



The efficacy of P⁵BL strategy in science education: Enhancing conceptual understanding and learning motivation among Egyptian Middle School students

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Abstract

This study investigated the efficacy of the Problem-Project-Product-Process-People-Based Learning (P⁵BL) strategy in improving students' conceptual understanding and learning motivation within the context of middle school science education in Egypt. Utilizing a quasi-experimental design, the researcher compared an experimental group with a control group. The study population included all second-year middle school students at a government school in Benha City. The final sample consisted of 74 students, divided into an experimental group (n = 38) and a control group (n = 36). Data were collected using two primary instruments: a conceptual understanding test and a learning motivation scale. The study concluded that the P⁵BL strategy significantly enhanced both conceptual understanding (explanation, interpretation, application, and perspective) and learning motivation (academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy). A statistically significant correlation was also found between student learning motivation and their conceptual understanding. The study recommended the adoption of the P⁵BL strategy to enhance students' understanding of scientific concepts and learning motivation. It also emphasized the importance of providing teachers with guidance on how to teach science using the P⁵BL strategy as a learner-centred teaching strategy to enhance

students' cognitive, affective, and skill-based learning. Finally, the study proposed several recommendations for future research.

Keywords: Learning motivation, scientific concepts, science, conceptual understanding, P⁵BL strategy.

Introduction

The world today is witnessing rapid changes in scientific knowledge and its applications, which require educational systems to be aware of these global changes in order to provide the learner with scientific concepts, support knowledge construction and deep understanding, enable the application of knowledge in complex real-life situations, and promote the ability to solve scientific and everyday problems, in addition to enhancing the learners' desire to learn. Therefore, it becomes important to involve the learner in the learning process and provide him with the experiences and skills that enable him to understand, describe and explain scientific phenomena (Phanphech et al., 2019). According to Stern et al. (2017), students should be central to the learning process, as they are required to assume responsibility for developing and refining scientific ideas through active engagement in higher-order thinking practices.

Conceptual understanding represents one of the major goals of science education that should be achieved by all students (Xu et al., 2022). It is defined as the learner's capacity to explain scientific concepts and principles and integrate them into a cohesive framework. It involves critically evaluating new information and incorporating it within existing cognitive structures, establishing diverse conceptual links, offering various interpretations of scientific problems, devising innovative solutions, and developing productive mental habits such as curiosity, problem-solving confidence, and self-regulation (Widiyatmoko, 2018). Furthermore, conceptual understanding reflects deep learning that the learner practices in different learning situations, through which they become able to accurately identify the cognitive structure of the content, link new ideas to previous knowledge, and explore the principles that govern the conceptual knowledge base (Boshuizen et al., 2020).

Many studies indicate that students lack a conceptual understanding of scientific concepts and hold misconceptions about them (Seprapti et al., 2023; Kalaycı Eyeoğlu et al., 2021). Accordingly, several studies also recommended the importance of developing students' conceptual understanding of science by using learner-centred science teaching strategies (Mekonnen et al., 2024; Kranz et al., 2023; Addido et al., 2022).

Motivation is also a critical factor in the processes of teaching and learning science, as it is responsible for motivating the learner to achieve many learning goals related to knowledge and skills acquisition and stimulates cognitive engagement at optimal levels. It constitutes the emotional aspect of the learner and expresses his constant tendency to follow learning activities, continue to enjoy learning, and achieve positive self-control in learning situations (Tiantian et al., 2024). It is a conscious effort that arises from within the individual to be able to learn and solve problems (Ajiwibawani et al., 2017). Moreover, motivation is a necessary condition for achieving conceptual understanding, as learners need to be motivated to engage with scientific concepts, stimulate their interest and actively participate in learning activities,

ask questions, and make a deliberate effort to link the new knowledge with relevant prior concepts (Awudi & Danso, 2023).

Therefore, studies have highlighted the importance of learning motivation and the necessity of developing it among learners through the use of various teaching strategies (Tiantian et al., 2024). One such strategy is the P⁵BL. The P⁵BL strategy represents an integrated instructional approach that extends Problem-Based Learning (PBL) and Project-Based Learning (PjBL) by incorporating Process-Based Learning, People-Based Learning, and Product-Based Learning.

Fruchter and Lewis (2003) indicate that the P⁵BL strategy is an educational framework based on the existence of a real problem that is presented to a group of students who work together as a team through a project to solve that issue or problem in order to reach the production of a valuable final product. Also, Tolba and AL-Dhmen (2024) pointed out that the P⁵BL strategy enhances the ability to process information, activates the learner's cognitive processes, motivates them to learn, and creates positive attitudes towards learning. Therefore, the current study aims to investigate the

efficacy of the P⁵BL strategy in science education in enhancing conceptual understanding and learning motivation among Egyptian middle school students.

Research problem

Despite the objectives of science teaching that emphasize the development of students' conceptual understanding, the reality of teaching processes focuses on acquiring scientific concepts and storing them in memory without processing them to achieve a conceptual understanding. Previous research has highlighted the importance of developing conceptual understanding in science, as it represents a true translation of the occurrence of deep learning in which various thinking skills are practised, and complex problems are solved (Kranz et al., 2023; Matovu et al., 2023; Addido et al., 2022; Duan, 2022; Kalaycı Eyeoğlu et al., 2021).

Studies also indicated that the most effective factor in learner performance is motivation to learn. It is a strong indicator of the quality of learning, reflects the learner's ability to self-regulate, and creates positive attitudes towards learning practice, through which the learner's cognitive and affective behaviours in the learning processes can be predicted (Tiantian et al., 2024; Wiyono & Wu, 2022; Zambuk, 2021).

Mystakidis (2021) pointed out that conceptual understanding requires the learner to go beyond knowledge of concepts by developing positive feelings toward the learning topic, engaging in scientific activities, discussing and developing ideas, reflecting on the learning process, and being willing to analyze and synthesize knowledge. Therefore, it is important to develop a conceptual understanding and motivation for learning science using teaching strategies (Suryanti et al, 2018; Adegboyega, 2018).

The P⁵BL strategy is one of the strategies that focus on real problems, and allows learners to interact with the content and benefit from the most appropriate cognitive activities to solve those problems, thereby enhancing their knowledge and the knowledge of others. It emphasizes meaning-making and reflects on thinking processes and learning outcomes, in addition to stimulating learners' interest, enjoyment, and desire to learn (Tolba & AL-Dhmen, 2024).

The P⁵BL model prioritizes authentic, real-world problem-solving, enabling learners to engage deeply with content through targeted cognitive activities. By focusing on core meaning and integrating

new information with prior experiences, students utilize diverse resources to apply knowledge in practical contexts. This reflective process not only enhances individual and collective knowledge but also fosters a genuine sense of curiosity and purposeful motivation to engage with complex tasks (Tolba & AL-Dhmen, 2024; Dos Santos & Benneworth, 2019). The current research explores the effectiveness of the P⁵BL strategy in enhancing students' conceptual understanding and learning motivation, as they are important outcomes in the educational process.

Research questions

Therefore, the research problem is defined in the following main question: What is the impact of the P⁵BL strategy in science education on enhancing conceptual understanding and learning motivation among second-year middle school students in Egypt? To address this primary question, the following sub-questions are explored:

1. To what extent does the P⁵BL strategy develop conceptual understanding (explanation, interpretation, application, and perspective) among second-year middle school students?

2. What is the impact of the P⁵BL strategy on developing students' learning motivation (academic ambition, curiosity, autonomy, challenge, drive for success, and self-efficacy)?
3. What is the nature of the correlation between learning motivation and conceptual understanding within the context of science education for second-year middle school students?

Research hypotheses

The research hypotheses were determined as follows:

1. There is no statistically significant difference between the mean scores of students in the experimental and control groups in conceptual understanding at a significance level of $\alpha \leq 0.05$.
2. There is no statistically significant difference between the mean scores of students in the experimental and control groups in learning motivation at a significance level of $\alpha \leq 0.05$.
3. There is no statistically significant correlation between learning motivation and conceptual understanding of science among students in the experimental and

control groups at a significance level of $\alpha \leq 0.05$.

Literature review

The contemporary educational landscape necessitates a shift from traditional curricula to integrated, learner-centred models that reflect the complexities of the world and foster active student-centred engagement. The P⁵BL (Professional Learning, Projects, Problem Solving, Processes, and Products) model emerges as a comprehensive framework and integrated educational approach that combines inquiry-based learning with collaborative social dynamics. By placing students at the heart of real-world problems and collaborative innovation, this model serves as a powerful engine for deepening conceptual understanding and stimulating learning motivation. This theoretical framework examines how the dimensions of the P⁵BL model transform the educational experience from rote memorization to a purposeful exploration of human potential.

P⁵BL strategy: Concept, main goals, assumptions and dimensions

Fruchter (1998) suggests that the P⁵BL strategy comprises five types of learning: problem-based, project-based, process-based, person-based, and product-based learning. These types of learning are combined to form what is known as the

P⁵BL strategy. P⁵BL strategy focuses on problem-solving and project-based activities as the central components of the teaching and learning process (Monteiro et al., 2017; Fruchter & Lewis, 2003; Fruchter, 2000).

In light of this, the P⁵BL learning model is one of the teaching models that seeks to build an educational environment that works to expand the scope of practice and application of practical skills by providing appropriate opportunities to practise these skills and improve the use of these skills that qualify them for the future labour market.

Tolba and AL-Dhmen (2024), Abed et al. (2023), Almulhem and Almulhem (2022), Baron Levi (2020), Monteiro et al. (2017), and Ganefri (2013) identified several primary goals of the P⁵BL strategy. It aims to improve learners' ability to develop knowledge and self-regulation for learning, applying metacognitive strategies, summarizing necessary knowledge, planning, accessing cognitive construction and exploration of prior knowledge, and improving learners' ability to construct and develop a cognitive structure for science, using self-regulation skills to access new knowledge, applying cognitive, metacognitive, and affective strategies. In

addition, P⁵BL fosters interpersonal and collaborative skills such as communication, leadership, and relationship-building, while cultivating analytical, critical, innovative, and reflective thinking to address scientific issues and generate solutions. It encourages active learning and increases learners' engagement in the learning situation, practising higher-order thinking patterns such as application, analysis, synthesis, and evaluation. It creates effective learning moments by incorporating different and effective learning patterns. By incorporating diverse and effective learning approaches, P⁵BL transforms the focus of the educational process from individual to collective, and from individual-based thinking to group thinking, and increases the level of idea deduction and development through collective thinking and planning, in addition to developing and acquiring conceptual understanding, skills, and practical practices.

The P⁵BL model focuses on activity-based learning centred around projects that yield tangible value (Fruchter, 1998). The specific dimensions of this model are defined as follows:

Problem-based learning: It is based on involving the student in a learning

situation that stimulates their cognitive aspect. It aims to connect the student's prior knowledge and experiences with new knowledge to solve a problem. The steps involved in PBL include problem exploration, attempting to solve the problem using the learner's existing information, identifying what is known and what needs to be known, formulating a research plan, and reflecting on the problem-solving process. Problem construction and execution are vital for the success of PBL (Abed et al., 2023). The characteristics of PBL are determined by the following: learning must necessarily be student-centred. Learning begins with an authentic problem, and the problems are used as a tool to achieve and investigate the required knowledge (d'Escoffier et al., 2025).

Project-Based Learning: PjBL is defined as an educational approach that centres on a curriculum-derived scientific problem that requires students to work together in groups to solve those problems. It enhances the growth of academic, personal, and social skills (d'Escoffier et al., 2025; Espino-Díaz et al., 2025; Ergül & Kargin, 2014). Hugerat (2016) emphasizes that PjBL allows the learner to practise various scientific activities; thus, it gives the learner effective and positive roles in the learning situation.

People-based learning: It represents a style of active, learner-centred learning that requires learners to engage in critical and reflective thinking about controversial issues before presenting different perspectives (Hrynychak & Batty, 2012). Also, it is a style of cooperative learning in which a group of students collaborate to solve a common problem (Hills, 2001). Lin (2019) and Parmelee et al. (2012) argue that the P⁵BL strategy views the classroom as a learning community, promoting team learning and interaction between students and the teacher during problem-solving and project implementation.

Process-based learning: This is a style of education that promotes the teaching of thinking strategies within a specific field of knowledge. The teacher's role is to stimulate mental activity, develop self-regulated learning strategies, and enhance students' various thinking skills (Baron Levi, 2020). Therefore, process-based learning aims to train learners to practice these processes to solve a wide range of issues, events, and problems, and to develop their ability to apply scientific knowledge to new situations. It also views science education as the systematic training of learners to enable them to live productive lives in a complex world (Samuel et al., 2018). It enables learners

to understand scientific concepts and provides them with sufficient guidance during their study of science to develop scientific processes and research skills. Accordingly, curricula are designed to focus on presenting science as a thinking process and building mental representations (Arlianty et al., 2017).

Product-based learning: It also includes a set of procedures or steps that the teacher should take to facilitate the learning process, student engagement and interaction, and guide them toward achieving valuable outcomes (Yulastri & Hidayat, 2017). In light of the product-based learning model, learning is defined as the development and addition to the body of knowledge, and students are given opportunities to create tangible results by applying various thinking processes and skills (Ganefri & Hidayat, 2015; Fruchter, 2003).

Conceptual understanding: Concept and importance

Concepts are the architecture of the human mind. Scientific concepts resemble mental representations in their simplest forms (Tolba, 2023). Cognitive scientists state that concepts are complex representational structures that assist in making inferences and explaining and interpreting complex ideas (Carey, 2000).

Teaching practices in science often emphasize the identification and memorization of scientific concepts, which can be considered a form of passive learning. In such cases, learners become capable of reproducing concepts without grasping their underlying meanings. This type of understanding is known as "literal understanding" (Kalaycı Eyeoğlu et al., 2021). Effective science education prioritizes comprehension over rote learning. Rather than gathering disconnected facts, students must develop deep insights and construct well-organized, cohesive conceptual structures (Widiyatmoko, 2018; Widiyatmoko & Shimizu, 2017).

Learning scientific concepts is the fundamental outcome of education, as it serves as the cornerstone for building the mind and provides the basis for higher-order cognitive processes. Therefore, achieving conceptual understanding of scientific concepts requires extensive practice, where students interact with new concepts within a socio-cultural context that enriches their deep understanding (Suryanti et al., 2018).

Conceptual understanding is at the heart of the learning process (Mills, 2016) and is considered a central goal of science education (Xu et al., 2020). It is a basic

requirement in science education and has implications for shaping students' scientific culture and scientific literacy (Addido et al., 2022). Conceptual understanding refers to students' ability to understand and transfer knowledge acquired in a subject in depth, build on it, and be able to apply it (Addido et al., 2022).

Consequently, literature has pointed to the importance of enhancing conceptual understanding (Mekonnen et al., 2024; Awudi & Danso, 2023).

Learning motivation as a catalyst for human nature

Motivation is one of the mental mechanisms behind all types of human actions. It is the factor that stimulates an individual's behaviour in a certain direction, or makes him behave in a specific way, and provides the energy needed for performance (Jansen et al., 2022). It includes the cognitive and emotional forces within the person that affect the direction, intensity and continuity of his behaviour. It is the integral part of the learner's life that directs their thinking and feelings (Siddiky & Haque, 2024). Motivation to learn is defined as the amount of mental energy expended when performing learning activities (Filgona et al., 2020),

an internal state that stimulates and sustains goal-directed behaviour and activity (Schunk & DiBenedetto, 2020).

Studies indicate that there is a very strong correlation between motivation to learn, academic performance, self-regulated learning among students, and obtaining more effective educational experiences. Motivation to learn is considered a prerequisite for academic success, academic well-being, enjoyment, the use of deep learning strategies, and the enhancement of psychological capital (Hendriks et al., 2024; Rahman et al., 2021). Moreover, it is a key factor that affects academic performance and predicts learning behaviours and their continuity among students (Urhahne & Wijnia, 2023), while also maintaining emotional engagement and enhancing students' confidence and resilience (Liu et al., 2024; Davidovitch & Dorot, 2023; Sewagegn & Dessie, 2021).

The dimensions of learning motivation are determined by: (a) Academic ambition: It refers to the learner's desire to continuously strive for success, achieve a high level of performance, and face failure constructively (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 task performance (Davidovitch & 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: It refers to an individual's desire to engage in tasks and activities that challenge his or her abilities (Wijnia et al., 2024). (e) Motivation to succeed: It refers to the learner'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 the learner's beliefs about his or her abilities and confidence in performing tasks efficiently (Wijnia et al., 2024).

Potential effects of the P⁵BL strategy on conceptual understanding and learning motivation

Over the past decades, there has been a significant shift from teacher-driven to student-driven learning, emphasizing the active role of learners in learning and knowledge construction (Loyens et al., 2023). One powerful approach in this direction is problem-based learning (PBL), which aims to enhance motivation and build meaningful learning by using realistic problems to engage learners in solving them., PBL uses real-world

contexts to motivate and engage students in the learning process, and provides an environment that motivates the learner to be enthusiastic about the learning topics (d'Escoffier et al., 2025; Altunışık et al., 2023; Abate et al., 2022; Sewagegn & Dessie, 2021; Servant-Miklos, 2019), Project-based learning (PjBL) focuses on real issues and problems that are useful to students and uses projects as a means to reach a real product, and enhances the learning of concepts, relationships, principles, laws and theories related to the field (Guo et al., 2020; Syarifah & Emiliyasi, 2019). PjBL has many motivational features. The collaborative aspect positively affects the learner's motivation, while simultaneously enhancing feelings of independence and creating a sense of "ownership" as he sees himself as having an active role in implementing the project (Wijnia et al., 2024; Renninger & Hidi, 2022; Blumenfeld et al., 1996). It also enables the learner to identify the problem and the important knowledge gaps within it, identify sources of knowledge, and connect prior knowledge with new knowledge to refine and discuss the problem, which increases motivation (Rotgans & Schmidt, 2019). In process-based learning, the focus is on developing science processes and thinking skills in

forming scientific concepts (Samuel et al., 2018; Arlianty et al., 2017). People-based learning, which provides students with opportunities to apply theoretical knowledge, build their knowledge, and form their experiences together (Tiantian et al., 2024; Lin, 2019; Parmelee et al., 2012). Product-based learning focuses on students reaching a final product that is useful to them while working on scientific projects centred on solving problems (Ganefri & Hidayat, 2015; Fruchter, 1998).

Numerous studies indicate that student-centred learning models—which emphasize projects, real-world problem-solving, and collaborative work—enhance the acquisition and retention of scientific concepts in long-term memory, build understanding, develop scientific ideas, establish connections between existing and new concepts, and utilize and expand these connections to engage in the construction of scientific theories. Furthermore, these models foster the application of diverse scientific processes and thinking styles to achieve high-quality results, build deeper understanding, and bridge the gap between prior knowledge and new information (Syarifah & Emiliyasi, 2019; Lin, 2019; Parmelee et al., 2012). Moreover, these models enhance learning

motivation, cultivate self-confidence, and encourage goal-oriented behaviours (Abate, 2022; Guo et al., 2020; Samuel et al., 2018; Ergül & Kargin, 2014).

Methodology

Research approach

To achieve the research objectives, a quasi-experimental design was used, which is based on applying a pre- and post-test design to two groups; the experimental group was taught using the P⁵BL strategy, whereas the control group was taught using a conventional method.

Research population and sample

The study focused on a specific demographic within the Egyptian

education system during the 2021-2022 academic year. The participants and selection framework are detailed below:

- Research population: The original research population comprised all second-year preparatory students enrolled in public schools in Benha during the first semester. According to official statistics, the total number of students was approximately 4,658. This population represented the target group of the study and was defined based on geographic units,

depending on the chosen sampling approach.

- Final research sample: A convenience sample was used based on accessibility; that is, students who were readily available were selected (Yildirim & Simsek, 2016). The actual study was conducted on a sample of 74 students from Benha Preparatory School, a public school in the Benha district. The experimental group consisted of 38 students who studied using the P⁵BL strategy, and the control group consisted of 36 students who studied using the traditional method.

P⁵BL implementation process (experimental treatment)

The teacher's guide was prepared as an experimental treatment tool for the experimental group, and it explains how to implement the lessons of the unit (Energy) using the P⁵BL strategy in order to enhance students' conceptual understanding and learning motivation. This unit consists of the following topics: the matter, heat and matter changes, heat and thermal energy, and the energy transformations. It contains 16 lessons and was taught over a period of six weeks. . This guide consists of the unit objectives, a brief overview of the P⁵BL strategy, conceptual understanding and

motivation for learning, time distribution of energy unit topics, and implementation of energy unit lessons using the P⁵BL strategy. The teacher's guide explains the research intervention designed to implement the (Energy) unit developed according to the P⁵BL strategy, which was implemented through five main learning patterns: (1) problem-based learning, in which the main questions of the unit topics are identified and formulated in the form of main problems; (2) project-based learning, in which scientific projects related to those problems are presented; (3) process-

based learning, in which instructions and "processing" procedures are provided to enable project implementation; (4) people-based learning, in which learning teams are built to implement projects and solve scientific problems; (5) product-based learning, in which specific outcomes are reached and the final product of the project is evaluated. Within each stage, both the teacher and the learner assume specific and important roles. Table 1 shows the implementation process carried out with the experimental group according to the main stages of the P⁵BL strategy.

Table 1: Procedures for implementing experimental treatment according to the main stages of the P⁵BL strategy.

<i>The first stage :Problem-Based Learning (Identify the main questions of the unit topics and formulate them in the form of main problems)</i>
The teacher presents scientific problems, for example: 1. A person's inability to perform various activities and work if he does not eat food for a long period (why?). 2. Developed countries resort to exploiting the energy emitted by the sun, wind and water movement (why?). 3. Mention the factors affecting potential energy, mentioning the relationship between each factor and potential energy, and writing the law that links them?. 4. A force of (65 N) affected a stationary body, so it moved a distance of (10 m) in the same direction of the force. Calculate the amount of work done. 5. A body with a mass of (5kg) fell vertically from a height of (8m). Calculate the potential energy of the body before it fell, and the height of the body when its potential energy becomes (300 J). knowing that the acceleration due to gravity = 10 m / s².

6. What are the consequences of energy transformations, and what would happen to ecosystems if there were no energy transformations?.
7. After studying the energy unit, X concluded that the law of conservation of energy is different from the concept of energy conservation and rationalization, while Y concluded the opposite, as he sees the law of conservation of energy as the concept of energy conservation and rationalization. How can you prove the validity of either conclusion, providing sufficient evidence?

The learner explores problems and gives possible answers, identifies prior knowledge and what he needs to know about these problems, constructs and implements a solution plan, reviews the solution, and thinks and reflects on solutions and the problem-solving process.

The second stage: Project-Based Learning (Presenting scientific projects related to energy unit topics)

1. The teacher directs the students to do some scientific projects, for example:
2. Building a project that revolves around energy transformations and their effects on the environment.
3. Building a project that addresses the importance of technology for humans, and the negative effects of each of the technological applications represented by explosives and atomic weapons.
4. Building a project that addresses the role of technological applications in storing energy in the same forms.
5. Building a project that deals with classifying technological applications into environmental pollutants and non-environmental pollutants.
6. Build a project that demonstrates that not all technological applications of energy transformations are appreciated by scientists.
7. Building a project that addresses energy transformations and examples of energy transformations and energy conversion efficiency.
8. Building a project on how to design a simple electric pole.
9. Building a project that addresses the relationship between renewable energy and climate change.
10. Building a project that deals with conducting a set of experiments that illustrate the conversion of mechanical energy by friction into thermal energy.
11. Building a project that deals with how to convert chemical energy into electrical energy.

12. Building a project on heat transfer by radiation and convection as a form of energy transfer, explaining what each of them means, and how heat transfer by radiation and convection can be exploited within home environments, explaining their effects on human health.
Students plan and implement science projects with members of cooperative learning groups.
<i>The Third stage: People-Based Learning (Building learning teams to implement projects and solve scientific problems)</i>
The teacher guides and follows up on students to implement scientific projects in cooperative work groups, enhances students' motivation and perseverance when implementing scientific projects, reinforces the importance of accepting different ideas presented during scientific projects and solving problems, and enhances teamwork skills while working on scientific projects.
Students plan, distribute tasks, implement scientific projects, and present main ideas and proposed solutions with members of cooperative learning groups. Each learner performs the task assigned to them in the scientific project.
<i>The fourth stage: Process-Based Learning (giving instructions and procedures, "processing" that enable the project to proceed)</i>
The teacher evaluates the steps, procedures and processes that students perform when implementing science projects and solving problems, and verifies that students have successfully completed science projects.
Students identify where and how to start science projects and solve problems, present the steps and results of science projects and problem-solving, and explain what has been accomplished.
<i>The fifth stage: Product-Based Learning (reaching specific outcomes and evaluating the final product of the project)</i>
The teacher directs students to present the outcomes and outputs of implementing scientific projects and solving problems, in addition to evaluating the students' final products.
Each learning team presents the most important products they have reached to the other learning teams. It also allows the learner to evaluate his learning.

Research tools

The research tools used

1. *Conceptual understanding test in the energy unit:* This test consists of 30 multiple-choice questions on the energy unit. The number of questions on the topics of matter, heat and matter changes, Heat and thermal energy, and Energy transformations is 6, 8, 8, and 8, respectively. These questions are distributed across the conceptual understanding dimensions: explanation, interpretation, application, and perspective. To calculate the reliability of the test using the split-half method, the test was administered to a pilot sample of 40 students. The reliability coefficient was 0.712, and it was corrected using the Spearman-Brown equation to reach 0.845, which is a high reliability coefficient. Pearson's correlation coefficient was calculated to determine the correlation between the scores of each item on the cognitive level and between each cognitive dimension of the test with the other dimensions and the total score of the test, to ensure the internal consistency of the test. The correlation coefficients ranged between 0.459 and 0.882, which is statistically significant at the
- 0.01 significance level, indicating the internal consistency of the test.
2. *The learning motivation scale:* The relevant literature on learning motivation was reviewed to identify the dimensions and items of the scale. Based on previous studies, including Surayanah and Karma (2018) and Adegboyega (2018), the scale consists of 36 items distributed across six dimensions: academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy. Each dimension contains six items. These items were formulated using a five-point Likert-type scale (always, often, sometimes, rarely, and never). The scale was administered to a pilot sample of 40 middle school students to ensure the clarity of its items and to determine the time required for completion, which was 30 minutes. Cronbach's alpha coefficient was used to calculate the scale's reliability, which was 0.87, 0.90, 0.81, 0.86, 0.88, and 0.84 for the dimensions of academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy, respectively. The overall reliability coefficient for the scale was 0.91. This indicates a high degree of reliability of the scale.

The pre-application of the study tools (equivalence of the two groups)

An independent samples t-test was used to identify differences between the mean scores of students in the experimental and control groups on the variables of

conceptual understanding and learning motivation, and to determine the equivalence of the two groups on these variables prior to the implementation of the experimental treatment. Table 2 illustrates these results.

Table 2: *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	38	7.40	1.78	72	1.21	0.231	Not significant
	Control group	36	6.94	1.39				
Learning motivation scale	Experimental group	38	83.29	5.52	72	1.055	0.295	Not significant
	Control group	36	85.17	9.39				

The results in Table 2 indicate that there are no statistically significant differences between the mean scores of the students of the experimental and control groups in the pre-application of the two research tools, which supports the equivalence of the students of the experimental and control groups before the experimental treatment.

Results and discussion

The efficacy of the P⁵BL strategy in enhancing conceptual understanding

After the experimental treatment, the t-value was calculated to compare the mean scores of the experimental and control groups on the conceptual understanding test as a whole and its dimensions to verify the validity of the first hypothesis. Table 3 illustrates these results.

Table 3: *Results of the post-application of the conceptual understanding test (explanation, interpretation, application, and perspective).*

<i>Conceptual understanding dimension</i>	<i>Group</i>	<i>N</i>	<i>Mean</i>	<i>Standard deviation</i>	<i>T-value</i>	<i>Squared eta η^2</i>	<i>D-value</i>	<i>Effect size</i>
Explanation	Experimental group	38	6.13	1.12	4.37	0.408	1.17	High
	Control group	36	4.92	1.27				
Interpretation	Experimental group	38	5.92	1.30	4.75	0.958	6.23	High
	Control group	36	4.58	1.11				
Application	Experimental group	38	5.68	1.04	4.52	0.903	6.10	High
	Control group	36	4.58	1.05				
Perspective	Experimental group	38	4.58	0.75	4.06	0.843	4.63	High
	Control group	36	3.86	0.76				
Conceptual understanding test as a whole	Experimental group	38	22.32	3.69	5.05	0.743	3.40	High
	Control group	36	17.94	3.75				

The results in Table 3 indicate that there are statistically significant differences between the mean scores of students in the experimental and control groups on the post-test of the conceptual understanding test as a whole, in favour of the experimental group (mean= 22.32, t-value = 5.05, p = 0.01, and η^2 = 0.743).

This indicates the strong effect of the P⁵BL strategy in enhancing conceptual understanding. This result can be attributed to the fact that the use of the P⁵BL strategy allows the learner to interact with, deal with, and understand scientific phenomena, form new scientific concepts and ideas based on previous

experiences. In addition, learners practise different scientific processes, thinking skills, communication skills, and collaboration skills by going through different learning styles such as problem-based, project-based, process-based, people-based, and product-based learning (Baron Levi, 2020).

This result can be interpreted in light of the learner-centred nature of the P⁵BL strategy, which emphasizes the learner's active role in learning and shaping new knowledge (Fruchter & Lewis, 2003; Fruchter, 1999), promotes the construction of meaningful learning (Abate et al., 2022; Sewagegn & Dessie, 2021; Servant-Miklos, 2019), and enhances the learning of concepts and the relationships between them to reach a real product (Guo et al., 2020; Syarifah and Emiliasari, 2019; Ergül & Kargın, 2014). In addition, the P⁵BL strategy allows the learner to identify the problem and the most important knowledge gaps within it, identify sources of knowledge, collect and select information, and conduct scientific experiments (Rotgans & Schmidt, 2019). It also supports the development of research skills such as observation, classification, interpretation, and prediction in reaching a good understanding of the scientific phenomenon and reaching a valuable

product (Samuel et al., 2018; Arlianty et al., 2017). Furthermore, the strategy provides adequate opportunities to carry out a series of scientific activities and apply knowledge in new contexts (Lin, 2019; Parmelee et al., 2012).

Moreover, this result can also be explained by the objectives of the P⁵BL strategy, which emphasize the importance of training the learner to self-organize knowledge, acquire, transfer, and apply knowledge in realistic contexts, practice creative and critical thinking skills, take responsibility for learning, and work in collaborative groups. In addition, the strategy encourages learners to move beyond individual-based thinking towards cross-group thinking, which enhances inference, idea construction, and development of ideas (Tolba & Al-Dhmen, 2024; Altunışık et al., 2023; Almulhem & Almulhem, 2022; Baron Levi, 2020; Monteiro et al., 2017; Ganefri, 2013).

This result can be explained in light of the objectives of the P⁵BI model, which emphasizes the importance of training the learner on organized knowledge, acquisition, transfer, and application of knowledge in the context of real-world problems, practising creative and critical thinking patterns, and assuming

leadership and responsibility in the learning process. The model also supports the effective use of acquired theoretical knowledge and highlights the role of domain-specific knowledge within the learning environment. Furthermore, it shifts the focus of the educational process from individual to collective, and from thinking based on the individual to thinking across groups, which increases the degree of deduction, construction, and growth of ideas (Tolba & AL-Dhmen, 2024; Abed et al., 2023; Almulhem & Almulhem, 2022).

The poor performance of the control group students in conceptual understanding can be attributed to the teacher's adoption of traditional teaching methods that weaken the learner's autonomy during the learning process,

reduce active participation in knowledge construction, provide limited focus on real-world problems, and present scientific content in an incoherent manner and as a set of separate facts and concepts.

The efficacy of the P⁵BL strategy in developing learning motivation

After the experimental treatment, the t-value was calculated to compare the mean scores of the experimental and control groups on the learning motivation scale as a whole and its dimensions (academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy) to verify the validity of the second hypothesis. Table 4 illustrates these results.

Table 4: *Results of the post-application of the learning motivation scale (academic ambition, curiosity, autonomy, challenge, motivation to succeed, and self-efficacy).*

Variable	Group	N	Mean	Standard deviation	T-value	Squared eta η^2	D-value	Effect size
Academic ambition	Experimental group	38	24.21	1.93	17.08	0.802	4.03	High
	Control group	36	17.47	1.40				
Curiosity	Experimental group	38	24.42	1.75	16.55	0.792	3.90	High

	Control group	36	17.64	1.78				
Autonomy	Experimental group	38	24.00	1.91	17.86	0.816	4.21	High
	Control group	36	16.53	1.66				
Challenge	Experimental group	38	24.47	1.72	18.38	0.824	4.33	High
	Control group	36	17.17	1.70				
Motivation to succeed	Experimental group	38	23.39	1.76	14.29	0.739	3.37	High
	Control group	36	17.19	1.97				
Self-efficacy	Experimental group	36	23.31	2.24	15.38	0.767	3.63	High
	Control group	38	16.53	1.44				
Learning motivation as a whole	Experimental group	36	143.82	10.41	21.81	0.869	5.15	High
	Control group	38	102.53	4.65				

The results in Table 4 indicate that there are statistically significant differences between the mean scores of students in the experimental and control groups on the post-test of the learning motivation scale as a whole, in favour of the

experimental group (mean=143.82, t-value = 21.81, $p = 0.01$, and $\eta^2 = 0.869$). This demonstrates a strong effect of the experimental treatment (P⁵BL strategy) on enhancing learning motivation., This effect can be attributed to the fact that

the use of the P⁵BL strategy, with its different learning styles, enhanced the learner's academic ambition, curiosity, independence, challenge, motivation to succeed, and self-confidence in educational situations. Moreover, the learners' exposure to different learning strategies, such as project-based and problem-solving learning, enhanced their motivation to learn, leading to an increase in their focus on tasks, their awareness of their value, and their engagement in learning activities (Tolba & AL-Dhmen, 2024; Wijnia et al., 2024).

These results highlight the effectiveness of the P⁵BL strategy, which integrates five key learning approaches to improve student outcomes. PBL fosters learner autonomy, motivation, self-confidence, and resilience, while maintaining academic ambition and perseverance in solving complex problems (d'Escoffier et al., 2025; Espino-Díaz et al., 2025; Abate et al., 2022; Servant-Miklos, 2019; Ampofo & Osei-Owusu, 2015). PjBL encourages students to ask critical questions and deepens their engagement in research, problem formulation, and data interpretation (Guo et al., 2020; Syarifah & Emiliasari, 2019; Rotgans & Schmidt, 2019). Process-based learning promotes cognitive development, fosters a sense of responsibility, and enhances

self-direction and self-motivation throughout the learning process (Arlianty et al., 2017). In people-based learning, students apply theoretical knowledge in a social context and engage in collaborative scientific activities, gaining collective experiences and constructing knowledge as a team (Tiantian et al., 2024; Lin, 2019; Parmelee et al., 2012). In product-based learning, learner behaviour becomes goal-oriented, focusing on achieving high-quality, tangible results through their efforts (Abate, 2022; Guo et al., 2020; Samuel et al., 2018; Ganefri & Hidayat, 2015).

This result can be attributed to the fact that the P⁵BL strategy emphasizes the active role of the learner in accessing knowledge (Loyens et al., 2023; Fruchter & Lewis, 2003; Fruchter, 1999), enhances motivation and engages learners in problem solving (Abate et al., 2022; Servant-Miklos, 2019), and fosters the development of learning goals, autonomy, sense of self-efficacy, passion for learning, and learning to control learning and knowledge (Rotgans & Schmidt, 2019). Additionally, it promotes openness to multiple perspectives (Blumenfeld et al., 1996) and enhances learners' interest in knowledge and control over knowledge (Loyens et al., 2023; Renninger & Hidi, 2022).

Furthermore, the lower performance of the control group students in learning motivation can be attributed to the teacher's control over the teaching situation and the use of traditional methods in teaching science, which lack authentic learning activities, do not provide opportunities for learner to engage in scientific issues or problems that enhance their academic curiosity and motivation towards learning, and

weaken their ability to construct and control knowledge.

The relationship between conceptual understanding and learning motivation

Pearson's correlation coefficient was used to test the validity of the third research hypothesis. Table 5 shows the correlation between conceptual understanding and learning motivation for students in the experimental and control groups.

Table 5: *Pearson's correlation coefficient between conceptual understanding and learning motivation.*

Variable	Group	N	Correlation coefficient	Significance level
Conceptual understanding and learning motivation	Experimental	38	0.559	Sig. 0.01
	Control	36	0.216	Not sig.

Table 5 shows that the correlation coefficient between conceptual understanding and learning motivation is statistically significant in the experimental group ($r=0.559$; $p<0.01$); thus, there is a positive relationship between the development of conceptual understanding and learning motivation among students who were taught using the P⁵BL strategy. However, the correlation coefficient between conceptual understanding and learning

motivation is not statistically significant in the control group who studied traditionally ($r=0.216$; $p>0.01$). This finding indicates that the dimensions of learning motivation are the main motivators for mobilizing energy, persistence, independence, adopting and striving for goals, developing the ability to direct one's behaviour, engaging in open-minded thinking and reflecting on the task, and building high levels of conceptual understanding (Jansen et al.,

2022). This finding supports previous studies that have found a very strong correlation between students' motivation to learn and their academic performance, as well as their ability to obtain more effective educational experiences (Tolba & AL-Dhmen, 2024; Hendriks et al., 2024; Rahman et al., 2021), and that motivation is a prerequisite for academic success, enjoyment, and the use of deep learning strategies (Hendriks et al., 2024; Rahman et al., 2021) and that it is the effective factor influencing academic performance (Urhahne & Wijnia, 2023).

The presence of a statistically significant correlation between learning motivation and conceptual understanding among students who studied using the P⁵BL strategy can be attributed to the existence of high learning motivation that allows them to work hard on the task, take risks, face complex situations with determination, pay attention to problem-solving situations, and work independently. (Adegboyega, 2018), in addition to the presence of some characteristics such as initiative, effort, activity, commitment, and self-regulation, self-efficacy in the learning process, mental alertness, and engagement in performing behaviours such as asking questions and offering explanations, and using learning

strategies that enhance deep understanding (Liu et al., 2024; Davidovitch & Dorot, 2023; Li et al., 2023; Sewagegn & Dessie, 2021).

Also, the effectiveness of the P⁵BL strategy is attributed to its learner-centred approach, which empowers students to actively construct their own knowledge (Tolba & AL-Dhmen, 2024; Altunışık et al., 2023). In problem-based learning, learners engage with real-world problems that stimulate critical thinking and facilitate the construction of new knowledge (d'Escoffier et al., 2025; Espino-Díaz et al., 2025; Abate et al., 2022; Servant-Miklos, 2019). In project-based learning, academic ambition, curiosity, and self-confidence are fostered. Through collaborative problem-solving and hypothesis testing, students significantly deepen their conceptual understanding (Guo et al., 2020; Syarifah & Emiliasari, 2019). In process-based learning, the teacher motivates students to confront scientific challenges through inquiry, guiding them to develop logical explanations and identify meaningful connections between scientific concepts (Samuel et al., 2018; Arlianty et al., 2017). In the people-based learning, students apply theoretical knowledge through collaboration, highlighting the social nature of learning, openness to

multiple perspectives (Wijnia et al., 2024; Lin, 2019; Parmelee et al., 2012; Fruchter & Lewis, 2003; Blumenfeld et al., 1996), expansion of learning scope (Loyens et al., 2023; Renninger & Hidi, 2022), and improved performance through group dialogue (Siddiky & Haque, 2024; Davidovitch & Dorot, 2023; Parmelee et al., 2012). Finally, in product-based learning, the focus shifts to autonomy, self-efficacy, innovation, and the achievement of a final product that strongly indicates student mastery of concepts (Yulastri & Hidayat, 2017). This stage stimulates high levels of interaction, where learners produce something original within a social or developmental context (Ganefri, 2013).

In general, the existence of a relationship between the dependent variables in the experimental group can be attributed to the strength of the independent variable (P⁵BL strategy). This relationship is weaker among students in the control group due to the teacher's control over the teaching situation and the prevalence of traditional teaching methods, which neither enhance learning motivation nor provide a conceptual understanding of scientific concepts.

Conclusion, recommendations and future research

The results showed, firstly, statistically significant differences at the 0.05 level between the mean scores of students in the experimental and control groups on the conceptual understanding test, in favour of the experimental group. Secondly, statistically significant differences at the 0.05 level were found between the mean scores of students in the experimental and control groups on the learning motivation scale, again in favour of the experimental group. Thirdly, a positive correlation was found between the experimental group's scores on the learning motivation scale and their scores on the conceptual understanding test in science. These results support the effectiveness of using the P⁵BL model in science teaching to develop conceptual understanding and learning motivation.

The study presents several recommendations, including the need to develop science curricula in accordance with the problem-based, project-based, process-based, people-based, and product-based learning patterns included in the P⁵BL strategy. It also recommends organizing training courses and professional development programmes for in-service science teachers on how to use the P⁵BL strategy in teaching science and

enhancing the students' cognitive skill-based, and affective domains. In addition, learner-centred teaching strategies such as the P⁵BL strategy should be incorporated into pre-service science teacher preparation programmes.

The study recommended conducting further research in science teaching, such as examining the effectiveness of the P⁵BL strategy in promoting investigative

and future thinking in science, studying the effectiveness of the P⁵BL strategy in promoting students' 21st century skills, scientific argumentation skills, and self-learning, studying the effectiveness of the P⁵BL strategy in developing students' scientific literacy, creative and critical thinking dispositions, deep understanding, and problem-solving ability in science.

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