play an important role in environmental pollution, especially in air, water, and soil pollution. Colloidal particles, such as aerosols in air pollution (PM2.5 and PM10), contribute to health problems, such as respiratory problems and lung cancer, and damage ecosystems. In water pollution, colloids come from industrial and agricultural effluents that carry heavy metals and chemicals, causing habitat destruction and human health problems. Meanwhile, colloids in soil pollution contaminate soil and plants, impacting the food chain. Colloids can spread far from the source of pollution, adsorb chemicals, and interact with organisms, exacerbating pollution. To overcome the impact of colloids, measures such as waste treatment, environmentally friendly technologies, government regulations, and environmental education and rehabilitation are necessary. (Response of Student 51, School C)

The findings from Schools B and C are consistent with the results from School A, demonstrating a contextualised learning approach through STEAM-PjBL in improving students' environmental literacy. In School B, students demonstrated a deep understanding of the role of colloids in water, air, and soil pollution, as well as treatment techniques such as coagulation and flocculation used to remove colloidal pollutants. Students in School C also highlighted the impact of colloids on human and ecosystem health and identified the importance of technologies such as activated carbon and nanotechnology in controlling pollution. These two examples show that students from different schools had a similar understanding of the relationship between colloids and environmental pollution, and the need for multifaceted solutions, including waste treatment, green technology, regulation, and education.

Environmental Literacy: Affective Element

The affective element of environmental literacy recorded an average score of 4.06 with a standard deviation of 0.87 (out of a maximum of 5 points). This suggests that students exhibit ed a strong awareness and a positive attitude toward environmental issues. The overall high score highlights their commitment to environmental stewardship which may be attributed to the increasing global attention to climate change, pollution, and biodiversity conservation. Environmental education integrated within school programmes likely plays a significant role in fostering students' positive attitudes toward the environment (Baek, 2023). Consequently, despite some variability in the level of concern, most students demonstrate a strong inclination towards environmental preservation (Coyle, 2005; Kollmuss & Agyeman, 2002).

Figure 3, Question A3, "I believe that toxic emissions from anthropogenic waste (i.e., motor vehicles, factories, etc.) can cause a negative environmental impact," received the highest average score of 4.41. The high score could be attributed to the growing global awareness and media coverage of pollution caused by vehicles and factories. Indonesian students may have been exposed to frequent news reports on air quality issues, smog in urban areas, and the harmful effects of industrial pollution on health and the environment, leading to a heightened awareness of this issue. Media coverage, educational curricula, and the direct experiences of students living in urban areas with visible air and water pollution likely contribute to this heightened concern (Keinonen et al., 2016). Furthermore, environmental education programmes that focus on the visible and immediate consequences of such emissions may have reinforced their understanding and concern (Çupi, 2023). Studies have shown that individuals exposed to high pollution levels are more likely to express strong environmental attitudes, particularly about air quality issues (Littledyke, 2008).

The lowest average score was observed for Question A23, "I believe no advanced technology can solve all pollution problems," which had a mean of 3.10. The low score on this item reflected a higher level of optimism among students regarding technological solutions to environmental challenges. This view aligns with the concept of "techno-fix" solutions (Huesemann & Huesemann, 2011), which are often promoted in environmental discourse, leading people to believe that technology can mitigate even complex environmental challenges. This could be related to the portrayal of technological advancements in media and education as a key solution to global issues, including climate change and pollution. Students might believe in the potential of green technologies, renewable energy, and innovations like electric vehicles and waste treatment technologies to mitigate pollution. However, this optimism may also reflect a limited understanding of the complexity of environmental issues, where social, political, and behavioural changes are just as crucial as technological interventions.

Students' responses to the open-ended questions demonstrated their affective environmental literacy, reflecting their interest and dedication to environmental issues. For example, student 129 from School A voiced concern about environmental pollution and the significance of implementing environmentally friendly activities and technologies to mitigate its detrimental effects. Student 6 from School B underlined the need to take decisive action in industrial waste management, by adopting sustainable technology, complying with environmental rules, raising awareness, and actively participating in environmental protection.

> I'm worried about pollution in the environment, especially contamination from colloids and industrial waste management. Adopting eco-friendly procedures and technology is crucial in order to lessen their detrimental effects on the environment and public health. (Response of Student 129, School A)

> Industrial waste management requires decisive action, including the use of environmentally friendly technologies, sustainable production processes, and strict adherence to environmental rules. Raising awareness of the necessity of environmental conservation is also necessary, as is encouraging active engagement in environmental preservation initiatives. I believe that with cooperation from government, industry, communities, and environmental

organisations, we can attain a cleaner, healthier, and more sustainable environment for future generations. (Response of Student 6, School B)

These findings demonstrate that incorporating design thinking into STEAM-PjBL in colloid learning helped students improve affective qualities linked to environmental literacy. Student responses suggest that this technique increases their cognitive knowledge of the role of colloids in environmental pollution, and strengthens their attitudes toward environmental issues. Both Student 129 and Student 6 demonstrate that design-thinking-based learning can provide students with practical knowledge while motivating them to be emotionally and actively involved in environmental protection efforts, making it an effective tool for instilling environmental commitment and responsibility in students. Tien-Chi Huang et al. (2023) stated that design thinking cultivates enhanced emotional engagement and favorable attitudes toward environmental issues among students, rendering it a useful instrument for fostering environmental understanding and responsibility. Grace Ximena Villanueva-Paredes et al. (2023) identified the transformative capacity of design thinking in sustainability education, demonstrating its role in fostering cognitive comprehension and a commitment to environmental stewardship among students. Other findings in the current study highlighted students' concerns about environmental pollution, as well as their decision-making attitudes about environmental issues.

I am deeply worried about environmental degradation, particularly the management of industrial waste and other pollutants that may contain colloids. I believe that managing industrial waste and reducing pollution should be a top concern for society and the government. This includes deploying improved technology, stricter rules, and raising knowledge about the environmental impact of human activities. In this approach, we can safeguard the environment and human health from the harmful effects of colloidal and other pollutants. (Response of Student 15, School B)

I am really concerned about environmental pollution, particularly industrial waste containing colloids. To limit the negative impact of waste, we must exercise greater caution and take appropriate action. (Response of Student 82, School C)

I am highly worried about environmental contamination, namely industrial waste management and colloidal pollution. It is critical to create long-term and responsible ways to mitigate its detrimental effects on the environment and human health. This includes implementing greener technologies, improving waste management, and raising awareness about the necessity of environmental preservation for future generations. (Response of Student 34, School A)

These findings demonstrate how STEAM PjBL-design thinking not only improves students' knowledge but also alters their attitudes toward environmental challenges. Thus, the incorporation of design thinking into STEAM-PjBL inspires students to be more concerned and interested in environmental pollution solutions, as well as fostering a more responsible and proactive decision-making approach. Thus, the incorporation of design thinking into STEAM-PjBL has a good impact on inspiring students to be more concerned and interested in environmental pollution solutions, as well as fostering a more responsible and proactive decision-making approach.

Environmental Literacy: Behavioural Element

The behavioural element of environmental literacy had an average score of 3.97 ± 0.77 on a 5-point Likert scale. This suggests that students generally display behaviour that promotes environmental protection, with the potential for further improvement. The findings indicate a positive inclination among students towards engaging in actions that foster environmental sustainability. The success of environmental education efforts in motivating students to adopt more eco-friendly behaviour may be reflected in these results. Exposure to environmental issues through academic curricula and extracurricular activities can raise awareness and inspire students to act (Kaiser & Wilson, 2004; Stern, 2000). However, the variability in scores implies that some students may require additional support or resources to strengthen their commitment to pro-environmental behaviours.

As can be viewed in Figure 4, Question BEH3, "I am willing to take care of our living environment (including school and neighbourhood) and make changes to the environmental conditions," received the highest score, with a mean of 4.29. The high score on this question may be influenced by communal values and cultural norms prevalent in Indonesia. Students may feel a collective responsibility towards their community and immediate environment, such as schools and neighbourhoods, which drives their intention to contribute positively to environmental improvements. In Indonesia, there is a collective responsibility towards community welfare, which can encourage students to be more active in local environmental care (Saadah et al., 2023). Studies have shown that students' environmental behaviour is often shaped by communal norms and social expectations, fostering a sense of ownership over their immediate environment (Perry et al., 2021). Conversely, the lowest average score was observed for BEH20, "I will buy polyethylene terephthalate (PET) bottled beverages," with a mean of 3.43. The lower score for avoiding PET bottled beverages can be attributed to several factors. One potential reason is a lack of awareness regarding the environmental impact of PET plastic. Despite efforts to promote sustainability, convenience often drives the consumption of bottled beverages, and there may be limited access to sustainable alternatives in many parts of Indonesia. Furthermore, students may perceive avoiding PET bottles as inconvenient or challenging, especially if alternative options are not readily available.

Students' responses to the open-ended questions demonstrated the behavioural aspect of their environmental literacy, particularly in how they approach environmental issues. For example, students mentioned that they could begin with small actions, such as disposing of rubbish in the bin. They identified behaviour that contributes to protecting the environment. Below are a few examples of their comments:

- We must support each other and remind others to protect the environment. We can do this through websites and social media. (Response from Student 13, School A);
- The solution I found to address environmental problems related to colloids is to reduce the use of motor vehicles and cars. (Response from Student 150, School B).

Students' comments indicate that the activities have heightened their awareness of taking action to tackle environmental issues, consistent with environmental education research that highlights experiential learning as a catalyst for behavioural change (Mittelstaedt et al., 1999). Student 13 indicated utilising social media to enhance public awareness, which is intricately linked to their habitual engagement with these platforms. This illustrates the increasing significance of digital media in environmental advocacy, as emphasised by Chi-Horng Liao (2024), who discovered that involvement by youth in environmental matters is frequently enhanced by social media.

Student 150 proposed minimising the utilisation of motor vehicles, highlighting that Jakarta has considerable issues with air pollution attributed to these vehicles which aligns with reports of poor urban air quality issues in Jakarta (Zulkarnain & Ghiffary, 2021). The questionnaire emphasised several measures students might use to enhance environmental sustainability, corroborating research that indicates actionable information is essential for environmental literacy (Hollweg et al., 2011).

Participants' responses suggested that the incorporation of design thinking into STEAM-PjBL favourably impacted their environmental literacy, aligning with the findings of Joaquín Ayerbe López and Francisco Javier Perales Palacios (2024), who illustrated that design thinking in PjBl improves students' problem-solving abilities and environmental awareness.

T-Test

Table 1 provides a summary of the t-test results between gender and environmental literacy across three elements: cognitive, affective, and behavioural, as well as an aggregate of all elements.

Table 1
Independent Samples t-test on Gender

Elements	Gender	N	M	SD	t	df	p
Cognitive	Male	69	3.063	0.706	-2.363	154	0.019
	Female	87	3.324	0.666			
Affective	Male	69	3.900	1.072	-2.060	154	0.041

Elements	Gender	N	M	SD	t	df	p
	Female	87	4.185	0.640			
Behavioral	Male	69	3.964	0.838	-0.091	154	0.928
	Female	87	3.975	0.718			
All elements	Male	69	3.643	0.626	-2.016	154	0.046
	Female	87	3.828	0.519			

Note. *p<0.05 (sig.).
Source. Own research.

The t-test results indicate significant differences between genders in the cognitive and affective elements of environmental literacy, as well as in the overall combined elements. However, no significant difference was found in the behavioural element. Female participants generally outperform male participants in environmental literacy in cognitive and affective domains. While behavioural actions are relatively equal between genders, the overall higher scores of females in combined elements highlighted a broader environmental awareness and commitment. This insight can guide educational strategies to further enhance environmental literacy across all demographics. Research suggests that gender socialisation plays a significant role in shaping attitudes and behaviour towards the environment. Girls are often encouraged to be more empathetic and caring, qualities that may translate into a stronger affective connection to environmental issues (Zelezny et al., 2000) which can result in higher cognitive engagement with environmental topics. Studies show that female students tend to be more engaged and motivated in academic settings, particularly in subjects that involve social and ethical dimensions, such as environmental studies (Chu et al., 2007; Tuncer et al., 2009). Higher levels of engagement can lead to better performance in the cognitive and affective aspects of environmental literacy. In many cultures, including in Indonesia, environmental stewardship may be more strongly associated with feminine roles, which can influence the attitudes and behaviour of female students towards environmental issues. This cultural association might explain why females outperform males in the cognitive and affective domains of environmental literacy.

Conclusion and Implications

The findings indicate that students exhibit varying levels of environmental literacy across cognitive, affective, and behavioural elements, with a stronger understanding of areas related to local environmental issues, such as biodiversity and pollution, while facing challenges in comprehending global environmental topics like greenhouse gases and renewable energy. Additionally, the contextualised learning approach through design thinking in STEAM-PjBL proves effective in enhancing students' environmental literacy, particularly in connecting theoretical knowledge with practical applications in pollution reduction and its technological solutions. Female students generally outperformed their male counterparts in cognitive and affective elements, highlighting gender differences in environmental awareness and commitment.

These findings suggest that integrating contextual learning approaches like STEAM-PjBL can significantly improve students' understanding of environmental issues by making theoretical concepts more relatable to real-world challenges. The success of this approach in fostering cognitive and affective engagement underscores the need to include practical, hands-on activities in environmental education. The gender differences observed in environmental literacy also indicate that educational strategies might benefit from addressing the unique needs and strengths of both genders, particularly in promoting higher cognitive engagement among male students.

To further enhance students' environmental literacy, educators should expand the curriculum to include global environmental issues such as renewable energy and greenhouse gases, using contextualised learning approaches that have proven effective. Increasing opportunities for student participation in environmental organisations and extracurricular activities would also foster a greater behavioural commitment to environmental action. Additionally, targeted interventions could be designed to support male students in engaging more deeply with the cognitive and affective aspects of environmental literacy, ensuring balanced progress across all demographics.

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Appendix available online.

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