

Instructional design and practice of project-based learning for cultivating scientific attitudes

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Abstract. Project-Based Learning (PBL) has demonstrated considerable effectiveness in fostering scientific attitudes among primary school students. This study conducts an in-depth analysis of the Grade 5 *Science* textbook published by the Education Science Press and selects the lesson "*Building Boats with Floating Materials*" as a suitable case for PBL-oriented instructional design. The story of Noah's Ark from the *Bible* is employed to construct a cognitively challenging and thought-provoking scenario, immersing students in dual challenges involving both engineering and ethical considerations. Students are thereby guided to adopt the dual roles of engineers and decision-makers, engaging in dynamic reasoning between scientific evidence and value judgment, with the aim of cultivating scientific attitudes. The effectiveness of this PBL approach is evaluated through teacher and student interviews. The findings indicate that employing project-based learning to cultivate scientific attitudes in primary school students receives strong positive affirmation. Based on the teaching practice, four pedagogical recommendations are proposed: prioritizing cognitive development in scenario design; flexibly and appropriately adapting instructional content; maintaining classroom order while fostering a supportive learning environment; and promoting the participation of students with higher levels of dependency in classroom activities.

Keywords: project-based learning, scientific attitudes, instructional design and practice

1. Introduction

Scientific attitude constitutes a vital component of core scientific literacy in primary education. Characterized by its implicit and context-dependent nature, it is difficult to cultivate effectively through traditional instructional approaches. Project-Based Learning (PBL), with its emphasis on authentic problem-solving, student-centered learning, and collaborative inquiry, aligns closely with the requirements for fostering scientific attitudes. Grounded in the ABC theory of attitudes, this study conceptualizes scientific attitude across three dimensions: scientific cognition, scientific affect, and scientific behavior. Taking the lesson "*Building Boats with Floating Materials*" from the Grade 5 (second volume) *Science* textbook published by the Education Science Press as an example, a PBL-oriented instructional design is developed. The teaching is situated within the narrative context of "Noah's Ar", where engineering tasks are seamlessly integrated with ethical inquiry. This approach encourages students to develop scientific attitudes through hands-on practice and value-based decision-making. The instructional effectiveness is evaluated through interviews with both

teachers and students. The findings suggest that this model effectively stimulates students' learning interest, empirical awareness, and sense of social responsibility. Finally, the study proposes several pedagogical recommendations: emphasizing cognitive development in scenario design, flexibly adjusting instructional content, effectively managing classroom order, and enhancing the participation of highly dependent learners. These insights offer valuable implications for primary science education.

2. Scientific attitudes and project-based learning in primary science education

2.1. The connotation and significance of scientific attitudes

From a psychological perspective, attitude is generally understood to comprise three dimensions: cognition, affect, and behavioral tendency—commonly referred to as the ABC theory of attitudes [1]. In the field of science education, scientific attitudes can be categorized into two types: *attitudes of science and attitudes toward science* [2]. The former refers to the modes of thinking and behavior that education seeks to cultivate in students, whereas the latter emphasizes the emotional stance and cognitive orientation students develop in the process of learning science, serving as a crucial driver of their interest in the subject [3]. At present, attitudes toward science have become a focal topic in science education research. Many scholars, drawing on the ABC theory, analyze its internal structure from multiple dimensions [4]. The *Science Curriculum Standards for Compulsory Education (2022 Edition)* [5] (hereafter referred to as the *New Curriculum Standards*) explicitly advocate a student-centered approach, requiring instructional design to "activate students' cognition, affect, and behavior". This principle closely aligns with the tripartite structure of attitudes. Based on this framework, the present study further divides *attitudes toward science* into three specific dimensions: scientific cognition, scientific affect, and scientific behavior. Scientific cognition refers to an individual's understanding and grasp of scientific facts, knowledge, and beliefs. Scientific affect encompasses the positive or negative emotional experiences individuals develop toward science-related phenomena. Scientific behavior is reflected in individuals' willingness to participate in scientific activities and their readiness to act. This classification not only adheres to the traditional dimensional framework of attitude theory but also corresponds to the educational orientation of the *New Curriculum Standards*.

The *New Curriculum Standards* place significant emphasis on the cultivation of scientific attitudes. In terms of curriculum philosophy, they advocate designing engaging scientific activities that students find enjoyable, creating a pleasant learning environment to protect students' curiosity, and stimulating their intrinsic motivation to learn science. Regarding the organization and presentation of instructional content, the standards highlight the importance of authentic learning contexts that can trigger students' intrinsic motivation and cognitive conflict, guiding them toward independent inquiry and collaborative communication while promoting active thinking. Furthermore, the standards aim to help students develop a preliminary holistic understanding of the natural world, comprehend the relationships among science, technology, society, and the environment, and, alongside the development of scientific competencies, foster scientific attitudes and a sense of social responsibility. These efforts lay the foundation for students to gradually form sound worldviews, life perspectives, and values. In terms of curriculum resource development and utilization, the standards also stress the effective use of diverse teaching resources to stimulate students' interest in science and enhance instructional effectiveness, thereby supporting the cultivation of scientific attitudes. As a key component of core scientific literacy, scientific attitudes are highly valued in the *New Curriculum Standards* and hold substantial significance for both research and practice.

2.2. The connotation and characteristics of project-based learning

Project-Based Learning (PBL) is a student-centered instructional approach that emphasizes the acquisition of knowledge and skills through the investigation of authentic and complex problems [6]. Its core characteristics include the following. First, problem orientation: learning begins with a driving question or situational context that stimulates active thinking. Second, *student centrality*: it highlights students' agency and initiative in the problem-solving process. Third, *collaborative learning*: PBL is typically conducted in groups, where members divide tasks and work together. Fourth, *inquiry-based learning*: students construct knowledge through practice, exploration, reflection, and collaboration. Fifth, *evaluative learning*: upon project completion, both teachers and students engage in reflective evaluation of the process and outcomes to promote continuous improvement [7].

PBL is highly compatible with the cultivation of scientific attitudes. Given the implicit nature of scientific attitudes, their development relies on authentic contexts and problem-driven learning, enabling students to gradually enhance their competencies through sustained thinking and inquiry [8]. PBL, with its emphasis on problem-driven learning, engages students through driving questions and real-world scenarios, demonstrating strong alignment in instructional philosophy. Moreover, scientific attitudes are difficult to measure through traditional paper-and-pencil tests and instead require process-oriented, comprehensive, and performance-based assessments. PBL, which values evaluative learning and advocates multiple forms of assessment, aligns closely with this requirement. In addition, the *New Curriculum Standards* promote the integration of teaching, learning, and assessment, emphasizing students' authentic responses and cognitive development throughout the learning process. From this perspective, employing PBL to cultivate scientific attitudes is also consistent with the evaluative demands of the standards. The *New Curriculum Standards* further specify that scientific attitudes should be reflected in behavioral traits such as "maintaining curiosity and enthusiasm for inquiry", "being willing to explore and practice", and "being adept at collaboration and willing to share". These qualities highlight students' autonomy, inquiry, and collaboration in learning. As a student-centered approach, PBL emphasizes student agency, inquiry, and collaboration, thus corresponding closely to the core requirements for cultivating scientific attitudes. In summary, considering the implicit nature of scientific attitudes, the pedagogical orientation of the *New Curriculum Standards*, and the defining features of PBL, the application of project-based learning in cultivating scientific attitudes demonstrates clear advantages and strong suitability.

3. Instructional design for cultivating scientific attitudes through project-based learning

The most widely used version of science textbooks in China is that published by the Education Science Press. Accordingly, this study is based on this edition and selects instructional content from Grade 5 primary science, integrating project-based learning into teaching practice with the aim of achieving the goal of cultivating students' scientific attitudes as required by the *New Curriculum Standards*.

3.1. Analysis of the Education Science Press Science textbook

An overview of the Grade 5 *Science* textbook published by the Education Science Press is presented in Table 1. It can be observed that the unit themes in this textbook are closely related to students' everyday lives. The content of each unit covers a wide range of knowledge, often spanning multiple domains, and each lesson incorporates inquiry-based activities, demonstrating strong integrative and exploratory characteristics. In this regard, the textbook shares notable similarities with the principles of project-based learning. Each volume of the textbook also includes themes related to environmental protection. For example, topics in the first volume

such as "The Impact of Human Activities on the Earth's Surface", and in the second volume such as "Do Human Activities Affect the Environment?", "What Environmental Problems Do Humans Face?", and "What Can Humans Do to Protect the Environment?" all reflect an emphasis on cultivating students' sense of social responsibility, including caring for the Earth, protecting the environment, and valuing life. In addition, both volumes begin with the section "How Scientists Work", which aims to inspire students to learn from the admirable qualities of scientists, implicitly reflecting the expectation of fostering scientific attitudes [9].

In summary, applying project-based learning to primary science teaching aligns closely with the design philosophy of the *Science* textbook, while cultivating students' scientific attitudes is also an implicit objective embedded within the textbook. In this study, the lesson "*Building Boats with Floating Materials*" from the unit "*Study of Boats*" in the Grade 5 (second volume) textbook is selected as the instructional context for the design, with the aim of fostering students' scientific attitudes.

Table 1. Unit structure of the Grade 5 *Science* textbook (education science press edition)

Unit	Unit 1	Unit 2	Unit 3	Unit 4
Grade 5 (Vol. 1)	Light	Changes on the Earth's Surface	Measuring Time	Healthy Living
Grade 5 (Vol. 2)	Organisms and Environment	Study of Boats	Environment and Us	Heat

3.2. Instructional design

The instructional design is developed in alignment with the three dimensions of scientific attitudes, the defining features of Project-Based Learning (PBL), and the learning requirements for Grade 5 as outlined in the *New Curriculum Standards*. Teaching objectives are formulated according to the three dimensions of scientific attitudes: scientific cognition, scientific affect, and scientific behavior. The objective for scientific cognition is for students to understand that floating materials can be used to build boats and that modifying structural design can increase a boat's load capacity. The objective for scientific affect is for students to experience both the enjoyment and challenges of engineering design, learn to listen to and understand others' perspectives, and develop a sense of social responsibility in valuing life and caring for the Earth. The objective for scientific behavior is for students to utilize provided buoyant materials to design and construct a small boat and to refine their designs through iterative improvement.

Guided by the principles of PBL and the learning expectations for Grade 5 in the *New Curriculum Standards*, the instructional approach in this study conceptualizes PBL as the driving force, with scientific knowledge, engineering practice, and ethical inquiry functioning as three parallel and mutually reinforcing components that collectively promote the development of students' scientific attitudes. The aim is not merely to cultivate students as proficient learners, but as individuals equipped with knowledge, a sense of responsibility, and humanistic concern. To this end, the lesson situates learning within the classic story of "Noah's Ark" from the *Bible*, constructing an authentic scenario rich in ethical tension centered on the theme of "protecting Earth's biodiversity". Within this context, a highly contemporary engineering task—"building a boat with the maximum load capacity"—is embedded. Through deliberation on the ethical question of "which living beings should be taken aboard", students are drawn into the dual challenges of engineering problem-solving and ethical decision-making. Assuming the dual roles of engineers and decision-makers, students engage in dynamic reasoning between scientific evidence and value judgment, thereby fostering the development of scientific attitudes. The instructional design is presented in Table 2.

Table 2. Project-based learning instructional design oriented toward cultivating scientific attitudes

Learning Stage	Teaching Activities	Design Rationale	Targeted Dimension
Scenario Creation	A learning scenario is introduced based on the story of Noah's Ark: a great flood is imminent, and a large boat must be built to preserve life on Earth. The teacher presents "life cards" (e.g., humans, dogs, cats, chickens, cows, wheat seeds, oak seeds, giant pandas, coral, bacterial samples). An engineering problem is posed: build a Noah's Ark with the maximum load capacity to carry as many forms of life as possible. Students are guided to consider how boat design can maximize capacity.	The use of a classic narrative stimulates students' interest and prompts them to consider the relationship between structure and function in boat design.	Scientific Cognition
Design and Construction	Group design: students discuss hull shapes and produce simple sketches. Hands-on construction: groups use material kits (foam boards, straws, rubber bands, paper cups, washers) to build their boats.	Through hands-on practice, students gain an intuitive understanding of the relationship between structure and function.	Scientific Behavior
Testing and Optimization	Initial testing: boats are placed in water tanks, and washers are gradually added to test maximum load capacity, with data recorded. Optimization: based on test results, students refine their designs to improve load capacity.	Data collection makes load capacity visible and introduces an optimization process, fostering engineering thinking.	Scientific Behavior
Communication and Evaluation	Ethical question: if the boat can carry only five types of life, which should be selected? Group discussion and decision-making are guided by criteria (e.g., usefulness to humans, rarity, emotional attachment, ecological importance). Sharing and debate: selected groups present their choices and reasoning; others are encouraged to question or offer alternative perspectives.	Transforms scientific activity into a setting for ethical inquiry, fostering skills of listening, argumentation, and compromise, and highlighting the complexity of real-world decision-making.	Scientific Affect
Summary and Extension	Conceptual summary: boats made from floating materials can carry more load when designed to be wider and larger. Thematic reflection: beyond building boats, making difficult choices reflects human values. Students are encouraged to become both competent engineers and responsible decision-makers. Extension: which life forms were included in the original Noah's Ark story? Why do we protect biodiversity today?	Elevates classroom experience from technical understanding to philosophical and societal reflection, guiding students to consider the broader purpose of science and humanistic values.	Scientific Affect

4. Instructional practice of cultivating scientific attitudes through project-based learning

Two classes of comparable overall academic level were selected as the experimental group and the control group. The experimental group adopted a Project-Based Learning (PBL) model oriented toward cultivating

scientific attitudes, while the control group followed a traditional instructional approach. Drawing on the Three-Dimensional Scientific Attitude Scale (TDSAS) developed by Zhang Danhui and Todd Campbell, members of the Association for Science Teacher Education [10], this study designed a *Teacher Interview Protocol* and a *Student Interview Protocol*. During the intervention, teachers and students from both groups were interviewed to examine the development of students' scientific attitudes, thereby evaluating the effectiveness of the instructional practice and informing subsequent reflection.

4.1. Teacher interviews

Based on the *Teacher Interview Protocol*, individual interviews were conducted with four science teachers who participated in the PBL-based instructional experiment aimed at cultivating scientific attitudes. Each interview lasted approximately 30 minutes and took the form of an open-ended dialogue centered on the protocol, with audio recordings made throughout. Following the interviews, the recordings were analyzed to extract the teachers' perspectives and reflections on the instructional experiment. The interview questions were as follows:

(1) In your view, which aspects of scientific attitudes should be emphasized for Grade 5 students (e.g., inquiry interest, evidence-based thinking, collaboration and sharing, pursuit of innovation)?

(2) Do you believe that project-based learning can cultivate students' scientific attitudes? Why or why not?

(3) What aspects should be taken into consideration when applying PBL to cultivate scientific attitudes in classroom teaching?

(4) What are the advantages and potential challenges of using PBL in primary science education to foster scientific attitudes?

The analysis of the interview data is summarized as follows:

First, regarding the key aspects of cultivating scientific attitudes, teachers generally noted that Grade 5 students exhibit strong curiosity, a high level of enthusiasm for hands-on activities, and a positive disposition toward learning science, while gradually transitioning toward more abstract thinking. Their awareness of collaboration is also rapidly developing. Accordingly, instruction should prioritize fostering students' interest in inquiry and their investigative abilities, cultivating evidence-based and objective thinking, strengthening their awareness of collaboration and communication skills, and developing a sense of social responsibility.

Second, in terms of the feasibility of using PBL to cultivate scientific attitudes, all interviewed teachers affirmed its importance and practicality in science education. PBL not only increases students' interest in learning but, more importantly, enables them to apply classroom knowledge to real-life problem-solving. This process deepens students' scientific understanding while also fostering positive personal qualities.

Third, regarding considerations for implementing PBL oriented toward scientific attitudes, teachers emphasized that projects should be authentic and closely connected to students' lives, and that learning scenarios should be engaging and meaningful. In addition, teachers highlighted the importance of process-oriented assessment and the use of diverse evaluation criteria to support the development of students' positive values.

Fourth, concerning instructional effectiveness and suggestions for improvement, teachers expressed strong approval of the instructional design presented in this study. They noted that it effectively stimulated students' interest in learning, demonstrated a clear and coherent structure across instructional stages, and successfully integrated knowledge acquisition with real-life application. At the same time, they offered several recommendations: improving time management during lessons, flexibly adjusting instructional content, strengthening classroom order during group experiments through clear role assignments, and ensuring full student participation through appropriate task distribution.

4.2. Student interviews

Individual interviews were conducted with 15 students from both the experimental and control groups before and after the instructional intervention, based on the *Student Interview Protocol*. Each interview lasted approximately 10 minutes and followed a question-and-answer format, with audio recordings made throughout. The interview questions were as follows:

- (1) Do you like your current science classes? Which aspects do you enjoy?
- (2) Do you think your science classes are helpful to you? In what ways?
- (3) In science class, do you listen attentively to your classmates and actively raise your hand to express your ideas?
- (4) During inquiry activities, how does your group divide tasks? Do you actively participate?
- (5) Would you like to continue learning science in the future?
- (6) Based on your experience, what suggestions do you have for improving your science classes?

Analysis of the interview recordings indicates that, prior to the intervention, there was no significant difference between the experimental and control groups in terms of students' scientific attitudes. After the intervention, no noticeable change was observed in the control group, whereas students in the experimental group demonstrated a marked improvement in their scientific attitudes. The findings from the experimental group interviews are summarized as follows:

First, regarding students' acceptance of the PBL approach oriented toward cultivating scientific attitudes, the results show a high level of classroom engagement. This can be attributed, on the one hand, to the alignment of the instructional design with students' learning characteristics, and on the other hand, to the relatively open and relaxed classroom atmosphere. PBL not only enabled students to acquire textbook knowledge but also helped them gain practical, real-life understanding, thereby fostering an initial aspiration toward science.

Second, in terms of participation in PBL-oriented instruction, students generally exhibited strong enthusiasm and active involvement in science classes. However, certain "marginalized" groups were also identified. Some students, due to introverted or timid dispositions, were reluctant to speak and were occasionally overlooked by teachers. Others were overshadowed by more dominant group members, who either monopolized experimental materials or assigned them less preferred roles, resulting in passive participation.

Third, regarding suggestions for improving PBL instruction aimed at cultivating scientific attitudes, students indicated that diverse teaching formats were highly engaging and well matched to their cognitive and comprehension levels. Additionally, many students expressed a desire to learn more scientific knowledge to gain recognition from adults, thereby enhancing their self-confidence and sense of achievement—factors that also serve as important motivational drivers for their continued learning.

5. Problems identified and recommendations for improvement

The foregoing analysis indicates that Project-Based Learning (PBL) oriented toward cultivating scientific attitudes is highly effective in enhancing primary school students' scientific attitudes. Nevertheless, several issues warrant attention in its implementation. These can be summarized as follows:

First, the design of learning scenarios should be authentic and conducive to cognitive development. PBL typically begins with a scenario or a driving question. Such scenarios should be both realistic and intellectually engaging, enabling students to become immersed in the process of problem-solving, thereby promoting cognitive growth and emotional resonance. In this study, the classic story of "Noah's Ark" serves as the

contextual framework, presenting students with dual challenges involving engineering and ethical considerations. This approach ensures that students remain oriented toward meaningful inquiry, while effectively integrating engineering thinking and fostering a sense of social responsibility. The thoughtful combination of engineering design and ethical reflection enriches the depth and real-world relevance of the learning experience.

Second, instructional stages should be prioritized, with flexible adjustment of content. Teachers need to maintain a macro-level understanding of the overall instructional design, identifying the connections between curricular objectives and students' actual learning conditions. At the same time, they should refine teaching details at a micro level, focusing on key instructional elements. It is not necessary to address every predefined knowledge point rigidly, as long as the overall instructional goals are achieved. For instance, while the introductory stage may benefit from varied formats, excessive activities are unnecessary; it is sufficient to effectively stimulate students' engagement and motivation.

Third, classroom order requires careful management, with emphasis on effective facilitation. Classroom management in PBL does not imply teacher dominance but rather the teacher's role as a facilitator and guide in students' learning processes. For example, before conducting experiments, students can be encouraged to articulate the rules and expectations themselves, thereby strengthening their awareness of discipline. Additionally, assigning roles such as group supervisors can help maintain order during group activities by leveraging students' own sense of responsibility.

Fourth, attention must be given to less active students to ensure inclusive participation. Inquiry-based classroom activities typically rely on group collaboration, which may lead to imbalances in participation. Students with more dominant personalities may take control of group tasks, while those with more dependent or reserved tendencies may become marginalized. Teachers should intervene appropriately: guiding dominant students to recognize the importance of collaboration through constructive dialogue, and providing encouragement and positive reinforcement to less assertive students. By acknowledging their strengths and encouraging them to express their ideas, teachers can help these students actively engage in group work and experience the benefits of collaboration.

6. Conclusion

Project-Based Learning (PBL) provides an effective pathway for cultivating scientific attitudes in primary science education. By integrating engineering practice and ethical inquiry within the instructional context of "Noah's Ark", this approach not only enables students to acquire knowledge of buoyancy and structural design through learning by doing, but also guides them to gain deeper insights through reflective thinking, experiencing the complexity of decision-making and the significance of social responsibility. The findings demonstrate that this instructional model externalizes the otherwise implicit nature of scientific attitudes through students' inquiry-based behaviors and collaborative discussions, thereby effectively promoting the coordinated development of scientific cognition, scientific affect, and scientific behavior. At the same time, the successful implementation of PBL places higher demands on teachers' classroom management skills and pedagogical expertise. Teachers are required to shift from being transmitters of knowledge to designers of learning contexts, facilitators of inquiry processes, and supporters of students' value formation. Future research may further explore the development of more refined process-oriented assessment systems to quantitatively trace the progression of scientific attitudes. In addition, attention should be given to ensuring that every student can genuinely benefit and achieve growth through participation in PBL. In this way, the cultivation of

scientific attitudes can extend to all learners, laying a solid foundation for nurturing future citizens equipped with both scientific literacy and humanistic concern.

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