Scientific and Social Research, 2025, Volume 7, Issue 5
https://ojs.bbwpublisher.com/index.php/SSR
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Reconstructing Science Learning through Multidimensional Project-Based Pedagogy: A STEAM-Integrated Crystal Exploration in Chinese Elementary Schools

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Abstract: Based on the project-based learning design framework, this paper designs specific project-based activities for sixth-grade elementary school students in conjunction with the elementary school science course "Crystals under the Magnifying Glass." The activities included searching for crystals around them, observing crystals using a microscope, making artificial crystals, crystal knowledge sharing session, crystal artwork creation, and exploring the conditions of crystal growth, aiming to deepen the students' understanding of crystal knowledge as well as to cultivate their scientific thinking, inquiry practice, and teamwork skills through exploratory, technological, creative, social, aesthetic, and moderated practices. The results showed that the students showed strong interest in the project-based activities, and their learning autonomy, cooperative learning ability, and innovation ability were significantly enhanced. However, the organic integration of subject knowledge and project-based activities and the breaking of students' inherent thinking need to be further strengthened.

Keywords: Project-based; Elementary school science curriculum; Activity design and practice

Online publication: June 6, 2025

1. Introduction

In promoting the development of science education in China, it is necessary to continuously strengthen the construction of science curriculum, improve the quality and level of science curriculum, and lay a solid foundation for cultivating more scientific and technological innovation talents [1]. Strengthening the construction of science curriculum and the improvement of its educational quality has become a key goal of science education reform. The elementary school science curriculum advocates an inquiry-based teaching method to cultivate students' scientific literacy. This inquiry-based teaching mode and practical science activities can effectively promote students' scientific thinking skills and their overall personal development. Project-based learning serves as an effective means to optimize the teaching methods of elementary school science and achieve curriculum integration [2]. Project-based learning refers to the acquisition of focused knowledge and skills by students over a period of time by studying and responding to an authentic, engaging, and complex problem, issue, or challenge [3]. It emphasizes the students' subject position and focuses on cultivating their practical ability, innovative thinking, and teamwork spirit. By guiding students throughout the process to participate in all aspects of the selection of project content, collection of information and knowledge, exploration of problematic activities and production of related activities, it forms a comprehensive project model that contains a variety of forms of activities, which has injected a new vitality into elementary school science education.

Project-based learning presents diverse forms of practice. The United States will be technical engineering and scientific inquiry into "science and engineering practice", pay attention to hands-on science activities, emphasizing "do middle school" [4]. In the Nordic countries, project-based teaching is widely used in vocational education, focusing on students' performance and attitudes, and the acquisition and application of metacognitive skills [5]. In contrast, a study at Seoul National University in South Korea revealed the importance of mutual evaluation among group members in project-based learning, especially the significant impact of peer-to-peer management and collaborative procedures on evaluation results [6]. The research on the application of project-based learning in elementary school science mainly focuses on the aspects of instructional design and the merits of activities [7–9]. The main features of project-based teaching are that the problems originating from real life are used as the driving force to carry out the activity of inquiry, the formation of a learning community, the form of group cooperation for inquiry learning, and the evaluation methods should be diversified [7]. Through the implementation of project-based teaching, it can effectively improve students' mastery of knowledge, behavioral skills development, problem-solving ability, and promote students' cooperation and communication [8]. Project-based learning improves children's foundational scientific skills, and project-based learning develops children's spiritual qualities of science [9]. China's research on the project-based learning approach in the teaching mode is relatively late, and there are fewer cases related to the theory-guided practice, mainly in physics, geography, biology, and other disciplines, and there are relatively few cases of research on elementary school science.

This paper takes the project-based learning design proposed by Xia Xuemei as a framework, combines the primary science "crystals under the magnifying glass" lesson and the analysis of the situation of elementary school fifth-grade students to design a specific project-based activity plan for elementary school science, and evaluates and analyzes the results of the implementation of the course activities through teaching practice and questionnaires [10]. It aims to provide elementary science teachers with case studies of project-based activities and to promote the innovative development of elementary science education.

2. Project-based learning design framework

Based on the eight "golden rules" of project-based learning proposed by the Buck Institute for Educational Research, some scholars have proposed six steps of project-based learning design based on the perspective of learning literacy [10–12].

2.1. Definition of core knowledge

Project-based learning design builds project-related basic knowledge and skills based on finding key concepts or competencies with the help of curriculum standards, textbooks, and other materials. While integrating interdisciplinary knowledge, it keeps close to the core of the discipline to ensure the clarity of learning objectives and the depth of content.

2.2. Design of driving questions

Project-based learning triggers students' thinking and exploration of concepts through questions. Teachers should express the core knowledge in the form of questions. These questions need to have the characteristics of enhancing essential understanding, connecting students' experiences, transforming facts into concepts, originating from students, and triggering conflict and controversy. Good driving questions stimulate higher-order thinking and provide a meaningful framework for learning content.

2.3. Clarifying higher-order cognitive strategies for projects

Project-based learning focuses on driving low-value cognition through higher-order cognition. Teachers need to clarify the higher-order cognitive strategies embedded in the driving questions and learning outcomes, so as to promote the integration of basic knowledge and skills through careful design and to realize in-depth learning of conceptual knowledge.

2.4. Identify key learning practices

Depending on the type of program, the characteristics of the driving questions, and the program process, teachers should incorporate appropriate learning practices. Clarifying the basic components of various practices can help design a journey that is more stimulating to students' thinking and learning.

2.5. Identify learning outcomes and how they will be disclosed

Based on the project-driven questions, initially conceptualize the learning outcomes for individual and groups of students, and develop clear and specific evaluation criteria and public presentation methods. The project outcomes should directly reflect the core issues of the discipline, and the assessment criteria should be detailed and comprehensive to ensure that students' mastery of the core knowledge can be accurately measured.

2.6. Design evaluation covering the whole process

Upon completion of the project design, the project outcomes and process evaluation should be refined, including the topic setting and marking arrangement. The evaluation should cover the results and the main practical process of students, reflecting the comprehensive and holistic nature, while encouraging students to participate in the evaluation, and jointly promoting the improvement of learning results and the overall development of students.

3. Project-based activity design for "Crystals under the Magnifying Glass"

Under the framework of project-based learning design, this paper chooses the elementary school science lesson "Crystals under the Magnifying Glass" to carry out project-based activity design (**Figure 1**).

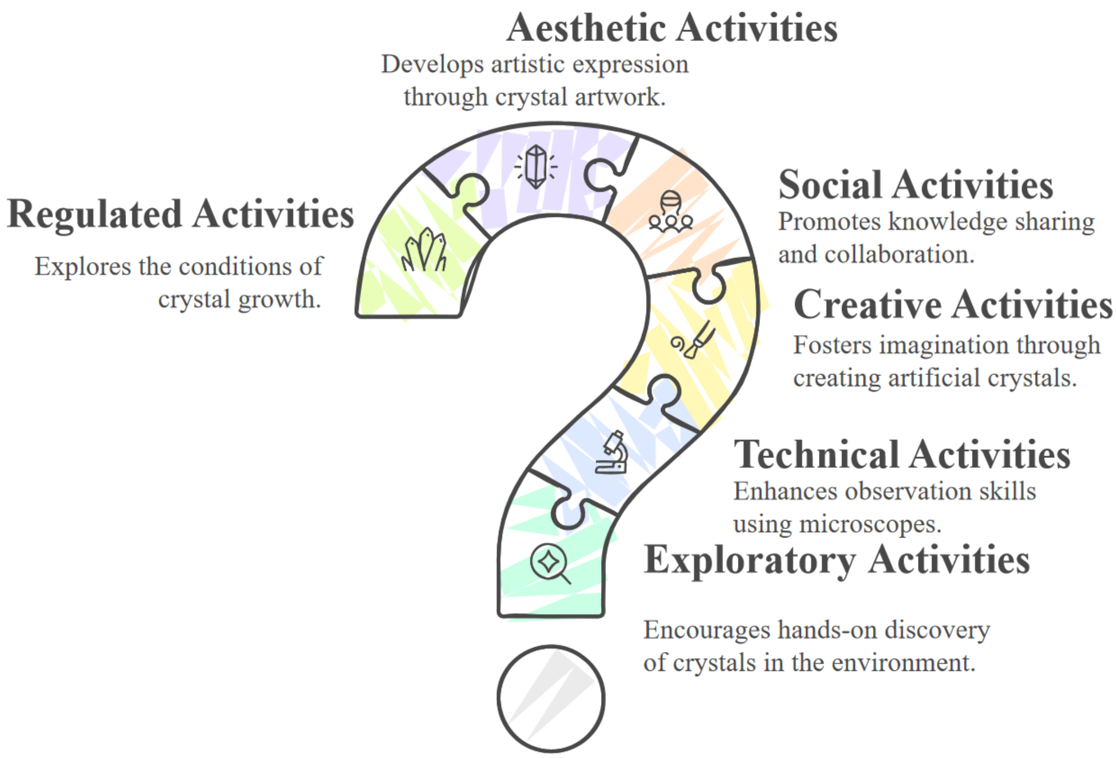

Figure 1. Project-based activity design chart for "Crystals under the Magnifying Glass"

3.1. Constructing project objectives based on core knowledge

Scientific conception: To recognize mineral crystal holes by collecting knowledge; to make crystals by using different methods, so that students can deepen their understanding of mineral crystal holes and stimulate their scientific interest and innovation potential.

Scientific thinking: To improve students' communication and collaboration skills through cooperation and discussion among groups and designing activity programs; to cultivate students' ability to apply knowledge and think logically through searching for information.

Exploration and practice: Through understanding the knowledge of crystals, stimulate students' autonomy of exploration through this activity; strengthen students' teamwork, scientific spirit, and improve students' hands-on creative ability, so that they can truly appreciate the magic of nature.

Attitude responsibility: Initial understanding of science to promote technological progress, students make their own artificial crystals and experience the fun of making mineral crystals. Observe with scientific eyes how the phenomena of nature are related to their lives.

3.2. Design Driving Questions

Driving question: What are the unique shapes of ice and snowflakes on the window glass in winter?

Contextualized design: On a winter morning, the teacher guides the students to observe the shape of the ice flowers on the windows, leading them to start an exploration of the beauty of nature. Guide students to think about the difference between snowflakes and ice flakes. Why do snowflakes come in so many shapes? Students are attracted to the wonders of nature's crystals and become interested in exploring them. Under the guidance of the teacher, use a magnifying glass or a microscope to observe the shapes of ice flowers and snowflakes and try to understand how they are formed, so as to gain a deeper understanding of the mysteries of the crystal world.

3.3. Finding higher-order cognitive strategies for the project

Analyzing and synthesizing: Students analyze the characteristics of different crystals, the formation process, and synthesize this information to make artificial crystals or draw crystal shapes.

Critical thinking: Students need to use critical thinking to evaluate the reliability of information, the validity of experiments, and the reasonableness of conclusions.

Creative thinking: Students are encouraged to design unique experimental solutions or observations to investigate the mysteries of crystals, as well as to creatively present learning outcomes, such as making models of crystals.

Problem solving: Students need to use problem-solving strategies to solve problems, such as how to observe crystals and how to make crystals.

Cooperative learning: Students develop teamwork and communication skills through group discussion, division of labor, and presentation of results.

3.4. Designing Learning Practices

3.4.1. Exploratory practical activities: Finding crystals around

Encourage students to look for crystals, such as table salt, sugar cubes, etc., at home or on campus, and use magnifying glasses to observe their shape, color, transparency, and other properties. Through direct observation, students can deepen their understanding of the basic concepts of crystals.

3.4.2. Technical practical activities: Observing crystals using a microscope

Under the guidance of the teacher, students learn to use microscopes to observe ice flowers, snowflakes or artificially made crystal samples and record the observations. Students develop microscopic observation skills and improve their understanding of the microstructure of crystals.

3.4.3. Creative practical activities: Making artificial crystals

Students work in groups, choose different methods to make crystals or other types of crystals, and record the process of making them. Through hands-on production, students deepen their understanding of the process of crystal formation and, at the same time, stimulate their creative potential.

3.4.4. Social practical activities: Crystal knowledge sharing session

Students work in groups to prepare content about crystal knowledge sharing, such as the definition, types, and formation principles of crystals, and share it in class. Students will develop their communication and teamwork skills as well as deepen their understanding of crystal knowledge.

3.4.5. Aesthetic practical activities: Crystal artwork creation

Students will use the crystals they have made or collected and combine them with other materials to create crystal artworks, such as crystal hanging ornaments and crystal paintings. Cultivate students' aesthetic ability and creativity, and at the same time let them feel the beauty and magic of crystals in practice.

3.4.6. Regulated Practical Activities: Exploring the conditions of crystal growth

Students work in groups to investigate the growth of crystals under different conditions by changing the conditions of temperature, humidity and concentration of solution, and record the experimental results. Students will develop their ability to design experiments and analyze data, as well as deepen their understanding of crystal growth conditions.

3.5. Designing public results and evaluation points

Individual results display: students present their crystal observation diaries, works produced, etc.

Team presentation: The team will present the results of the crystal production workshop, including the production process, work display, and so on.

Evaluation and feedback: Teachers and classmates evaluate their own and other people's works and make suggestions for improvement.

3.6. Designing whole-process evaluation

Process evaluation: To assess students' participation, cooperation, and problem-solving ability during the implementation of the project.

Outcome-based evaluation: To assess students' learning outcomes, including the mastery of crystal knowledge, observation and record-keeping abilities, and the skills of making crystals.

Reflective assessment: To guide students to self-reflection, summarize their learning experience, and clarify the direction of improvement.

Transferability assessment: To assess whether students can apply what they have learned about crystals in real life, as well as their innovative thinking and transferability.

4. Project-based activity practice of "Crystals under the Magnifying Glass"

The sixth-grade students of Hengshan County Kaiyun Township Central School were selected as the target of the survey, and their mastery of science knowledge was relatively good, and they were more interested in hands-on science courses, which well reflected the differences between science and other language and mathematics courses.

4.1. Implementation of project-based activities

4.1.1. Project-based activities

Teacher preparation: Teachers need to prepare the necessary materials in advance, such as magnifying glasses, microscopes, and chemical reagents needed for crystal making. At the same time, teachers need to familiarize themselves with the project process, design the activity plan, and prepare relevant guiding questions and contextualized design.

Student preparation: Students need to understand the basic requirements and objectives of the project, and prepare notebooks and pens for recording observations and the production process. Meanwhile, students also need to have a basic understanding of crystals, which can be acquired by previewing the textbook or consulting the information.

4.1.2. Activity implementation stage

Exploratory practice: Teachers guide students to look for crystals at home or in the schoolyard and use magnifying glasses to observe their shape, color, transparency, and other properties. Students need to record their observations and discuss and exchange them in groups.

Technical practice: Under the guidance of the teacher, students learn to use a microscope to observe crystal samples. Teachers need to teach students the correct way to use the microscope and guide them to observe the microstructure of crystals. Students need to record their observations and analyze and discuss them.

Creative practice: students work in groups to make artificial crystals. Teachers need to provide different methods and materials for students to choose and try out. Students need to record the production process, problems encountered and solutions, and share and exchange them within the group.

Social practice: Students prepare the sharing content of crystal knowledge in groups and share it within the class. Teachers need to arrange the time and place of the sharing session in advance and provide necessary support and assistance. Students need to actively participate in the sharing session, listen attentively to the content shared by other groups, and ask their own questions and suggestions.

Aesthetic practice: Students create crystal artworks using crystals they have made or collected. Teachers need to provide the necessary materials and tools, and guide students to use their imagination and creativity to create their works. Students need to present their works and explain the ideas and process of creation.

Moderated Practice: Students work in groups to investigate the growth of crystals under different conditions. Teachers need to provide guidance on experimental design and data analysis, and guide students to draw conclusions. Students need to record the experimental process, data and analysis results, and discuss and exchange them in their groups.

4.1.3. Activity summarization stage

Individual results presentation: Students present their individual results, such as their crystal observation diaries and the works they made. Teachers need to evaluate and provide feedback on the students' results and make suggestions for improvement.

Team presentation: The team will present the results of the crystal making workshop, including the production process and the works. Teachers need to evaluate and feedback on the group's results and encourage communication and sharing among the groups.

Reflection and transfer: Teachers guide students to reflect on themselves and summarize their learning experiences and gains. At the same time, teachers need to assess whether students can apply what they have learned about crystals in real life, as well as their innovative thinking and transfer ability. Teachers can design some transferable tasks or problems for students to try to apply what they have learned to new situations.

4.1.4. Activity evaluation and feedback

Teachers need to evaluate students' participation, cooperation ability, problem-solving ability, and learning outcomes according to the design of whole process evaluation. Teachers also need to assess students' ability to reflect and transfer.

Teachers need to give students timely feedback and suggestions to help them improve their learning and production methods. At the same time, teachers need to encourage mutual evaluation and feedback among students to promote communication and cooperation among them.

4.2. Evaluation of the implementation of project-based activities

After the implementation of project-based activities, students' feedback was positive, and their interest in learning increased significantly. 76% of the students indicated that they were very willing to participate in such activities, and 82% liked the project-based activity model, which indicated that the course design was well received by the students and promoted the enhancement of students' learning autonomy. However, 56% of the students thought that continuing learning after class was very compatible, indicating that the guiding role of knowledge needs to be further strengthened in the classroom design, extending learning into students' lives, and reflecting the concept of lifelong learning.

In terms of cooperative learning, 78% of the students were able to communicate well with their classmates, 80% were able to carry out division of labor effectively, and 92% were clear about their group responsibilities. These figures exceeded the expectations, indicating that the design of the project activities effectively enhanced the students' ability to work in groups.

The transfer of knowledge is still weak. Only 58% of the students thought that the integration of knowledge into the study of "crystals" was very suitable. In making crystals, some students ignored their previous knowledge of dissolution in Grade 4 science. 64% of students were able to think about the design options in various ways, but their creativity still needs to be strengthened. More than half of the students were able to choose the optimal solution and adjust the design solution, demonstrating some ability in practical problem solving.

44% of the students were willing to show their work to other groups, and 76% of them could suggest improvements to the work of others, which practiced independent thinking and the ability to integrate knowledge. 76% of the students had a good understanding of "crystals", and 98% of them had mastered the scientific knowledge of the lesson, thus achieving the knowledge-based objectives. Although only 70% of the students were very satisfied with the transfer of knowledge, their ability to transfer knowledge has been strengthened compared with that before the lesson. 82% of the students were able to complete the design of their works on time, practicing their hands-on ability to make and invent, and developing the good habits of thinking independently, thinking quickly, and not procrastinating.

5. Conclusion

In this paper, on the basis of integrating the project-based learning design as a framework, combining primary science "crystals under the magnifying glass" to design specific primary science project-based activities, and evaluating the effect of project-based learning through teaching practice. An analysis of the sixth-grade students' learning situation in the pre-activity period revealed that most of the students were able to design experiments according to the teacher's requirements, but their ability to think independently and innovate on their own was relatively weak. After the implementation of the project, students' attitudes towards learning science have changed greatly, and their cooperative learning ability as well as their innovation ability have been very well practiced in the project-based activities. The new learning model based on project-based activities strengthens the cultivation of students' independent learning ability, so that students can quickly experience integration and utilization of multiple disciplines in the activities, and the transfer of knowledge is strengthened.

Funding

Research Project on Teaching Reform in Higher Education Institutions in Hunan Province (Project No.:

202401001748); Scientific Research Program of Hunan Provincial Department of Education (Project No.: 23B1134); Philosophy and Social Sciences Planning Project of Hainan Province in 2022 (Project No.: HNSK(ZC)22-155).

Disclosure statement

The authors declare no conflict of interest.

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