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The effectiveness of the P^{5}BL model in teaching biology for developing high school students' deep understanding and academic achievement motivation

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ABSTRACT

This study aims to identify the effectiveness of the P^{5}BL model in developing high school students' deep understanding and academic achievement motivation in biology. To achieve the study objectives, a quasi-experimental design was adopted. The research sample consisted of 112 male students divided into two groups: a control group (54 students) and an experimental group (58 students). The research tools are a deep understanding achievement test, consisting of 20 multiple-choice questions, and the academic achievement motivation scale, consisting of 32 items. The results revealed that the P^{5}BL model is effective in developing second-grade high school students' deep understanding (explanation, interpretation, application and perspective) and academic achievement motivation (academic ambition, goal orientation, achievement orientation and cognitive motivation). A correlation was also found between developing second-grade high school students' deep understanding and academic achievement motivation. The most important recommendations include the need to prepare guidance for science teachers to help them teach using the P^{5}BL model, as well as inform science teachers of the importance of using the P^{5}BL model to develop deep understanding and academic achievement motivation. Many suggestions are also presented, including conducting further research on teaching biology, such as investigating the impact of the P^{5}BL model on developing students' creative thinking and inquiry skills and investigating the effectiveness of the P^{5}BL model in developing pre-service biology teachers' tendency toward self-reflection and reflective thinking skills.

Contribution/Originality: The study's findings contribute to the enhancement of students' ability to develop a deep understanding of biology, form new meanings, and develop academic achievement motivation (academic ambition, goal orientation, achievement orientation, and cognitive motivation) as a driver of human behavior through the P^{5}BL model, which includes five types of learning: people-based learning, problem-based learning, process-based learning, product-based learning, and project-based learning.

1. INTRODUCTION

Recent trends in science education emphasize the active role of the learner in the learning process, interaction and participation within group work, asking various questions, participating in concept discovery, understanding and interpreting scientific phenomena, developing thinking skills, and solving problems using scientific methods.

Stern, Ferraro, and Mohnkern (2017) also emphasized the importance of involving students in the learning process and taking responsibility for their own education as well as developing their thinking. These form the foundation of what is known as deep understanding, which is considered one of the most important learning outcomes specified in the global learning standards (Tytler, 2002). It is important to focus on developing deep understanding when addressing content within the classroom. Biology encompasses an organized cognitive structure consisting of facts, concepts, relationships, generalizations, principles, laws, and scientific theories. Thus, achieving deep understanding of this cognitive structure should be a primary goal in biology learning.

To achieve deep understanding, it is important to enhance learners' motivation as an internal self-driven force that directs behavior toward a specific goal. In addition, it has been recognized as a crucial factor among the variables that influence most educational outcomes (Rashwan, 2006) as well as a factor influencing behavioral orientation (Singh, 2011) learning tasks, and achieving goals in various aspects of academic and professional life (Amrai, Motlagh, Zalani, & Parhon, 2011).

Therefore, the need arises for a model that takes human nature into consideration, and one such model is the P^5BL model, which stands for "People, Problem, Process, Product and Project Based Learning". It is an extension of the Project-Based Learning (PBL) model and has been used in the field of environmental engineering to train and enhance the competency of graduate students (Fruchter, 1998).

Fruchter and Lewis (2003) and Zancul, Sousa-Zomer, and Cauchick-Miguel (2017) pointed out that the P^5BL model is based on constructivist theory, which focuses on the learner's cognitive processes, their acceptance of learning, motivation toward learning, and their ability to process information. It emphasizes the learner's active construction of meaning by interacting with the external world and connecting new information with the correct scientific meaning. Therefore, the P^5BL model aims to provide students with opportunities to participate in collaborative, project-based teamwork, where they can practice using the acquired theoretical knowledge and apply it to similar new situations.

Although some studies have shown the effectiveness of the P^5BL model in developing certain learning outcomes, such as achievement, attitude toward teamwork, and problem-solving skills (Fruchter, 1998; Fruchter, 1999; Fruchter, 2000) there is a scarcity of studies that have examined the effectiveness of this model in developing deep understanding and academic achievement motivation. The current research aims to reveal the effectiveness of the P^5BL model in developing deep understanding and academic achievement motivation, as they are important outcomes in the educational process.

1.1. Research Problem

Despite the objectives of science teaching that emphasize the development of students' deep understanding, the reality of teaching revolves around knowledge itself, focusing on memorization and superficial demonstration without paying attention to the processes of thinking and deep understanding. As a result, some studies have sought to address the weakness in deep understanding and its development among high school students in biology by experimenting various teaching strategies and models (Ketpichainarong, Panijpan, & Ruenwongsa, 2010; Suryanti, Fitriani, Redjeki, & Riandi, 2018).

Kuhn, Arvidsson, Lesperance, and Corprew (2017) pointed out that deep understanding requires learners to engage in scientific activities that contribute to developing deep understanding. This goes beyond mere conceptual knowledge and involves reaching the stage of deep processing and analysis, which leads to constructing meanings and connections among concepts, facilitating ease of learning and deep understanding. Therefore, it becomes important to foster deep understanding by using different teaching strategies and models (Lara-Alecio et al., 2018; Suryanti et al., 2018).

According to Surayanah and Karma (2018) the objectives of science education are centered around developing deep understanding of ideas generated by concepts, models, and theories and applying these ideas to real-life situations. These objectives require learners to possess a high level of motivation. Therefore, there is an interest in the concept of academic achievement motivation in the field of education, as it serves as a core element in the educational process, motivating learners to achieve deep understanding and utilize appropriate teaching strategies and models to help students develop their achievement motivation (Adegboyega, 2018; Artun & Özsevgec, 2018; Lawrence & Barathi, 2016; Surayanah & Karma, 2018). The current research aims to use the P^5BL model to enhance levels of deep understanding and academic achievement motivation among high school students.

1.2. Research Questions

The research investigates the following questions:

1. What is the effectiveness of using the P^5BL model to develop second-year high school students' deep understanding (explanation, interpretation, application, and perspective)?
2. What is the effectiveness of using the P^5BL model to develop second-year high school students' academic achievement motivation (academic ambition, goal orientation, achievement orientation, and cognitive motivation)?
3. What is the correlation between academic achievement motivation and deep understanding in biology learning among second-year high school students?

1.3. Research Hypotheses

The current research sought to verify the validity of the following hypotheses:

1. There is no statistically significant difference at the $a \leq 0.05$ significance level between the mean scores of the students in the experimental and control groups in the deep understanding test.
2. There is no statistically significant difference at the $a \leq 0.05$ significance level between the mean scores of the students in the experimental and control groups in the academic achievement motivation scale.
3. There is no statistically significant correlation at the $a \leq 0.05$ level between developing academic achievement motivation and deep understanding in biology among the students in the experimental and control groups.

2. LITERATURE REVIEW: THEORETICAL BACKGROUND AND RELATED STUDIES

2.1. The First Axis: P^5BL Model

2.1.1. P^5BL Model: Concept and Importance

Fruchter (1998) developed the P^5BL model, which integrates five types of learning: People-based learning, Problem-based learning, Process-based learning, Product-based learning, and Project-based learning. This model enhances students' ability to work in multidisciplinary teams and develops their communication and negotiation skills, which positively affect their performance in practical fields.

Fruchter (2000) emphasized that the P^5BL model places the learner in a project-based environment where they collaborate with others to accomplish the project's goals. It also highlights the connection between projects and the social, economic, or political contexts in which they are implemented. The model recognizes the significant role in decision-making processes for project completion. Moreover, it emphasizes learning through participation in multidisciplinary teams or leading them to build or design projects consciously, safely, and with high quality in an easier and faster manner (Fruchter & Lewis, 2003).

Dos Santos and Benneworth (2019) suggested that the P^5BL model has the potential to develop students' competencies and skills, serve the community, and create a space for engaging community institutions and individuals in developing their ideas and testing their products. At the same time, students acquire knowledge and competence while performing their learning tasks. The P^5BL model is recognized as one of the prominent models that achieves positive outcomes in teaching and learning processes (Monteiro, Reis, Silva, & Souza, 2017). It is known as an instructional methodology that focuses on problem-based activities as a foundation and involves projects that deliver products that benefit the community. It involves reengineering processes and requires bringing together people from various disciplines to collaborate as a team (Fruchter, 2000).

The importance of the P^5BL model lies in providing learners with a conceptual understanding of scientific concepts through perceptual discussion. It equips them with proposed solutions and obstacles encountered during problem-solving. It also fosters the formation of a community of practice among students through interaction between different disciplines within the team. The model offers guidance opportunities for learners from a constructivist perspective that explores the structures of knowledge, facilitating the process of reflecting on cognitive processes (Fruchter, 2000; Fruchter & Lewis, 2003).

2.1.2. Main Goals and Assumptions of the P^5BL Model

Chinowsky, Brown, Szajnman, and Realph (2006); Fruchter (1998); Fruchter (1999); Fruchter (2000); Fruchter and Lewis (2003); Baron Levi (2020); Almulhem and Almulhem (2022) and Abed et al. (2023) outlined the basic goals and assumptions of the P^5BL model:

1. Teach learners how to engage in different learning topics and lead learning groups.
2. Train learners on organized knowledge and understand its role in a multi-system environment based on practical projects.
3. Help learners to be more effective by learning how to acquire, transfer, and apply knowledge in real-world problem contexts.
4. Improve learners' ability to develop knowledge and self-regulation for learning, applying metacognitive strategies, summarizing important information, planning, accessing prior knowledge, and promoting self-monitoring.
5. Encourage learners to be independent in the learning process; develop their skills in dialogue, communication, leadership, and building relationships with others; practice critical thinking; analyze problems; and possess self-directed learning.
6. Learning does not occur in a vacuum but requires a problem that drives the learning process. This problem represents the heart of project-based learning, and through working on it, students face numerous challenges and difficulties that drive them to learn in order to overcome them.
7. Expand students' competence to benefit from acquired theoretical knowledge and understand the role of domain-specific knowledge in a multi-disciplinary learning environment based on P^5BL from a constructivist learning perspective.

2.1.3. Dimensions of the P^5BL Model

The P^5BL model is based on activities that are centered around projects that deliver value (Fruchter, 1998). The dimensions of model are determined as follows:

2.1.3.1. The First Dimension: Problem-Based Learning

Problem-based learning places students in a learning situation that stimulates their cognitive ability. It aims to connect the students' prior knowledge and experiences with new knowledge to solve a problem. The steps involved in problem-based learning include problem exploration, attempting to solve the problem using the learners' existing information, identifying what is known and what needs to be known, formulating a solution plan, and reflecting on the procedures and problem-solving process. Problem-based learning is a process where students are given a problem or trigger, either in the form of a statement or a case, and allows them to work together to solve it. Problem construction and execution are vital for the success of problem-based learning (Abed et al., 2023). The importance of problem-based learning stems from the fact that problems provide opportunities for maximizing learning and gaining deeper understanding. Thinking begins with the problem-solving process and continues as a conceptual knowledge-related thinking process, utilizing the results to clarify various inferences through induction and deduction and arriving at decisions and evaluating them. Teachers play an important role in problem-based learning sessions, which involves stimulating active learning, working in groups, and providing constructive feedback to encourage the students' learning path, support understanding and learning processes, respect the learners' reflection processes, and achieve the goals of the curriculum (Almulhem & Almulhem, 2022; Fernandes, 2021; Sattarova, Groot, & Arsenijevic, 2021).

2.1.3.2. The Second Dimension: Process-Based Learning

Fruchter (2000) indicates that the P^5BL model provides a context that allows learners to explore and develop knowledge by processing the information they have and use it in problem-solving situations. Information processing refers to a set of cognitive and mental processes, skills, and procedures required for inputting, storing, and retrieving information in the brain. These processes include attention, encoding, storage, and retrieval. It encourages students to develop different thinking skills and increase cognitive and metacognitive awareness while performing problem-solving activities under the supervision of the teacher (Duman & Yakar, 2019). It allows learners to activate short-term and working memory, increase mental capacity, and engage in active cognitive processes within the information processing system, such as recognition, organization, analysis, synthesis, explanation, interpretation, and thinking (Tolba, 2017). Process-based instruction is a strategy that simplifies the learning of science through the use of basic and integrated science process skills. It enhances students' self-learning, gives them a sense of responsibility during the learning process, and increases the sustainability of learning (Samuel, Libata, & Sabitu, 2018). 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).

2.1.3.3. The Third Dimension: People-Based Learning

The P^5BL model relies on teamwork, where learners collaborate as a team to accomplish specific tasks collectively. They agree on the problem, identify the steps necessary to solve the problem, and apply the project to create a product that benefits all team members. Compatibility and harmony among team members are crucial as it affects the workflow and, consequently, the final product (Fruchter, 2000). Hills (2001) defined people-based learning as a learning style in which a group of members collaborate to solve a shared problem. The objectives include achieving personal satisfaction, learning from each other, promoting continuous professional development, and building good relationships within the team. It involves continuous peer evaluation and incorporates evidence-based teaching practices, such as cooperative learning, feedback or assessment for learning, reciprocal teaching, and whole-class interactive teaching. It represents a form of learner-centered and active learning and involves dialectic teaching, where learners need to learn and apply the power of acquired mind by practicing critical thinking before presenting different perspectives (Hrynchak & Batty, 2012).

2.1.3.4. The Fourth Dimension: Project-Based Learning

Project-based learning is defined as a learning approach in which students work together to solve problems related to curriculum topics. They collect information from various sources and analyze, synthesize, evaluate and extract knowledge from it. Project-based learning includes skills such as collaboration, critical thinking, and problem-solving thinking (Solomon, 2003). It is also known as a student-centered approach, where students pursue knowledge by answering their own questions that sparked their curiosity through the construction of a scientific project. The teacher supervises and approves each step of the project before students engage in collaborative work with their peers (Bell, 2010). Mubassyr, Rahayu, and Muldayanti (2021) pointed out that project-based learning is an educational model that focuses on solving real-life problems. It consists of sequential, logical stages, such as defining the scope of the problem and the information available, determining a solution plan, implementing the solution plan, generating alternative solutions and evaluating them based on appropriate and specific criteria, and constructing a model. It promotes a wide range of skills in students, including information research and retrieval, idea representation, formulating results, collaborative work skills, and continuous evaluation of outcomes (Mioduser & Betzer, 2008). It improves students' active learning and thinking, collaborative ability, and adaptability to meet the demands of future work and project learning (Zhou, 2023).

2.1.3.5. The Fifth Dimension: Product-Based Learning

Ganefri (2013) defined product-based learning as the procedures or steps that a teacher should undertake to facilitate active learning, engagement, and interaction, while guiding students' competencies to produce a certain product. It requires a pre-defined plan and specifications for the product, which are then produced and tested to meet the market needs (Bellanca, 2015). 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). The advantage of the product-based learning process is that it can improve students' entrepreneurial spirit and increase their interest in entrepreneurship (Kurniawan, Nopriyanti, & Darlius, 2020). Yavuzcan, Şahin, Gür, Sevgül, and Yavuz (2019) argued that in product-based learning, learners may fail to reach a specific outcome; however, failure can be a powerful learning tool. Students can only experience failure through their work toward achieving a final product and they can only determine whether their products have any issues or not through testing and meeting the specified conditions and standards. The stages of product-based learning are determined by analyzing the curriculum content and learners' characteristics, identifying and analyzing the product, creating essential questions about the product, categorizing the questions, determining the tools and materials needed for the product, setting a timeline for product completion, producing the product, and evaluating it (Hidayat, 2015). Fruchter and Lewis (2003) pointed out the importance of using the P^5BL model in learning and emphasized its effectiveness as an educational approach that focuses on problem-solving activities, which require completing a project to achieve a specific product.

2.2. The Second Axis: Deep Understanding

Deep understanding is defined as the critical examination of new ideas and facts, integrating them into the cognitive structure and making multiple connections between these ideas. Through understanding, learners search for meanings and focus on evidence, which are essential concepts needed to solve a specific problem. It involves interaction and making connections between different models and real-life situations (Newton, 2000). Deep understanding is a mental process that relies on several interrelated abilities, such as problem identification, explanation, interpretation, and application in new situations. Zirbel (2006) indicated that deep understanding is associated with interconnected concepts and meanings that can be recalled quickly.

Deep understanding encompasses the following dimensions: explanation, which refers to the learner's ability to present and explain the scientific content while linking related concepts; interpretation, which denotes the learner's ability to provide reasons behind the scientific results and phenomena; application, which represents the learner's ability to apply scientific knowledge in new contexts; perspective, which signifies the learner's ability to consider scientific problems from different angles and critically evaluate non-scientific viewpoints; empathy, which reflects the learner's capacity to understand diverse thinking and recognize the feelings and situations of others, as long as they do not contradict scientific facts; and self-knowledge, which refers to the learner's ability to efficiently evaluate oneself and understand the skills that should be mastered (Brown, 2015; Wiggins & McTighe, 2005). As explained by Chin and Brown (2000) the manifestations of deep understanding include generative thinking, the nature of explanations, posing questions, metacognitive activities, and the learner's persistence in understanding the content and making connections with prior experiences, as well as constructing hypotheses and engaging in predictions.

Promoting deep understanding by establishing connections between complex scientific concepts and phenomena and real-life situations is the primary goal of science education (Amo-Asante & Bonyah, 2023). Deep understanding involves engaging in the processes of interpretation, application, and perspective-taking regarding these phenomena (Wiggins & McTighe, 2005). It also enhances learners' ability to apply learned scientific concepts in daily life and helps them to recognize new information and build scientific explanations (Awudi & Danso, 2023).

Consequently, studies have emphasized the importance of developing deep understanding. For example, Ketpichainarong et al. (2010) conducted a study that highlighted the effectiveness of inquiry-based learning in students' comprehension of biological concepts. Gero, Zoabi, and Sabag (2014) conducted a study that demonstrated the effectiveness of a computer-based module in developing deep understanding among students who have difficulty understanding the principle of transistor operation. Lara-Alecio et al. (2018) indicated the importance of knowledge-building and inquiry-based education in establishing a deep understanding of scientific concepts. Also, Awudi and Danso (2023) indicated the effectiveness of the demonstration method to improve students' academic performance and enhance conceptual understanding when learning physical concepts related to heat transfer.

2.3. The Third Axis: Academic Achievement Motivation

The concept of academic achievement motivation refers to "the behavior of activating motivational forces." It is the force that directs behavior toward achieving meaningful and valuable goals (Dörnyei, 2001). It helps in understanding human behavior and explains why individuals naturally work to reach higher levels of performance. It is one of the factors that affects a learner's performance and academic engagement in a learning situation, persistence in doing things well, and independence in performance. It is associated with cognitive, affective, and behavioral indicators of students' investment in their educational pursuits and directly impacts academic achievement and ambition (Tucker et al., 2002). The goal orientation theory suggests that learners with a goal-oriented disposition are motivated by a desire to increase their knowledge on a particular topic or by enjoying the learning process. Learners with goal-oriented behavior are more likely to engage in more complex learning tasks and topics, such as problem-solving tasks and situations, adopt effective cognitive and metacognitive strategies, and have a tendency to be happier with the learning environment and themselves as learners (Dowson & McInerney, 2001).

Moreover, many motivations are necessary as stimulating systems, and one of these systems is achievement motivation, which serves as a unique human drive. It strives to overcome challenges, improve oneself, and achieve excellence and success (Jacob & Parameshwara, 2018). It is also an effective solution to problems and supports risk-taking behavior to achieve goals (McClelland, 1961), self-esteem (Accordino, Accordino, & Slaney, 2000), self-efficacy, and goal-oriented behavior. It includes academic ambition and orientation toward academic excellence (Adegboyega, 2018).

Achievement motivation is an individual's orientation toward success in academic studies. It includes academic ambition and striving for academic excellence. It refers to behavior directed toward achievement and is influenced by various factors, including the motivation for success, the motivation to avoid failure, the perceived likelihood of success, and the value attached to success (Paul, 1982). It is also influenced by the emotional state of the individual. Learners with low emotional intelligence face greater difficulty in dealing with achievement motivation, which undermines their academic motivation (Drago, 2004). Many theories have focused on explaining the motivational process, particularly the need for achievement and the fear of failure (Brophy, 1998; Noohi, Shakoori, & Nakhei, 2009), suggesting that learners utilize their time and energy to achieve the set performance goals (Nuthana & Yenagi, 2009).

The dimensions of academic achievement motivation are determined by:

1. Academic ambition: This is related to continuously striving for success, accomplishment, and the achievement of a particular goal, as well as the avoidance of failure (Ampofo & Osei-Owusu, 2015).

2. Goal orientation: This is associated with the behaviors or actions performed by a learner in a specific situation related to a task. It is influenced by the learner's experience in that particular situation and their emotional state (Kaplan & Maehr, 2007).

3. Achievement orientation: This is linked to the cognitive processes that influence how learners engage with achievement activities, interpret them, and respond to them. It focuses on developing competence and the mastery of tasks (Kozlowski & Bell, 2006).

4. Cognitive motivation: This is related to the need or desire to perceive and understand the empirical world and make it logical. Behaviors associated with this dimension include curiosity, a desire for understanding, a tendency to engage in reflective thinking, problem formulation and solving, and a love of exploration (Cacioppo, Petty, Feinstein, & Jarvis, 1996).

Narasimhan (2018) indicated that the dimensions of achievement motivation allow learners to maximize their potential and have an impact on their tendencies toward exploration and cognitive inquiry (Adegboyega, 2018). These dimensions also contribute to a deep understanding of scientific concepts (Artun & Özsevgec, 2018), academic achievement (Lawrence & Barathi, 2016; Singh, 2023), academic performance (Barcena, 2022), and general self-efficacy (Li, Yang, Zhao, & Li, 2023) promoting student success and well-being in educational institutions (Chauhan & Singh, 2023). Therefore, it is important to provide learners with the necessary strategies to help them develop an appropriate level of motivation for achievement (Surayanah & Karma, 2018).

3. METHODOLOGY

3.1. Research Approach

To achieve the research objectives, a quasi-experimental design was used, which is based on applying a pre- and post-test to two groups; the experimental group studied using the P^5BL model, and the control group studied in the traditional method.

3.2. Research Population

The research population is defined as all individuals, persons, or things who are the subject of the research problem (Obeidat, Abdel Haq, & Adas, 2015). The population comprises all second year secondary school students in a government school in Dammam during the first semester of the academic year 1441 AH/1442 AH, totaling 1,520 students, according to the Information Center's statistics and the Statistics Unit of the Planning and Development Department of the Education Department in the Eastern Province.

3.3. The Research Sample

The research sample is defined as a subset of the components of the study population under investigation, specifically chosen to represent the study population (Al-Adl, 2014). The research sample consisted of 112 second year secondary school students in a government school in the Dammam region. The experimental group consisted of 58 students studying according to the P^5BL model, and the control group consisted of 54 students studying according to the traditional method. The sample was purposive because this school is equipped with the devices and tools needed to conduct this research.

3.4. Experimental Treatment and Research Tools

3.4.1. The Experimental Treatment Was Prepared Through the Following Steps

1. Choosing the educational content: The "mammals unit" of the biology course was chosen because it contains many vital phenomena related to the learners' environment, which prompts thinking about how to interpret

these phenomena, and it contains many questions that enhance the learners' academic achievement motivation and deep understanding. In addition, it contains biological concepts, tasks and activities that are easy to formulate according to the P^5BL model.

2. Content analysis of the unit: A list of biological concepts included in the mammals unit in the biology course for the second year of secondary school (2020–2021) was identified, and after conducting the analysis, the following steps were used to calculate the validity and reliability:
   - Validity: The list of biological concepts was presented to selected biology teachers and a group of specialists in curricula and teaching methods to ensure that the list contains all the biological concepts contained in the mammals unit. They confirmed the validity in light of the unit of analysis (biological concepts), and they also confirmed the comprehensiveness of the analysis of the concepts included in the unit (48 concepts).
   - Reliability: The reliability of the analysis was calculated using the reliability of individuals and the agreement between the analysis results reached by the researchers and two of their colleagues. The reliability value is 0.96 (Holsti, 1968) which is high and indicates that the analysis results are reliable.
3. Preparing the teacher's guide: A teacher's guide for the mammals unit of the biology textbook using the P^5BL model was prepared to develop high school students' deep understanding and academic achievement motivation. This guide includes the objectives, the importance, the scientific basis for the P^5BL model, the roles of the teacher and the learner in the P^5BL model, the variables (deep understanding, academic achievement motivation), educational objectives, time distribution of topics, and teaching the mammals unit using the P^5BL model.
4. Sending to the arbitrators: The teacher's guide was presented to a group of biology teachers and a group of arbitrators who specialize in curricula and methods of teaching biology to ensure its face validity. The arbitrators' opinions were expressed regarding the extent of its scientific and linguistic validity. Some modifications were made based on the arbitrators' suggestions, and the guide was then ready in its final form for application.

3.5. Research Tools

3.5.1. The Research Tools Used

1. Deep understanding test: This test consists of 20 multiple-choice questions on the characteristics of mammals (10 questions) and the diversity of mammals (10 questions) distributed over the dimensions of deep understanding: explanation (4 questions), interpretation (6 questions), application (6 questions), and perspective (4 questions). To ensure the validity of the test, it was presented to a panel of curricula and methods of teaching biology staff members and biology teachers and supervisors to judge the extent to which the items belong to the dimensions of deep understanding, the appropriateness of the alternatives for each question, the scientific validity and linguistic integrity, and the comprehensiveness of the questions for the educational content. Some modifications were made in the light of their opinions. The total score of the test was 20. The test was applied to a pilot sample consisting of 47 students outside the research sample to calculate the test reliability using the split half method, which is equal to 0.667, and it was corrected using the Spearman–Brown equation to reach a reliability coefficient of 0.80, which is high and acceptable. The internal consistency validity of the deep understanding test in biology was calculated using the Pearson correlation coefficient to determine the correlation between the scores of each item at the cognitive level, which ranged between 0.407 and 0.696, and between each cognitive dimension of the test with the other dimensions and the total score of the test, which ranged between 0.413 and 0.834. These are statistically significant correlation coefficients at a significance level of 0.01, and this indicates that the test is internally consistent. The difficulty and ease coefficients for each item also ranged between 0.32 and 0.68, which are within the acceptable range of

20% to 80%. The item discrimination coefficients ranged between 46% and 69%, which are acceptable. The appropriate time for the test was determined by calculating the average time taken to actually perform the test, which was 40 minutes.

2. The academic achievement motivation scale: The related literature on academic achievement motivation was reviewed to identify scale items and dimensions. Drawing on studies including Narasimhan (2018); Adegboyega (2018); Surayanah and Karma (2018); Artun and Özsevgec (2018) and Lawrence and Barathi (2016), the scale consisted of 32 items. Based on the reviewers' feedback, the scale has four dimensions: academic ambition (8 items), goal orientation (8 items), achievement orientation (8 items), and cognitive motivation (8 items). The student's academic achievement motivation was measured using a five-point Likert scale (always, often, sometimes, seldom, never). To ensure the face validity of the scale, it was reviewed by more than ten experts in the field of education, psychology, curricula, and science teaching methods. Furthermore, a pilot study was conducted for the scale using 47 students from a Saudi high school to ensure the clarity of the scale items and to determine a sufficient time to complete the scale (25 minutes). Cronbach's alpha was calculated for scale reliability, academic ambition (0.81), goal orientation (0.88), achievement orientation (0.87), and cognitive motivation (0.85), and the scale as a whole (0.94). This indicates that the scale has a high degree of reliability. The internal consistency validity of the academic achievement motivation scale was calculated using the Pearson correlation coefficient to determine the correlation between the scores of each dimension of the scale with the other dimensions and the total score of the scale, which ranged between 0.392 and 0.812.

3.5.2. The Pre-Application of the Study Tools (equivalence of the two groups)

To determine the equivalence between the experimental and control groups in the deep understanding test and the academic achievement 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) as shown in Table 1, and in the scale of academic achievement motivation and its dimensions (academic ambition, goal orientation, achievement orientation, and cognitive motivation) as shown in Table 2.

Table 1. The equivalence of the experimental and the control groups in the pre-test of deep understanding and its dimensions (Explanation, interpretation, application, and perspective).

Deep understanding dimension	Group	N	Mean	Standard deviation	T-value	Value of sig.	Significance
Explanation	Experimental group	58	0.54	0.65	1.86	0.071	Not significant
	Control group	54	0.77	0.82			
Interpretation	Experimental group	58	2.11	1.46	1.78	0.077	Not significant
	Control group	54	1.70	1.41			
Application	Experimental group	58	2.36	1.17	1.90	0.060	Not significant
	Control group	54	2.75	1.45			
Perspective	Experimental group	58	1.35	0.96	0.18	0.858	Not significant
	Control group	54	1.35	0.87			
Deep understanding test as a whole	Experimental group	58	6.37	2.25	0.48	0.632	Not significant
	Control group	54	6.53	2.40			

Tables 1 and 2 show equality between the experimental and control groups before conducting the research experiment pre-performance. That is, there are no statistically significant differences between the average scores of the experimental and control groups in the pre-application of the two research tools (the deep understanding test and the academic achievement motivation scale).

Table 2. The equivalence of the experimental and control groups in the pre-application of the academic achievement motivation scale and its dimensions (Academic ambition, goal orientation, achievement orientation, and cognitive motivation).

Variable	Group	N	Mean	Standard deviation	T-value	Value of sig.	Significance
Academic ambition	Experimental group	58	30.39	3.52	1.53	0.129	Not significant
	Control group	54	29.28	4.98			
Goal orientation	Experimental group	58	30.36	4.71	0.98	0.329	Not significant
	Control group	54	29.58	4.56			
Achievement orientation	Experimental group	58	30.38	4.32	0.44	0.661	Not significant
	Control group	54	30.03	5.06			
Cognitive motivation	Experimental group	58	29.03	3.96	1.36	0.176	Not significant
	Control group	54	27.94	5.37			
Academic achievement motivation as a whole	Experimental group	58	120.16	9.73	1.57	0.120	Not significant
	Control group	54	116.83	14.97			

3.5.3. The Treatment

The research experiment lasted two weeks (10 sessions), with five sessions per week for each group. The experimental group was taught using the P^5BL model, while the control group was taught in the traditional way. Then the deep understanding test and the academic achievement motivation scale were re-administered to both groups after the completion of teaching.

4. RESULTS AND DISCUSSION

4.1. The Effectiveness of Using the P^5BL Model in Developing Deep Understanding

To test the validity of the first hypothesis, which states that there is no statistically significant difference at the a ≤ 0.05 significance level between the mean scores obtained by the students in the experimental and control groups in the deep understanding test, the t value was calculated to compare the mean scores of the experimental and control groups in the post-application of the deep understanding test as a whole and its dimensions (explanation, interpretation, application, and perspective), as illustrated in Table 3.

Table 3. Results of the post-application of the deep understanding test and its sub-dimensions (Explanation, interpretation, application, and perspective).

Deep understanding dimension	Group	N	Mean	Standard deviation	T-value	Squared eta $\eta 2$	D-value	Effect size
Explanation	Experimental group	58	3.29	0.77	5.15	0.194	0.98	High
	Control group	54	2.41	1.04				
Interpretation	Experimental group	58	5.34	0.71	7.50	0.338	1.43	High
	Control group	54	3.78	1.41				
Application	Experimental group	58	4.97	0.98	4.51	0.156	0.86	High
	Control group	54	3.89	1.57				
Perspective	Experimental group	58	3.09	0.78	4.10	0.132	0.81	High
	Control group	54	2.35	1.10				
Deep understanding test as a whole	Experimental group	58	16.69	1.44	8.24	0.382	1.57	High
	Control group	54	12.43	3.64				

Table 3 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 deep understanding test as a whole, favoring the experimental group with a mean of 16.69, where $t = 8.24$, $p = 0.000$, and $\eta 2 = 0.382$. This indicates that the first null hypothesis cannot be accepted.

The effect size is greater than 0.8 for each dimension of the deep understanding test and for the test as a whole. This indicates that the impact of the P^5BL model in developing deep understanding in general is high, and this can be attributed to the fact that using the P^5BL model allows learners to understand biological phenomena and build scientific knowledge and new ideas and concepts based on previous experiences and knowledge and learn through different styles of learning (problem-based learning, process-based learning, people-based learning, project-based learning, and product-based learning). This helps learners to practice cognitive and metacognitive mental processes, apply scientific concepts in new and complex situations, such as problem-solving situations or while participating in a scientific project, and deduce new scientific concepts and deeper cognitive structures (Baron Levi, 2020; Chinowsky et al., 2006).

This is consistent with other studies, such as (Fruchter & Lewis, 2003) that indicated the effectiveness of the P^5BL model and its different learning styles in teaching. It is also consistent with some studies that emphasized the importance of developing a deep understanding of scientific concepts through using teaching models that give learners an active role in the learning process and enhance their activity and positivity in educational situations (Awudi & Danso, 2023; Lara-Alecio et al., 2018; Gero et al., 2014; Ketpichainarong et al., 2010).

The superiority of the students' deep understanding in the experimental group can also be attributed to the use of the P^5BL model in teaching biology, as it allows learners to participate and engage in various learning topics, persevere, understand the role of knowledge in carrying out scientific projects and solving problems, acquire, transfer and apply knowledge in the real-world problems, and be independent in the learning process through learning leadership (Chinowsky et al., 2006; Fruchter, 1998; Fruchter, 1999; Fruchter & Lewis, 2003; Zhou, 2023).

Also, the superiority of the experimental group, who studied using the P^5BL model, over the control group with regard to deep understanding can be explained due to model giving learners a conceptual understanding of biological concepts through active learning, dialogue, discussion, and practicing scientific activities and various thinking processes, such as understanding, application, analysis, synthesis and evaluation, building scientific explanations, and the exploration of new knowledge structures and their application in the context of real-world problems (Abed et al., 2023; Almulhem & Almulhem, 2022; Fruchter, 2000; Fruchter & Lewis, 2003).

In addition, this result shows that the P^5BL promotes the use of structured knowledge and its application in a project-based learning environment and higher-order thinking patterns, such as scientific thinking, critical thinking, and problem-solving (Fruchter, 2000; Fruchter & Lewis, 2003). Learners using the P^5BL model employ real learning based on deep understanding, which helps them to solve problems and carry out investigations more related to their lives. Therefore, the performance of the students in the experimental group was high in the dimensions of deep understanding, such as explanation, interpretation, and application, compared to the control group, who employed the traditional method of study, which is based on the superficial learning of scientific concepts.

4.2. The Effectiveness of Using the P^5BL Model in Developing Academic Achievement Motivation

To test the validity of the second research hypothesis, which states that there is no statistically significant difference at the $a \leq 0.05$ significance level between the mean scores obtained by the students in the experimental and control groups in the academic achievement motivation scale. The t-value was calculated to compare the mean scores of the experimental and control groups in the post-application of the academic achievement motivation scale as a whole and its dimensions (academic ambition, goal orientation, achievement orientation, and cognitive motivation), as illustrated in Table 4.

Table 4 shows statistically significant differences at the 0.01 level between the mean scores of the experimental group and the control group in the post-performance related to the academic achievement motivation scale as a whole, favoring the experimental group with a mean of 133.07, where $t = 6.47$, $p = 0.000$, and $\eta 2 = 0.28$. This indicates that the second null hypothesis cannot be accepted.

The effect size is greater than 0.8 for each dimension of the academic achievement motivation scale. This indicates that the effect size of the experimental treatment (P^5BL model) in developing academic achievement motivation is high, and this is because using the P^5BL model allowed the learners to practice different styles of learning, which enhance academic ambition, goal orientation, achievement orientation, and cognitive motivation in educational situations.

Table 4. Results of the post-application of the academic achievement motivation scale and its sub-dimensions (Academic ambition, goal orientation, achievement orientation, and cognitive motivation).

Variable	Group	N	Mean	Standard deviation	T-value	Squared eta η2	D-value	Effect size
Academic ambition	Experimental group	58	32.72	3.18	4.51	0.16	0.90	High
	Control group	54	29.28	4.80				
Goal orientation	Experimental group	58	33.75	3.81	4.51	0.14	0.80	High
	Control group	54	30.63	4.32				
Achievement orientation	Experimental group	58	33.79	3.55	5.19	0.20	0.99	High
	Control group	54	30.02	4.14				
Cognitive motivation	Experimental group	58	32.81	4.33	4.39	0.15	0.85	High
	Control group	54	28.89	5.12				
Academic achievement motivation as a whole	Experimental group	58	133.07	7.83	6.47	0.28	1.23	High
	Control group	54	118.28	13.88				

This result is consistent with other studies, such as Singh (2023); Li et al. (2023); Adegboyega (2018); Artun and Özsevgec (2018); Surayanah and Karma (2018) and Lawrence and Barathi (2016), which have indicated that using teaching strategies and models helps students develop achievement motivation. This shows that the P⁵BL model adopts many learning patterns, such as project-based learning and problem-based learning, which enhance learners' motivation to learn, and these strategies result in learners being more task-oriented and more engaged in the learning process (Dowson & McInerney, 2001).

This result reinforces the importance of the learning styles included in the P⁵BL model, such as problem-based learning, which enhances learners' curiosity, knowledge, academic ambition and insistence to solve the problem (Ampofo & Osei-Owusu, 2015; Tolba, 2017). Process-based learning motivates learners' thinking and information processing in order to effectively store information in the brain (Duman & Yakar, 2019; Tolba, 2017). People-based learning allows students to learn together, learn from others, and achieve personal satisfaction (Hills, 2001). Project-based learning encourages learners to ask questions, and it motivates curiosity, understanding, the tendency to engage in thinking, formulate and solve problems, and involves the learner more in learning and exploration activities (Bell, 2010; Cacioppo et al., 1996). Product-based learning motivates learners' goal orientation to reach a valuable output and turns the experience of failure into a powerful tool for learning (Hidayat, 2015; Kaplan & Maehr, 2007).

These results also indicate that the P⁵BL model motivates learners' academic achievement motivation, increases sensitivity when dealing with problems related to life and when choosing learning tasks (Mubassyr et al., 2021), and achieves personal satisfaction (Hills, 2001). It also allows learners to actively and effectively engage in activities that promote thinking, ask questions about scientific phenomena (Bell, 2010) design knowledge-seeking plans, implement those plans through collecting data and evidence, and use different patterns of thinking, such as logical and scientific thinking, to interpret data and scientific phenomena (Solomon, 2003). It also improves learners' competence to enable them to reach a valuable final product (Ganefri, 2013) practicing mental processes with achievement activities (Kozlowski & Bell, 2006) and the desire for understanding and preoccupation with thinking, formulating and solving problems (Cacioppo et al., 1996).

In light of this, the low performance of the students in the control group in academic achievement motivation can be attributed to using the traditional method that does not allow learners to activate their academic achievement motivation, lacks real activities for learning, and does not allow them to engage in educational situations that meet their needs or enhance their ambition and motivation toward learning and orientation toward achieving valuable goals.

4.3. The Correlation Between Developing Deep Understanding and Academic Achievement Motivation

To test the validity of the third research hypothesis, which states that there is no statistically significant correlation at the a ≤ 0.05 level between developing deep understanding and academic achievement motivation among the students of the experimental and control groups. The Pearson correlation coefficient was used, as shown in Table 5.

Table 5. The Pearson correlation coefficient between students' scores on the deep understanding test and the academic achievement motivation scale in the experimental and control groups.

Variable	Group	Number	Correlation coefficient	Significance level
Deep understanding and academic achievement motivation	Experimental	58	0.352	Sig. 0.05
	Control	54	0.209	Not sig.

Table 5 shows that the correlation coefficient in the experimental group reached 0.352, which is significant at the 0.05 level; therefore, there is a positive correlation between developing deep understanding and academic achievement motivation among students who were taught using the P^5BL model. The correlation coefficient for the control group who studied traditionally reached 0.209, which is not significant.

This result indicates the importance of academic achievement motivation for constructing scientific knowledge and promoting deep understanding of scientific concepts and developing the ability to generate correct scientific interpretations of these concepts. The ability to form and construct scientific concepts is linked to academic ambition, the search for scientific facts, the desire to realize and understand scientific phenomena, mental openness, goal orientation, asking questions, the preoccupation with thinking, developing plans and strategies for conducting research, setting goals, and the desire to understand (Ampofo & Osei-Owusu, 2015; Cacioppo et al., 1996; Kaplan & Maehr, 2007; Kozlowski & Bell, 2006). This result also indicates that the dimensions of academic achievement motivation are the main motivators of learners' ability to direct their behavior and engage in open thinking and effective learning in which they can deeply process scientific concepts (Dörnyei, 2001; Jacob & Parameshwara, 2018).

This confirms that the dimensions of academic achievement motivation allow learners to use their abilities well (Narasimhan, 2018) and have an impact on their attitudes toward inquiry and cognitive research (Adegboyega, 2018), deep understanding of scientific concepts (Artun & Özsevgec, 2018) general self-efficacy (Li et al., 2023) and academic achievement (Barcena, 2022; Lawrence & Barathi, 2016; Singh, 2023), focusing on the learning process, and achieving learning goals (Nuthana & Yenagi, 2009).

The statistically significant positive relationship between academic achievement motivation and deep understanding among the students of the experimental group can be attributed to the fact that the P^5BL model contains several stages of learning that enhance cognitive motivation. In the problem-based learning stage, the learner is exposed to an educational situation that motivates his cognitive side, stimulates cognitive construction, and uses procedural knowledge in depth to apply it to real-life situations and problems (Tolba, 2017). In the project-based learning stage, the goal-orientation motive is activated, as the students are asked to work in groups to solve life-related problems, practice science processes represented in formulating hypotheses and verifying them, conduct investigations, search for information, collect data and evidence, and then reach and interpret results to achieve a high degree of deep understanding of scientific concepts and to be aware of mental processes (Bell, 2010; Mioduser & Betzer, 2008; Mubassyr et al., 2021; Solomon, 2003). In the process-based and people-based learning stages, goal orientation and achievement motivation are activated as the teacher encourages their students to carry out various activities on the subject matter, practice inquiry, explore and develop conceptual knowledge consciously, process information to reach more accurate scientific interpretations, construct meaning, and focus attention on the real goal of learning (Duman & Yakar, 2019; Tolba, 2017). Thinking processes are also activated to achieve personal satisfaction through practicing thought-provoking activities (Hills, 2001; Hrynchak & Batty, 2012). In the product-based learning stage, the learners' academic ambition and goal orientation are activated when the teacher asks the students to determine how to reach a final valuable and high-quality product, identifying the most important ideas that have been reached, knowing the scientific phenomenon, and revising new knowledge structures. This is a strong indication of a deep understanding of the scientific problem or phenomenon (Bellanca, 2015; Ganefri, 2013; Hidayat, 2015; Yavuzcan et al., 2019; Yulastri & Hidayat, 2017).

This result also indicates the effectiveness of the P^5BL model in providing learners with the necessary strategies that help them enhance academic achievement motivation, practice good thinking, deal with new scientific concepts, and embed them in their minds (Surayanah & Karma, 2018). It also indicates that learners who are task-oriented are more likely to engage in challenging tasks, adopt useful cognitive strategies, and tend to be happier with the learning environment and with themselves as learners (Dowson & McInerney, 2001).

More specifically, the correlation between the dependent variables (deep understanding and academic achievement motivation) among the experimental group is due to the strength of the independent variable (P^5BL model), which provides students with various examples, situations and activities. It allows them to participate in scientific activities, move directly from conceptual knowledge to procedural knowledge, interact with colleagues when solving problems and undertaking scientific projects, and enhance effective thinking. It also motivates students internally and they become more inclined to continue performing the learning task efficiently, accessing new scientific concepts and retaining critical information and ideas consistently. This is in contrast to the control group, for which the correlation coefficient at the 0.05 significance level confirmed the non-statistically significant correlation between academic achievement motivation and deep understanding. This is due to the traditional method of teaching that does not motivate students toward academic achievement and doesn't provide them with a deep understanding of scientific concepts.

5. IMPLICATIONS

There are some theoretical and practical implications stemming from this research. It theoretically contributes to filling a gap in the literature by linking the P^5BL model as a teaching model with a deep understanding of biological concepts and academic achievement motivation as the primary motivator of behavior. These results can benefit teachers in adopting this model within biology classes to achieve a deep understanding of biological concepts and make learners more effective in acquiring, transferring and applying knowledge in a real context, and motivate them to perform complex biology tasks.

From the practical side, this research focuses on the importance of using the P^5BL methodology for teaching and learning, which focuses on problem- and project-based activities that allow learners to provide a product that benefits society. It also creates a community of students who work together collaboratively within a team. Therefore, it becomes important to enhance the P^5BL methodology to implement biological teaching and learning processes, enhance practice-based learning and expand students' competence, enable them to understand complex biological phenomena in daily life situations, practice the processes of explanation, interpretation, application, and perspective, and mobilize all their energies to build a deep understanding of the biological concepts involved in these phenomena.

One potential implication of the study is to recommend that teacher preparation programs should guide teachers to be more familiar with the dimensions of learning included in the P^5BL model, which will lead them to create a movement in teaching biological concepts and drive change in the learning environment.

Another important implication of this study is that it confirms the existence of a relationship between the dependent variables (academic achievement motivation and deep understanding) and therefore indicates that the cognitive and emotional sides should not be separated when learning biology. It is important to activate these two aspects in learners through using the P^5BL model as a methodology for designing biology curricula that contain realistic problems that allow students to work as a team to solve them.

6. CONCLUSIONS AND RECOMMENDATIONS

In the light of the results of this research, many recommendations are presented, including directing science curricula planners and developers to develop science curricula at all stages of education according to learning styles (problem-based learning, project-based learning, process-based learning, people-based learning, and product-based learning) included in the P^5BL model, directing biology teachers' attention toward the importance of using the P^5BL model in developing deep understanding and academic achievement motivation through holding training courses for teachers, and qualifying pre-service teachers and training them to use models and strategies based on constructivist theory in teaching science, such as the P^5BL model. It is necessary to prepare a guide for teachers that demonstrates how to apply the P^5BL model in developing deep understanding, and a student activity book that includes many different activities based on the P^5BL model that helps to develop their academic achievement motivation and deep understanding.

Many suggestions are also presented, including conducting further research in teaching biology, such as investigating the impact of the P^5BL model on developing students' creative thinking in biology, investigating the impact of the P^5BL model on developing students' inquiry and thinking skills and biological concepts, investigating the effectiveness of the P^5BL model in developing pre-service biology teachers' tendency toward self-reflection and reflective thinking skills, and investigating the effect of the P^5BL model in developing students' deep understanding of biology and self-regulated learning skills.

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