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APPLICATION OF P5BL MODEL INTEGRATED WITH EDUCATION FOR SUSTAINABLE DEVELOPMENT TO DEVELOP MOTIVATION AND CONCEPTUAL UNDERSTANDING IN SCIENCE

E. G. A. Tolba*[1] & N. H. Youssef[2]

[1]Department of Educational and Psychological Sciences, Faculty of Specific Education, Mansoura University, Egypt
[2]Department of Curricula and Instruction, College of Education, Imam Abdulrahman Bin Faisal University, Saudi Arabia

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ABSTRACT

Education for sustainable development (ESD) is a priority for modern societies and a central focus of learning. The current study aims to apply the P5BL model, integrated with education for sustainable development, to develop motivation and conceptual understanding in science among middle school students. To achieve the study objectives, a quasi-experimental design was adopted. The research sample comprised 148 students, divided into two groups: an experimental group (76 students) and a control group (72 students). The research tools are a conceptual understanding test and the motivation scale. The results showed statistically significant differences at the 0.01 level between the experimental and control groups' mean scores on the conceptual understanding test after the test, favoring the experimental group ($M = 22.32$; $t = 5.05$, $p = 0.01$, $\sigma^2 = 0.75$). The effect size ($d = 3.40$) was greater than 0.8 for the test as a whole. Statistically significant differences at the 0.01 level were also found between the experimental and control groups on the overall learning motivation scale, favoring the experimental group (mean = 143.85; $t = 21.81$, $p = 0.01$, $\sigma^2 = 0.87$). The effect size ($d = 5.15$) was greater than 0.8 for the scale as a whole. Therefore, integrating education for sustainable development within the P5BL model not only contributes to the transfer of scientific knowledge but also transforms students from passive recipients into active students with strong intrinsic motivation and the ability to connect scientific concepts to real-world problems and their sustainability. In other words, the P5BL model, integrated with sustainability, successfully transformed the "energy unit" from rigid theoretical content into a practical experience that fostered conceptual understanding (explanation, interpretation, application, and perspective) and increased student motivation (academic ambition, curiosity, independence, challenge, desire to succeed, and self-confidence). Key recommendations include developing guidelines for science teachers to help them teach using the P5BL model integrated with education for sustainable development (ESD) to foster motivation and conceptual understanding, and to integrate P5BL with sustainable development principles and practices into science curriculum instruction. Several research proposals were also presented.

Keywords: P5BL model; Education for Sustainable Development (ESD); conceptual understanding; motivation

INTRODUCTION

Education for Sustainable Development (ESD) is now viewed as a comprehensive and transformative education that addresses learning content and outcomes, teaching principles, and the learning environment, and creates interactive, student-centered teaching. Therefore, ESD has emerged as a key theme, aiming to equip students with the skills and knowledge necessary to address sustainability challenges (Leicht et al., 2018). At the same time, education is a driving force for addressing issues and achieving the

***Correspondence Address**
E-mail: ehabtolba@mans.edu.eg

Sustainable Development Goals (Vaughter et al., 2016; Nguyen et al., 2024). Integrating sustainable development into teaching, learning, and curricula (Leal Filho et al., 2015; Mintz & Tal, 2016) does not stop at merely transferring knowledge; rather, it is linked to enhancing the ability to critically engage with complex scientific, environmental, cultural, economic, and societal issues (Nolting et al., 2020; Ahel & Schirmer, 2022).

Education is considered an essential tool for achieving the Sustainable Development Goals (SDGs); it enhances conceptual understanding of global issues such as energy, climate change, and health, and the recognition of their links, helping individuals recognize the importance of sustainable development. It also enhances motivation, enabling individuals to understand the concept and apply the knowledge and skills needed to contribute to solving scientific, environmental, cultural, and societal issues. It allows students to recognize the impact of their actions on society and the environment, and they become more motivated to take positive steps towards sustainable development (Rychen & Tiana, 2004; Leicht et al., 2018; Takala & Korhonen-Yrjänheikki, 2019; Corres et al., 2020; Jacobs et al., 2022).

The interest in sustainable development stems from the fact that the world is currently witnessing rapid changes in scientific knowledge and its applications. This requires educational systems to keep pace with these global changes, equipping students with scientific concepts, building deep knowledge, applying them to complex life situations, solving scientific, societal, and personal issues, and enhancing their desire to learn. Therefore, it becomes essential to engage students in the learning process and provide them with the experiences and skills that enable them to understand, describe, and explain scientific phenomena (Bigozzi et al., 2018; Phanphech et al., 2019). Stern et al. (2017) also emphasized the importance of engaging students in the learning process and assuming responsibility for understanding and developing scientific concepts through the practice of thinking. Shabrina et al. (2024) and Machado & Davim (2023) explained that education for sustainable development increases participation and responsibility in learning and decision-making, and enhances individuals' ability to understand scientific concepts and apply them to real life.

Conceptual understanding represents one of the major goals of science education that all students should achieve (Nadelson et al., 2018; Widiyatmoko & Shimizu, 2018; Xu et al., 2022; Prajoko et al., 2023). It is defined as the student's ability to explain and clarify scientific concepts and link them together, critically examine new ideas and place them in the cognitive structure, build multiple connections between these ideas, provide different interpretations of a problem and find new solutions, and form mental habits such as curiosity, problem-solving confidence, and self-regulation (Widiyatmoko, 2018). Also, it is a translation of deep learning that the student practices in different learning situations, in which they become able to know the cognitive structure of the content accurately, link new ideas to previous knowledge, explore the principles that govern the conceptual knowledge base, actively evaluate new ideas and conclusions, practice critical thinking skills, and independent learning, communicate effectively while learning, and work collaboratively (Decristan et al., 2015; Martínez et al., 2016; Boshuizen et al., 2020; Prajoko et al., 2023).

Conceptual understanding is at the core of the learning process (Mills, 2016) and a key goal of science education. It is a mental process that relies on several interconnected abilities, such as problem identification, explanation, interpretation, and application to new situations. It is a prerequisite for learning and mastering abstract concepts and understanding scientific phenomena and is closely linked to the student's cognitive structure (Tolba, 2023).

Many studies indicate that students lack a conceptual understanding of scientific concepts and harbor misconceptions about them (Rosa et al., 2018; Eyeoğlu et al., 2021; Badruldin & Alias, 2022; Seprapti et al., 2023; Prajoko et al., 2023). Studies also emphasized the importance of developing students' conceptual understanding of science through diverse science teaching strategies and models (Addido et al., 2022; Altunışık et al., 2023; Kranz et al., 2023; Matovu et al., 2023; Mekonnen et al., 2024).

Education for sustainable development also enhances students' motivation to learn and engage in a more comprehensive and effective educational experience. It prepares students to address scientific, societal, and environmental challenges, issues, and problems, and to change unsustainable behavior patterns (Rychen & Tiana, 2004; Osman et al., 2017). This stems from the fact that motivation is a crucial factor in science teaching and learning processes, as it motivates students to achieve many learning objectives related to acquiring knowledge and skills and stimulates the brain to work at its maximum capacity. It shapes the student's emotional side and reflects his constant tendency to pursue learning activities, continue to enjoy learning, and achieve positive self-control in learning situations (Wiyono & Wu, 2022). It is one of the mental mechanisms behind all types of human actions. It is the factor that stimulates an individual's behavior in a certain direction, shapes his behavior in a specific way, provides the energy needed for performance (Jansen et al., 2022), and affects the path the individual follows. It is also a necessary condition for achieving conceptual understanding, as students need to be motivated to engage with scientific concepts; to arouse their interest and actively participate in the process, ask questions, and make a deliberate effort to connect new knowledge to related concepts he already possesses (Schmid & Telaro, 2018; Stovner & Klette, 2022; Awudi & Danso, 2023).

Studies indicate that there is a very strong correlation between motivation to learn, academic performance, metacognitive skills, and scientific knowledge among students, and obtaining more effective educational experiences (Rahman et al., 2021; Hariyono et al., 2023; Syahmani et al., 2023; Hendriks et al., 2024), and that motivation to learn is a prerequisite for academic success, academic well-being, enjoyment, the use of deep learning strategies, and the enhancement of psychological capital (Rahman et al., 2021; Peng & Fu, 2021; Slåtten et al., 2023; Hendriks et al., 2024), and it is an effective factor that affects academic performance, and predicts learning behaviors and their continuity among students (Islam & Tasnim, 2021; Urhahne & Wijnia, 2023), and maintains emotional engagement and enhances students' confidence and resilience (Davidovitch & Dorot, 2023; Liu et al., 2024).

The dimensions of motivation are determined by: (a) Academic ambition: It refers to the student's desire to continuously strive for success, achieve a high level of performance, and face failure (Ampofo & Osei-Owusu, 2015). (b) Curiosity: It refers to the individual's desire to seek knowledge, show interest in performing the task, and actively participate in performing the task (Davidovitc & Dorot, 2023). (c) Autonomy: It refers to the individual's desire to perform tasks independently without relying on the teacher or others (Van den Berghe et al., 2016). (d) Challenge: An individual's desire to perform tasks and activities that stretch his or her abilities (Wijnia et al., 2024). (e) Motivation to succeed: It refers to the student's desire to exert effort and continuously strive towards excellence in performing learning tasks and maintaining high levels of achievement (Urhahne & Wijnia, 2023). (f) Self-efficacy: It refers to students' beliefs about their abilities and their confidence in performing tasks efficiently (Urhahne & Wijnia, 2023; Wijnia et al., 2024).

Studies indicate that various factors influence students' motivation to learn, such as participation in learning classes, participation in curricular activities, and the use of effective educational curricula, teaching strategies and models that place the student at the heart of the learning process, and the student-teacher relationship and the learning environment, prior knowledge, and learning habits that enhance motivation to learn, which in turn positively affects students' academic performance (Vermote et al., 2020; Ravat et al., 2021; Syahmani et al., 2023; Hariyono et al., 2023; Wijnia et al., 2024; Siddiky & Haque, 2024).

Education for sustainable development (ESD) aims to build new knowledge, develop conceptual understanding, and enhance values, attitudes, and motivations (Tilbury, 2011; Lutfianis et al., 2021). Therefore, it becomes important to integrate education for sustainable development into school curricula in general and science curricula in particular to encourage students to understand the importance of science in life and apply their knowledge to help sustain society and manage and conserve natural resources such as energy, and to provide students with the knowledge and skills necessary for survival, sustainable development, and meeting global sustainability challenges (Hang & Srisawasdi, 2021; Setiawan et al., 2023; Shabrina et al., 2024; Do et al., 2025). Education for sustainable development can be integrated with more student- and community-centered teaching and learning models, real-world problem-solving, and environmental sustainability (Aina et al., 2023; Li & Shein, 2023; Gericke et al., 2024). One such model is the P^5BL (Problem-Project-Process-People-Product). The P^5BL model is a development of the problem-based learning (PBL) and project-based learning (PjBL) approaches, and is based on the integration of (Problem-based learning, Project-based learning, Process-based learning, People-based learning, Product-based learning). It promotes scientific project-building and active participation in problem-solving, especially energy-related sustainability issues, co-creation, deep and comprehensive understanding, and motivation to produce knowledge (Fatiyah et al., 2021; Leijon et al., 2022; Gallagher & Savage, 2023).

Fruchter & Lewis (2003) indicate that the P^5BL learning model is a teaching methodology that depends on the existence of a problem presented to a group of individuals representing the work team, who agree to solve it through a project to produce a final product of value. It focuses on realistic problems and on interacting with content, cognitive processes, and cognitive activities most appropriate for solving them. It also focuses on meaning, obtaining knowledge from various sources, and applying it to realistic situations. It also generates feelings of interest and a desire to learn (Tolba & Al-Dhmen, 2024).

The P^5BL model is based on activities that revolve around valuable projects that promote reflection and self-regulation of the learning process, and provide spaces for learning and interaction with other community members (Fruchter, 1998; Shabrina et al., 2024; Luque & Alcantud-Díaz, 2024). The components of the model are identified as:

Problem-based learning (PBL): This approach involves engaging students in a learning situation that stimulates their cognitive abilities. It aims to connect the student's prior knowledge and experience with new knowledge to solve a problem. The steps of PBL include exploring the problem, attempting to solve it using available information, developing and implementing a solution plan, and reflecting on the solution processes (Abed et al., 2023; Kanphukiew & Nuangchalerm, 2024). The PBL approach represents an effective tool for developing sustainable development competencies such as self-awareness, critical thinking, and emotional connection (Brundiers et al., 2021). It represents an effective tool for preparing students to understand and address complex problems to move towards more sustainable societies (Llach & Bastida, 2023). It starts with real problems, which serve as tools to investigate the required knowledge and apply problem-solving skills to reach a solution (Suradika et al., 2023; Tolba & Al-Dhmen, 2024). Llach & Bastida (2023) see problem-based learning as precisely working towards the achievement of sustainable development goals by providing authentic scenarios; emotionally impactful topics and problems; promoting teamwork and the exchange of opinions between groups; learning through reflection on experiences; and developing and implementing projects with real impact on society.

Project-based learning (PjBL): It is considered one of the most important instructional models that gives students a fundamental role in the learning process (Aksela & Haatainen, 2019; Suradika et al., 2023). PjBL is defined as a student-centered educational approach that focuses on taking responsibility for learning, searching for, analyzing, and synthesizing information to solve a problem, building knowledge, and developing creative thinking skills and personal and social skills (Hugerat, 2016; Syarifah & Emiliasari, 2019; Espino-Díaz et al., 2025). It is an active pedagogical approach that engages students in authentic and meaningful learning experiences, collaboratively solving real-world problems, and collaboratively addressing complex challenges to produce a tangible product. It builds sustainable competencies by defining learning objectives and criteria addressed by the project, designing a motivating question or challenge to guide the project and stimulate students' curiosity, planning project activities and completion phases, facilitating the project process, providing guidance and feedback to students during work, and evaluating project outcomes (Žerovnik & Šerbec, 2021; Llach & Bastida, 2023; Chen, 2023; Wibowo et al., 2024; Requies et al., 2024).

Education for sustainability requires a transformative, participatory, and action-oriented educational approach that promotes independent thinking and learning and encourages collaboration. PjBL is an ideal pedagogical strategy for achieving this, through which students learn to develop projects that are important and relevant to their culture, lives, and future (Evans, 2019; Schutte et al., 2025). PjBL is the most effective educational approach for enhancing the competencies needed for sustainable development (Casanovas et al., 2022; Requies et al., 2024; d'Escoffier et al., 2025), promoting education for sustainable development practices, and achieving the Sustainable Development Goals through active participation in practical and realistic projects (Beagon et al., 2022; Requies et al., 2024), creating and designing projects to contribute to the effective achievement of the Sustainable Development Goals (Cottafava et al., 2019; Birdman et al., 2022), significantly improving motivation and academic performance (Requies et al., 2024), and enhancing understanding and critical thinking skills (Chen, 2023; Wibowo et al., 2024).

People-Based Learning: It represents a form of active, student-centered learning that involves dialectical teaching, where students must learn and apply the power of reasoning acquired through critical thinking before presenting different perspectives (Hrynchak & Baty, 2012). It is also a learning style in which a group of members collaborates to solve a shared problem (Hills, 2001). Education for Sustainable Development (ESD) recognizes the need to adopt a pedagogical approach that engages students in constructing knowledge within interactive learning environments focused on real-world problems (Beagon et al., 2022). Lin (2019), Parmelee et al. (2012), and Fruchter & Lewis (2003) argue that the P^5BL model facilitates interaction between the student team and the teacher, which enhances the learning process, builds good relationships within the team, facilitates reflection on cognitive processes, and presents multiple perspectives. Education for sustainability has emphasized the importance of learning from others, understanding and respecting their needs, perspectives, and actions (empathy), understanding, communicating with, and being sensitive to others (empathic leadership), managing conflict in groups, and facilitating collaborative and participatory problem-solving as core competencies for sustainability. People-Based learning enhances the perspective of education for sustainable development, allowing students to understand the complexity of scientific problems from environmental, economic, and social perspectives (Guerra, 2017; Machado & Davim, 2023; Uggla & Soneryd, 2023), present multiple perspectives through fruitful discussions, enhance scientific knowledge and higher-order thinking skills to find solutions to problems, decision-making abilities, and build a deeper understanding of global issues (Guerra, 2017; Nousheen et al., 2020; Ekselsa et al., 2023), and help students better understand the interconnectedness of sustainability issues, which enhances the development of critical and reflective skills (Carrión-Martínez et al., 2020; Olojo, 2021), and transform perspectives on different issues and problems (Nguyen et al., 2024). Within this type of learning, diversity in student teams affects inquiry, communication, collaboration, team psychology, team learning, access to negotiable meaning, and the development of socially constructed understanding (Zhang & Wang, 2021; Pucha & Dunbar, 2022; Nguyen et al., 2024).

Process-Based Learning: It is defined as instruction aimed at teaching domain-specific thinking strategies. The role of the teacher is to enhance students' various thinking skills, stimulate mental activity, and develop self-regulated learning strategies (Baron Levi, 2020). Process-based instruction is a strategy that simplifies the learning of science by using basic, integrated science processes. It enhances students' self-directed learning and instills a sense of responsibility during the learning process (Samuel et al., 2018). The goal of process-based instruction is to train students to develop the ability to apply science processes and scientific principles, such as science process skills, to solve a wide range of problems. Science education is thus the structured training of students to enable them to lead productive lives by solving their daily problems (Samuel et al., 2018). Education for Sustainable Development emphasizes the importance of enabling students to solve real-life problems (Forment et al., 2015), generating learning outcomes through self-directed learning, fostering a sense of responsibility, and building self-reliance and self-regulation (Garmendia et al., 2021), adopting approaches that aim to promote discussions, data identification, and reflection during the learning process, learning to ask critical questions, observe experiences, formulate conclusions, and use complex real-life problems as a starting point for developing higher-order thinking skills and knowledge search processes, practicing critical thinking skills, and transforming the student's role from a mere recipient of information to an actor in knowledge construction, such as process-based learning (Barrows, 1985; de Graaf & Kolmos, 2007; Guerra, 2017; Nousheen et al., 2020; Lutfianis et al., 2021; Govender and Pillay, 2022; Ekselsa et al., 2023). Therefore, process-based learning is a method that enables students to understand scientific concepts and engage in various mental operations, such as measurement, observation, classification, and prediction (Arlianty et al., 2017).

Product-Based Learning: It also involves a set of procedures or steps that the teacher should undertake to facilitate the learning process and student participation and interaction, and guide them toward achieving valuable outcomes (Yulastri & Hidayat, 2017). In the light of the product-based learning model, learning is defined as the acquisition of knowledge, and students are given opportunities to develop outcomes through thinking, skills, and cooperation (Ganefri & Hidayat, 2013). Fruchter (2000) emphasized that the outcomes indicate that students are active in the learning process and that there is positive interaction among the work team, which enables them to achieve the goal. Education for sustainability emphasizes the importance of adopting learning models that focus on scientific and societal problems, solution-oriented processes, and a more product-oriented approach (Garmendia et al., 2021; Gallagher & Savage, 2023; Menchaca-Torre et al., 2024), guiding the learning process with the final product (Llach & Bastida, 2023), and applying pedagogical approaches that embody tangible innovations and support product-based solutions (Maharjan et al., 2022). Therefore, in product-based learning, problems play a major role in the educational process, and dialogue and the formation of small working groups that form a collaborative team are key to solving them. (Bereiter & Scardamalia, 2000).

The P^5BL model aligns with social constructivism, which posits that knowledge is constructed through social interaction and collaboration, fostering learning communities. Individuals learn best when placed in a real-world social context and engaged in tasks that require cooperation and participation in scientific projects (Rahman et al., 2018). It is also linked to experiential learning theory, which suggests that learning begins with a tangible experience (the project), followed by reflective observation, conceptualization, and finally active experimentation (to achieve a tangible product) (Nguyen, 2025). Furthermore, it is linked to self-regulated learning (SRL) theory, which plays a vital role in learning, where students learn how to set goals, monitor their progress in the project, evaluate their performance, and adjust their strategies based on the results (Evenson et al., 2001; Gu et al., 2025). Project-based environments are the ideal laboratory for developing self-regulation, as they grant students autonomy that requires them to manage their time and resources effectively, which supports the sustainability of lifelong learning (Stefanou et al., 2013).

Education for Sustainable Development (ESD) is gaining increasing importance as a comprehensive educational framework that equips students with the knowledge and skills to address sustainability challenges. Integrating ESD into the curriculum is not limited to knowledge transfer; it also requires enhancing students' critical thinking, problem-solving, and positive engagement with scientific, environmental, and social issues. However, the challenge lies in finding effective educational models that meet these requirements and motivate students to learn and participate actively. In this context, the P^5BL (Problem-Project-Process-People-Product) model has emerged as an integrated educational model that combines problem-based learning and projects, promoting active participation and critical thinking, particularly in sustainable development topics related to energy and the environment. Nevertheless, there is still a need to evaluate the effectiveness of this model in developing motivation and conceptual understanding of science among middle school students, especially in light of ESD requirements. Therefore, the research problem stems from the need to test the effectiveness of the P^5BL model, integrated with the principles of Education for Sustainable Development (ESD), in developing a deep, effective conceptual understanding and enhancing motivation among middle school students. This aims to equip them to face the challenges of sustainable development with awareness, knowledge, and practical skills. Consequently, the research questions are:

Q1: How effective is the P^5BL model, integrated with ESD, in developing the conceptual understanding of science among middle school students?

Q2: How effective is the P^5BL model, integrated with ESD, in developing the motivation of middle school students to learn and actively participate in the educational process?

METHODS

This research used a quasi-experimental design, with a pre- and post-test applied to two groups: the experimental group studied using the P^5BL model, and the control group studied conventionally. The population comprises all second-year middle school students at a government school in Benha City during the first semester of the academic year 2021-2022 AD. The research sample consisted of 148 second-year middle school students from a government school in Benha, Qalyubia Governorate, Egypt. The experimental group consisted of 76 students studying according to the P^5BL model integrated with Education for Sustainable Development, and the control group consisted of 72 students studying according to the traditional method, which is based primarily on the teacher presenting information and scientific concepts related to the energy unit directly to students through explanations and lectures. The student's role is limited to receiving and memorizing information, with little interaction and participation, and with few activities that encourage active learning related to the energy unit and link it to sustainable development issues.

The sample was selected using convenience sampling (Etikan et al., 2016); that is, the sample was available, known, targeted, and chosen intentionally because this school is easily accessible and equipped with the necessary equipment, tools, scientific journals, and textbooks to conduct this research.

To implement the P^5BL model integrated with Education for Sustainable Development, a teacher's guide was prepared as an experimental tool for the pilot group. The guide explains how to implement the "Energy" unit lessons using the P^5BL model, integrated with Education for Sustainable Development, to develop conceptual understanding and motivation. This unit consists of the following topics: matter; heat and changes in matter; heat and thermal energy; and energy transformations. The unit contains 16 lessons and was taught over 8 weeks, following the logical sequence (matter → heat → energy transformations → environmental impact). The number of hours allocated to each stage of the P5BL model is determined according to this timeline: a lesson to identify and explain the problem in detail, including the scientific concepts and laws involved; a lesson to define the project, build the team, and assign roles; a lesson to present the project and the resulting product, highlighting the key steps, procedures, and processes that students follow when implementing scientific projects and solving problems; and a lesson to evaluate the final product. This guide includes an introduction to the P5BL model, its objectives, importance, and scientific basis; the roles of the teacher and student; variables (conceptual understanding and motivation); learning objectives; and the formulation of learning objectives that combine the physical content of energy with sustainable development goals. For example, a student might apply the law of conservation of energy (scientific objective) to design a system that reduces electricity waste (sustainability objective). The guide also covers the allocation of time to each topic and the teaching of the "Energy" unit using the P5BL model integrated with education for sustainable development. The teacher's guide explains the research intervention for implementing the "Energy" unit, designed according to the P5BL model integrated with education for sustainable development, as a step towards transforming the "Energy" unit from mere theoretical texts into a real-world experience that creates change. The guide is implemented according to the main learning styles, which are:

1) Problem-based learning: The main questions for the unit's topics are identified and formulated as key problems with environmental and social implications, such as: A person's inability to perform various activities and work if they go without food for an extended period (explain this statement, highlighting its consequences). Why are developed countries racing to invest in solar, wind, and water energy despite the availability of fossil fuels? Discuss this shift and how it contributes to protecting the right of future generations to a clean environment. Developed countries harness energy from the movement of the sun, wind, and water (explain this statement, highlighting its current and future effects on humanity). Dams rely on potential energy to generate electricity. Identify the factors affecting this energy and the physical law associated with it. Then suggest a suitable geographical location for a dam that maximizes potential energy while causing minimal harm to the surrounding ecosystem. List the factors affecting potential energy and write the law that connects them. How can this energy be utilized in life? Explore the factors affecting kinetic and potential energy, the transformations of mechanical energy, the results of energy transformations, and what would happen to ecosystems if energy transformations did not occur. An object with a mass of 8 kg falls from a height of 12 meters. Calculate its potential energy before the fall and its height when its potential energy becomes 500 J, given that the acceleration due to gravity is $10\ m/s^2$. Considering these results, how can understanding potential energy help us predict the risks of rockfalls caused by climate change, and what urban sustainability measures can be taken to avoid these risks? After studying the unit on energy, X concludes that the law of conservation of energy differs from the concepts of energy conservation and efficiency. In contrast, Y concludes the opposite, believing that the law of conservation of energy is the concept of energy conservation and efficiency. Discuss the environmental impacts of fossil fuels compared to clean energy. How can you prove either conclusion correct, providing sufficient evidence? Why do some countries consume enormous amounts of energy to produce food while others suffer from famine? In a debate about resource sustainability, X argues that energy is inexhaustible under the laws of physics, so there is no need to worry. Y says that energy is finite and needs to be conserved. Prove the validity of the conclusion that distinguishes between (the preservation of energy as a physical quantity) and (the deterioration of its quality and its transformation into a useless form through protest), and how this understanding supports the case for sustainable consumption.

2) Project-based learning: This involves presenting scientific projects related to these problems, such as: developing projects focused on energy transformations and their impact on the environment; the importance of technology for humanity and the development of environments and societies; the negative effects of technological applications such as explosives and nuclear weapons; the role of technological applications in energy storage; classifying technological applications as environmental and non-environmental pollutants and their effects on humans and society; energy transformations; energy conversion efficiency; how to invest in energy transformations; the relationship between renewable energy and climate change; converting mechanical energy through friction into thermal energy; converting chemical energy into electrical energy; heat

transfer by radiation and convection as forms of energy transfer; how to utilize heat transfer by radiation and convection in domestic environments and explain its effects on human health; designing a project that addresses building a thermally insulated house using environmentally friendly materials to reduce energy consumption; designing a simple solar water heater to understand heat transfer by radiation; or building a model of a simple chemical cell to understand the conversion of chemical energy into electricity; and designing an interactive model that illustrates the path of energy from source to consumption, analyzing what happens in each energy transformation and proposing environmentally friendly alternatives. Developing a model for an energy storage system that demonstrates the role of technology in conserving surplus energy for use during peak times, thus reducing waste. Conducting experiments on energy conversion through friction and linking it to improving the efficiency of machinery and engines to minimize energy loss as waste heat, which contributes to preserving global energy resources.

3) Individual-based learning: The teacher divides students into heterogeneous groups and assigns roles. Students are guided to carry out scientific projects within collaborative work groups, fostering motivation, perseverance, and determination. The teacher also emphasizes the importance of dialogue skills, accepting diverse ideas presented during scientific and environmental discussions, and promoting scientific teamwork skills during project implementation.

4) Process-based learning: The teacher provides instructions and procedures for project implementation, evaluates the steps, procedures, and processes students follow when carrying out scientific projects and solving problems, presents the steps and results of the scientific projects, and explains what has been accomplished. The teacher observes how students analyze data and what scientific procedures are used to convert mechanical energy from friction into heat.

5) Product-based learning: This type of learning aims to achieve specific outcomes and evaluate the final project product in light of its scientific, environmental, and social value. Students present the results of their scientific projects and problem-solving, and their impact on the environment, society, and human health. An exhibition addressing the future of global energy may be organized, with students displaying their models or posters.

This research used two tools: the Conceptual Understanding Test in the Energy Unit and the motivation scale. The conceptual understanding test in the energy unit consists of 30 multiple-choice questions on the matter (6 questions), Heat and Matter Changes (8 questions), Heat and thermal energy (8 questions), and the Energy transformations (8 questions) distributed over the dimensions of conceptual understanding: explanation (8 questions), interpretation (8 questions), application (8 questions), and perspective (6 questions). The test's total score was 30. The test was applied to a pilot sample of 40 students outside the research sample to calculate test reliability using the split-half method, yielding a reliability coefficient of 0.712. This was corrected using the Spearman–Brown equation, yielding a reliability coefficient of 0.845, which is high and acceptable. The internal consistency validity of the conceptual understanding test in science was calculated using the Pearson correlation coefficient to determine the correlation between the scores of each item at the cognitive level, which ranged between 0.567 and 0.876, and between each cognitive dimension of the test with the other dimensions and the total score of the test, which ranged between 0.459 and 0.882. These are statistically significant correlation coefficients at the 0.01 significance level, indicating that the test is internally consistent. The appropriate time for the test was determined by calculating the average time required to perform it, which was 50 minutes.

The motivation scale was developed based on a literature review and studies on motivation to identify its items and dimensions. The scale consisted of 36 items. Based on the reviewers' feedback, the scale has six dimensions: academic ambition (6 items), curiosity (6 items), autonomy (6 items), challenge (6 items), motivation to succeed (6 items), and self-efficacy (6 items). The student's learning motivation was measured using a five-point Likert scale (always, often, sometimes, seldom, never). To ensure the scale's face validity, it was reviewed by more than 10 experts in education, psychology, curricula, and science teaching methods. Furthermore, a pilot study was conducted with 40 students from middle school to ensure the clarity of the scale items and to determine a sufficient time to complete the scale (30 minutes). Cronbach's alpha was calculated for scale reliability, academic ambition (0.87), curiosity (0.90), autonomy (0.81), challenge (0.86), motivation to succeed (0.88), and self-efficacy (0.84), and the scale as a whole (0.91). This indicates that the scale has high reliability. To determine the equivalence between the experimental and control groups. in the conceptual understanding test and the learning motivation, a t-test for independent samples was used to identify the differences between the experimental and control groups as a whole and for each dimension (explanation, interpretation, application, and perspective), and in the scale of learning motivation and its dimensions (academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy) as shown in Table 1

Table 1. The Equivalence of the Experimental and the Control Groups in the Pre-test of Conceptual Understanding and Learning Motivation

Research Tools	Group	N	Mean	Standard deviation	df	T-value	Value of sig.	Significance
Conceptual understanding test	Experimental group	76	7.40	1.80	146	1.21	0.23	Not significant
	Control group	72	6.94	1.40				
Learning Motivation Scale	Experimental group	76	83.3	5.52	146	1.06	0.30	Not significant
	Control group	72	85.2	9.40				

Table 1 shows that the experimental and control groups are equal before the research experiment. That is, there are no statistically significant differences in the mean scores of the experimental and control groups before applying the two research tools (the conceptual understanding test and the motivation scale).

RESULTS AND DISCUSSION

Table 2 shows the "t" value for comparing the mean scores of the experimental and control groups after the conceptual understanding test was administered, overall and by its dimensions (explanation, interpretation, application, and perspective).

Table 2. Results of the Post-application of the Conceptual Understanding Test and its Sub-dimensions

Conceptual understanding dimension	Group	N	Mean	Standard deviation	T-value	Squared eta η2	D-value	Effect size
Explanation	Experimental group	76	6.13	1.12	4.40	0.41	1.17	High
	Control group	72	4.30	1.27				
Interpretation	Experimental group	76	5.92	1.30	4.80	0.96	6.23	High
	Control group	72	4.60	1.11				
Application	Experimental group	76	5.70	1.04	4.52	0.91	6.10	High
	Control group	72	4.60	1.05				
Perspective	Experimental group	76	4.58	0.75	4.10	0.85	4.63	High
	Control group	72	3.90	0.76				
Conceptual understanding test as a whole	Experimental group	76	22.32	3.69	5.05	0.75	3.40	High
	Control group	72	17.97	3.75				

Table 2 shows that there are statistically significant differences at the 0.01 significance level between the mean scores obtained by the experimental and control groups in the post-performance of the conceptual understanding test as a whole, favoring the experimental group with a mean of 22.32, where $t = 5.05$, $p = 0.01$, and $\eta 2 = 0.75$. The effect size (d=1.17; 6.23; 6.10; 4.63; 3.40) is greater than 0.8 for each dimension of the conceptual understanding test and for the test as a whole.The high efficacy of the P^5BL model, when integrated with Education for Sustainable Development (ESD), is primarily driven by its ability to bridge the gap between abstract scientific concepts and real-world applications. By engaging with various learning dimensions—including problem-, project-, process-, people-, and product-based learning—students can critically analyze complex environmental issues and refine their cognitive processes through diverse instructional styles (Mintz & Tal, 2016; Baron Levi, 2020).

This result can be attributed to the fact that the P⁵BL model integrated with education for sustainable development is a student-centered model that emphasizes the student's active role in learning, building and deeply understanding knowledge, applying it in complex life situations, and solving life issues and problems (Fruchter, 1999; Fruchter & Lewis, 2003; Hoidn & Klemenčič, 2021; Loyens et al., 2022). It fosters meaningful learning by engaging students in the learning process and providing them with experiences and skills that enable them to understand, describe, and explain scientific phenomena (Servant-Miklos, 2019; Abate et al., 2022). It promotes the learning of concepts and their relationships to produce a real product that has an impact on humans, the environment, and society (Syarifah & Emiliasari, 2019; Guo et al., 2020). It also allows the student to define the problem and the most important knowledge gaps within it, identify sources of knowledge, collect information, and conduct scientific experiments, developing research skills such as observation, measurement, classification, and prediction helps students build and develop a useful and productive understanding of scientific concepts and apply this understanding to help sustain society and manage and conserve natural resources such as "energy" (Arlianty et al., 2017; Samuel et al., 2018; Rotgans & Schmidt, 2019; Setiawan et al., 2023; Shabrina et al., 2024). It provides sufficient opportunities to conduct a series of scientific activities, implement worksheets, and construct diagrams that address the relationship of energy topics to sustainable development and apply scientific knowledge in new contexts that increase students' understanding of this knowledge and its relationship to sustainability issues (Parmelee et al., 2012; Lin, 2019; Shabrina et al., 2024).

This result is also attributed to the fact that the P⁵BL model, integrated with education for sustainable development, promotes practice-based learning and the student's ability to explain, apply, and interpret scientific concepts in an environmental context. It also encourages students to be independent in the learning process, to learn dialogue skills, and to practice higher-order thinking skills such as application, analysis, synthesis, and evaluation (Fruchter, 1998, 1999; Fruchter & Lewis, 2003; Konicek-Moran & Keeley, 2015).

The results indicate that integrating education for sustainable development with the P⁵BL model, which focuses on the student, the community, and solving scientific problems related to sustainability issues related to energy topics, contributes to creating effective learning moments because it includes multiple learning styles (e.g., problem-based learning, project-based learning, process-based learning, people-based learning, and product-based learning), leading to a deep understanding of the concepts included in the "Energy" unit (Leijon et al., 2022; Aina et al., 2023; Li & Shein, 2023; Gallagher & Savage, 2023; Gericke et al. 2024).

This result can be explained in light of studies that supported the importance of the P⁵BL model in training the student on organized knowledge, acquiring, transferring, and applying knowledge in the context of real problems, independence in learning, and understanding the role of scientific knowledge in developing life (Fruchter & Lewis, 2003; Ganefri, 2013; Monteiro et al., 2017; Baron Levi, 2020; Kurniawan et al., 2021; Almulhem & Almulhem, 2022; Abed et al., 2023; Altunışık et al., 2023; Tolba & Al-Dhmen, 2024). It can also be interpreted in light of studies that support the importance of applying different learning models within the context of education for sustainable development to promote the development of scientific projects that have a real impact on society and are relevant to their culture, lives, and future, active participation in problem-solving, understanding and addressing complex issues to achieve more sustainable societies, improving thinking skills, and achieving sustainable development goals, such as exploration and conceptual understanding of scientific topics related to sustainability issues (Arisetiyana et al., 2020; Lutfianis et al.,2021; Llach & Bastida, 2023; Shabrina et al., 2024; Espino-Díaz et al., 2025).

In general, the effectiveness of the P⁵BL model, integrated with education for sustainable development, can be explained in light of various learning theories, such as social constructivist learning theory, which emphasizes the importance of knowledge construction through social dialogue and interaction with others; experiential learning theory, which sees the importance of the student engaging in a learning process that begins with tangible experience, followed by reflection, knowledge construction, and active experimentation; and self-regulated learning theory, which sees the importance of the student setting their own goals, monitoring their progress during the learning process, and adjusting their thinking strategies to build the outcomes they achieve (Evenson et al., 2001; Stefanou et al., 2013; Rahman et al., 2018; Nguyen, 2025; Gu et al., 2025).

In light of this, the poor performance of the control group students in conceptual understanding can be attributed to the use of the traditional method that focuses on the teacher's role as a transmitter of knowledge and does not support student autonomy during the learning process, the lack of participation, the weak immersion in real-world problems related to the environmental and social context in which they live, and the presentation of science as a set of separate facts and concepts that are not effectively linked to sustainability issues.

Table 3 shows the "t" value for comparing the mean scores of the experimental and control groups in the post-application of the learning motivation scale as a whole and its dimensions (academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy).

Table 3. Results of the Post-application of the Learning Motivation Scale and its Sub-dimensions

Variable	Group	N	Mean	Standard deviation	T-value	Squared eta η2	D-value	Effect size
Academic ambition	Experimental group	76	24.21	1.93	17.10	0.80	4.03	High
	Control group	72	17.50	1.40				
Curiosity	Experimental group	76	24.42	1.8	16.60	0.80	3.90	High
	Control group	72	17.64	1.78				
Autonomy	Experimental group	76	24.00	1.91	17.90	0.82	4.21	High
	Control group	72	16.53	1.70				
Challenge	Experimental group	76	24.50	1.72	18.40	0.83	4.33	High
	Control group	72	17.17	1.70				
Motivation to succeed	Experimental group	76	23.40	1.80	14.30	0.74	3.40	High
	Control group	72	17.19	1.97				
Self-efficacy	Experimental group	76	23.31	2.24	15.40	0.77	3.63	High
	Control group	72	16.53	1.44				
Learning motivation as a whole	Experimental group	76	143.85	10.41	21.81	0.87	5.15	High
	Control group	72	102.55	4.65				

Table 3 shows statistically significant differences at the 0.01 level between the experimental and control groups' post-performance mean scores on the learning motivation scale as a whole, favoring the experimental group (M = 143.85), t (21) = 21.81, p = 0.01,d $\eta 2$ = 0.87. The effect size (d=4.03; 3.90; 4.21; 4.33; 3.40; 3.63; 5.15) is greater than 0.8 for each dimension of the learning motivation scale. This indicates that the effect size of the P^{5}BL model integrated with education for sustainable development in improving motivation is high, and this is because using the P^{5}BL model integrated with education for sustainable development allowed the students to practice different styles of learning, which enhances academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy in educational situations.This result is consistent with studies that have indicated that the use of teaching models is one of the factors that influence students' motivation to learn, such as Wijnia et al. (2024), Tiantian et al., (2024), Siddiky & Haque (2024), Li et al. (2023), Ravat et al. (2021), Vermote et al. (2020), and Surayanah and Karma (2018), and with studies that have indicated that integrating education for sustainable development with more student-centered teaching and learning models helps students develop the affective aspects of students in realistic contexts, develop the motivation to produce knowledge, participate in learning classes and engage in learning activities, and make a deliberate effort to connect new knowledge to relevant concepts they already possess (Stovner & Klette, 2022; Awudi & Danso, 2023; Requies et al., 2024; Espino-Díaz et al., 2025). The P^{5}BL model adopts several learning styles, such as project-based learning and problem-based learning, which enhance students' motivation to learn, perceive the value of the task, and engage in it (Rychen & Tiana, 2004; Osman et al., 2017; Tolba & Al-Dhmen, 2024; Wijnia et al., 2024). Furthermore, education for sustainable development enhances students' motivation to learn and engage in a more holistic and effective learning experience. It also prepares students to address scientific, societal, and environmental challenges, issues, and problems, and to change unsustainable behavior patterns (Lutfianis et al., 2021; Leijon et al., 2022; Gallagher & Savage, 2023)

This finding reinforces the importance of learning approaches embedded in the P[5]BL model and integrated within the context of education for sustainability development, such as problem-based learning, which enhances students' curiosity, autonomy, challenge, motivation to succeed, self-efficacy, academic ambition, and persistence in problem-solving, and develops sustainable development competencies such as self-awareness and emotional connectedness (Ampofo & Osei-Owusu, 2015; Lozano et al., 2017; Servant-Miklos, 2019; Arisetiyana et al., 2020; Brundiers et al., 2021; Abate et al., 2022). Project-based learning (PjBL) motivates students to ask questions and address real, meaningful issues and problems. It stimulates curiosity, initiative, understanding, and the tendency to engage in thinking, formulating, and solving problems. It also encourages students to develop projects that are important and relevant to their culture, life, and future. It also creates a more interactive learning environment that engages students more in learning and exploration. It facilitates interaction between the student team and the teacher, thereby enhancing the learning process and building strong relationships within the team (Syarifah & Emiliasari, 2019; Rotgans & Schmidt, 2019; Guo et al., 2020; Requies et al., 2024; Schutte et al., 2025). Process-based learning stimulates students' thinking, makes them self-directed and responsible for their learning process, fosters a sense of responsibility, and builds self-reliance and self-regulation (Forment et al., 2015; Arlianty et al., 2017; Duman & Yakar, 2019; Garmendia et al., 2021), and People-based learning, which provides students with opportunities to apply theoretical knowledge, build their knowledge, and create their experiences together by carrying out a series of scientific activities collectively, understanding and respecting their needs, perspectives, and actions (empathy), understanding, communicating with, and being sensitive to others (empathic leadership), and being positively oriented toward understanding the complexity of scientific problems from environmental, economic, and social perspectives (Parmelee et al., 2012; Lin, 2019; Machado & Davim, 2023; Uggla & Soneryd, 2023; Tiantian et al., 2024). Product-based learning motivates students to acquire goal-oriented behaviors to achieve high-quality outcomes, focusing on solution-oriented processes, and enhancing students' engagement and interaction, guiding them toward achieving valuable outcomes (Samuel et al., 2018; Guo et al., 2020; Abate et al., 2022; Gallagher & Savage, 2023; Menchaca-Torre et al., 2024).

This result can be attributed to the fact that the P[5]BL model integrated with education for sustainability focuses on the student, the active role of the student in accessing knowledge and solving scientific, environmental, cultural, and societal issues and problems, which allows students to know the impact of their actions on society and the environment, making them more motivated to take positive steps towards sustainable development (Fruchter, 1999; Fruchter & Lewis, 2003; Takala & Korhonen-Yrjänheikki, 2019; Corres et al., 2020; Hoidn & Klemenčič, 2021; Loyens et al., 2022; Jacobs et al. 2022), enhancing motivation and engaging students in problem solving (Abate et al., 2022; Servant-Miklos, 2019), interest and formulation of learning goals, building sustainable competencies through setting learning goals and autonomy, a sense of self-efficacy, a passion for learning, engaging in authentic and meaningful learning experiences in a collaborative manner, stimulating curiosity (Rotgans & Schmidt, 2019; Llach & Bastida, 2023; Requies et al., 2024), and achieving joy in learning (Conesa et al., 2022), and enhancing feelings of interest in and control over knowledge (Renninger & Hidi, 2022; Loyens et al., 2023).

In light of this, the low performance of the control group students in learning motivation can be attributed to the use of traditional methods, which do not support the use of authentic learning activities and the design of meaningful and authentic projects to effectively contribute to the achievement of the Sustainable Development Goals (SDGs) (Cottafava et al., 2019; Birdman et al., 2022; Chen, 2023). Furthermore, these methods do not allow students to engage in scientific issues or problems that enhance their academic ambition and motivation to learn. They also weaken their ability to control knowledge, preventing them from engaging in realistic experiences related to the SDGs and directly interacting with real-world challenges (Martínez Casanovas et al., 2022; Requies et al., 2024). Furthermore, they do not create a safe and stimulating environment that encourages students to experiment with knowledge and interact with it (Espino-Díaz et al., 2025).

CONCLUSION

The results demonstrated the effectiveness of integrating the P[5]BL model with education for sustainability in developing conceptual understanding and motivation in science. This study thus contributes to the growing body of knowledge on the applications of the P[5]BL model, integrated with education for sustainability, in developing the conceptual understanding processes necessary to address energy-related sustainability issues. It also increases motivation and curiosity when students can explore their interests in the context of energy-related challenges, positively influencing their behavior and attitudes toward sustainability. The results confirm that the model did not merely transmit information but addressed the need for active engagement and the achievement of conceptual understanding, which were central to the research problem. The students' ability to critically analyze the scientific, environmental, and societal issues related to the energy unit to arrive at a "real product" signifies that the research intervention successfully equipped them with the practical skills necessary to address sustainability challenges consciously and responsibly. This study provides evidence that the P^{5}BL model, with its three dimensions (problem-based learning, project-based learning, and process-based learning), can be used with science students to develop sustainability education objectives (conceptual understanding and motivation) through scientific problems and projects that address energy topics from environmental and social perspectives. In general, more research is needed, including larger student samples, different scientific topics, and other disciplines such as physics, chemistry, and biology, to obtain more accurate results at scale. The study recommends restructuring science units in light of the P^{5}BL model and adopting it as a framework for developing middle school science curricula.

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