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South to North Water Diversion: Exploring the Secrets of Water Diversion Projects: A Design Based Problem Solving STEM Curriculum

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A R T I C L E I N F O

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A B S T R A C T

This article introduces the design and implementation of a STEM course centered on the theme of 'South-to-North Water Diversion. ' The course uses real engineering projects as its backdrop, constructing a framework of 'scientific inquiry-engineering design-system optimization. ' It covers core topics such as the principles of inverted siphons and water conveyance device design, integrating practical activities like experimental simulations and sandbox operations to cultivate students' interdisciplinary thinking and problem-solving abilities. The teaching objectives encompass dimensions such as physical concepts and scientific thinking, with the overarching question of 'designing a cross-river water conveyance device' guiding unit instruction. Through diverse evaluation methods, the course ensures learning outcomes, providing a practical model for STEM education in primary and secondary schools (Baek et al., 2011).

1. Introduction

The 'STEM Education Action Plan 2035' clearly states the need to establish high-quality STEM courses and project systems to cultivate students' critical thinking, problem-solving skills, and innovative practical abilities, thereby promoting the development of advanced scientific thinking. STEM courses based on real engineering scenarios serve as crucial vehicles for achieving this goal by deeply integrating knowledge of science, technology, engineering, and mathematics into actual engineering problems. Through a project-based learning path that involves 'problem-driven, interdisciplinary integration, and practical exploration, 'these courses guide students to achieve knowledge integration, cognitive advancement, and skill enhancement while solving complex engineering challenges, laying a foundation for cultivating innovative talents adaptable to future technological developments.

The South-to-North Water Diversion Project, a strategic inter-basin water transfer project in China, integrates knowledge from multiple disciplines such as geographical and topographical analysis, physical principles of water flow, engineering design, and ecological environment assessment. It serves as an exemplary case for real engineering scenario-based STEM teaching. This course is themed 'South-to-North Water Diversion: Exploring the Mysteries of Water Transfer Engineering. 'Leveraging the complexity and comprehensiveness of the project, it constructs a learning framework focusing on 'scientific inquiry, engineering design, and system optimization. ' The course centers on core issues such as the principle of inverted siphons, route selection for engineering lines, and ecological protection. Through activities like experimental exploration, sandbox simulation, and plan design, it guides students to uncover the scientific mysteries of water transfer projects during interdisciplinary integration and real problem-solving, fostering systemic thinking, innovation capabilities, and a sense of social responsibility. This provides a practical model for deepening STEM education reform in primary and secondary schools (Miller et al., 2017).

2. Unit teaching objectives and teaching design

2.1 Teaching objectives

This unit's teaching design is based on the national curriculum standards, taking into account the cognitive development level of fifth-grade students. It aims to implement the core competencies in physics, carefully setting teaching objectives from four dimensions: physical concepts, scientific thinking, scientific inquiry, and scientific attitude and responsibility. In terms of physical concepts, students will design and build water conveyance models to understand the basic principles of water flow, learn how to use natural forces to make water flow, and solve practical problems related to water resource conveyance in different terrains, thereby developing their scientific inquiry and problem-solving skills (Anderson et al., 2019). In terms of scientific thinking, students will compare inverted siphons with other water conveyance methods (such as tunnels and aqueducts), understand the advantages and disadvantages of these methods in practical applications, and learn how to select appropriate technologies based on different geographical conditions, thus developing interdisciplinary comprehensive thinking. In terms of scientific inquiry, students will create inverted siphon models through

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experiments, personally observe and record experimental data, analyze changes in water flow during experiments, and develop skills in data collection, analysis, and reasoning, enhancing their scientific observation and experimental skills (Bruder & Prescott, 2013). In terms of scientific attitude and responsibility, students will work in groups to complete the design, experiment, and presentation of inverted siphon systems, improving their teamwork and communication skills, and by presenting their design ideas and experimental results, they will enhance their scientific expression abilities. This unit's teaching cases, through scientific inquiry and engineering practice, help students deeply understand the complexity and importance of the South-to-North Water Diversion Project, enhancing their scientific inquiry, engineering practice, and system thinking skills, while also fostering critical thinking, innovative thinking, and teamwork (Kelly, 2012).

2.2 Unit teaching design

This unit explores the 'South-to-North Water Diversion' project through scientific inquiry and engineering practice. Students will learn core concepts such as water resource management, engineering technology, and environmental protection (Bybee, 2010). They will understand the background and significance of the South-to-North Water Diversion project, recognize the environmental impact of construction, and appreciate the importance of ecological protection and water quality assurance in design. Through hands-on experiments, data analysis, and model design, students will enhance their scientific communication and problem-solving skills. Initially, students will study the basic principles of the South-to-North Water Diversion project and the practical applications of water resource management and water conservancy technology. They will explore the principles of water conveyance technologies such as inverted siphons, tunnels, and aqueducts through research and experiments. In practical sessions, students will improve their hands-on skills, learn to collect and analyze data, and verify the working principle of the inverted siphon system in real-world scenarios. The project emphasizes fostering students' innovative thinking and problem-solving abilities, encouraging them to think critically and propose improvements when exploring engineering design solutions (Little & Anderson, 2016). Additionally, through group collaboration and project presentations, students will develop teamwork and communication skills, learn to analyze problems from multiple perspectives, and share their research findings with others.

Table 1. Overall teaching ideas of the unit

The big question	How to design an effective water transport device that can cross the river, solve the practical problems in water conservancy projects, and ensure smooth water flow and stable system.		
subproblem	subtask	Learning outcomes	estimate
How to understand the various technical ways of crossing rivers, and their applicable scenarios and limitations?	Introduce different water conservancy technologies (such as inverted siphon, tunnel, aqueduct, etc), explain the principle and limitation of each technology.	Technology comparison table, design log, scheme planning	Reasonableness of technology selection, data support and scenario analysis
How to understand the principle of siphon phenomenon and experience the principle of inverted siphon through experiments?	Demonstrate the siphon phenomenon and let students experience it by themselves through experiments.	Experiment record sheet, experiment report	The correctness of experimental operation, the integrity of data recording and the accuracy of analysis
How to deepen the intuitive understanding of the principle of inverted siphon through experimental investigation?	The reverse siphon experiment was carried out, and the data were recorded and the water flow changes were analyzed.	Experiment log, data table, analysis report	Experimental standardization, data collection quality, analysis and reasoning rationality
How to ensure smooth water flow in the inverted siphon system in practical application and optimize the design?	Different environmental conditions are simulated to optimize the design of the inverted siphon system to ensure smooth water flow.	Design model, optimization report and experimental comparison table	Innovation, optimization effect, environmental adaptability and system stability

3. Teaching implementation —— Take the second lesson of "The inverted siphon in the Yellow River Project" as an example

3.1 Teaching content and learner analysis

Through the understanding of engineering problems and the exploration of siphonic technology in previous lessons, this course provides students with a foundation in hydraulic engineering technology. This lesson focuses on the experimental verification of the inverted siphon principle and the analysis of its influencing factors, complemented by practical sandbox simulations to help students understand the application of this technology in real-world projects. The core content of this lesson is the exploration of the application principles and influencing factors of inverted siphon technology. Through video introductions, experimental investigations, data analysis, and sandbox simulations, students will not only grasp the basic principles of the inverted siphon but also gain a deep understanding of the factors that affect the smooth flow of water through experiments and discussions. Additionally, this lesson requires students to analyze the technical applications in real-world scenarios, fostering their ability to apply and solve problems comprehensively. Before this lesson, fifth-grade students have already acquired basic knowledge of physics, including concepts such as gravity, simple water flow, and the impact of water level differences on water flow speed. However, their understanding of more complex physical principles, such as pressure and fluid mechanics, is still limited. In terms of skills, students can perform simple observations and record experimental phenomena, understand cause-and-effect relationships, and make initial inferences. However, their thinking is still at a concrete operational level, and they need to rely on intuitive models and hands-on practice to understand abstract concepts. During this lesson, students may struggle with data recording and analysis, finding it challenging to accurately connect experimental data with real-world engineering problems. They also lack systematic methods for data analysis during group discussions (Treacy & O'Donoghue, 2014). To address these issues, teachers should design detailed data recording templates in advance, demonstrate them on-site, and guide students to establish a connection between data and actual water supply problems (NGUYEN et al., 2020).

3.2 Teaching process

This lesson focuses on cultivating engineering thinking, following the logical sequence of 'cognitive construction—practical verification—innovative application'. It guides students to explore the engineering principles of inverted siphon technology through a layered task design (Pordanjani &

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Salehi, 2024). The teaching process emphasizes the authenticity of scenarios and task-driven learning, integrating knowledge from multiple disciplines. Through activities such as experimental operations, data modeling, and team collaboration, students are encouraged to solve real-world problems related to the Yellow River Crossing Project. This process helps them build scientific concepts, enhance their investigative skills, and develop the habit of systematically analyzing complex engineering issues.

Context Introduction, Stimulating Thinking: This stage aims to create a real and inspiring learning environment by presenting various intuitive materials. It quickly captures students' attention, helps them establish basic scientific concepts, and sparks their curiosity and desire to explore the South-to-North Water Diversion Project. Through questions and discussions, it encourages students to think critically and guides them to explore influencing factors in practical applications, preparing them for subsequent experimental design and data analysis (Barbey & Barsalou, 2009). The teacher begins by showing an animation video of the inverted siphon technology, illustrating how the system works (Figure 1). This helps students intuitively understand the basic principles of water flow and how the inverted siphon system is applied in real life. The teacher then poses questions about the factors that influence the application of inverted siphon technology to ensure stable water flow. Students, after watching the animation video, think about the working process of the inverted siphon and try to understand why water can flow.

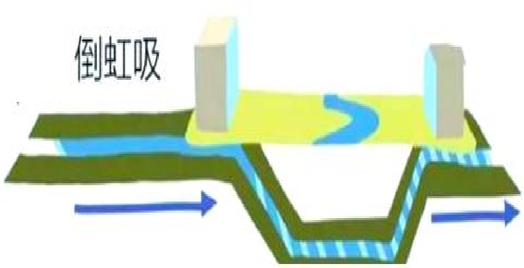

Figure 1. Backflow system

In this stage, the teacher distributes experimental materials to students and explains the steps for making a siphonic model (Figure 2) and how to operate the equipment. The teacher then demonstrates the operational methods, helping students understand how to set different pipe heights and water pipe cross-sectional areas, as well as how to control the experimental conditions. Under the teacher's guidance, students perform the experiment, creating the siphonic model and adjusting the pipe height and water pipe cross-sectional area. They continuously observe changes in the water flow and record experimental data. Through hands-on experimentation, students can apply theoretical knowledge to practical operations and gain a firsthand understanding of the siphonic principle. By recording data and observing changes in water flow, students can develop skills in data collection and preliminary analysis, laying a foundation for further discussions on experimental results and drawing conclusions. Data analysis, interpretation, and explanation. In this stage, teachers guide students to analyze experimental data, compare changes in water flow under different conditions, and explore the impact of pipeline height and pipe cross-sectional area on water flow. This leads to questions about which factors have the greatest impact on water flow. Students analyze experimental data, compare changes in water flow at different heights and with different cross-sectional areas, and identify patterns. They participate in group discussions to analyze and determine the main factors affecting water flow efficiency, and propose suggestions for optimizing the inverted siphon system. Through data analysis, students can develop critical thinking and scientific reasoning skills, extract useful information from experimental data, and enhance their ability to analyze experiments and solve practical problems.

Figure 2. Experimental materials and inverted siphon model

The integration of theory and practice, with a focus on refining solutions. This phase aims to help students understand the integration of theory and practice through sandbox simulations. By designing and optimizing solutions, students will develop engineering thinking and teamwork skills, enabling them to apply their knowledge in real-world scenarios. Teachers use sandbox models to demonstrate how inverted siphon technology is applied in actual engineering, simulating water conveyance processes under various geographical conditions. They also discuss how to adjust the design of inverted siphons to ensure smooth water flow in different environments. Students are guided to discuss and analyze the challenges that inverted siphon technology may face in real-world projects, and to explore ways to optimize design solutions. Using the sandbox model, students observe the effectiveness of inverted siphon systems in different environments, engage in discussions and adjustments, and simulate the optimization of inverted siphon systems. Through these activities, teachers and students exchange ideas and discuss the best optimization strategies.

3.3 Teaching evaluation

The teaching evaluation is shown in Table 2.

Table 2. Teaching evaluation

Direction of evaluation	Evaluation content	Level 1	Level 2	Level 3
Data processing and problem solving	Whether students can effectively process experimental data and draw reasonable conclusions.	Students failed to accurately process the experimental data, and the conclusions drawn were not based on evidence.	Students were able to process the data and draw preliminary conclusions, but some of the data was not fully explained.	Students can complete the processing of experimental data and draw accurate and reasonable conclusions.
Valid reasoning and evidence support	Whether the student can effectively support the argument with the evidence provided.	The student's argument is not supported by sufficient evidence or uses irrelevant evidence.	Students can use some relevant evidence, but the evidence is insufficient or does not fully support the argument.	Students can provide sufficient and relevant evidence to support their arguments accurately.
Experimental design and data recording	Whether the student can accurately record and analyze the data according to the experimental design steps.	Students fail to record data as required or the data is incomplete.	Students recorded most of the data, but some key data was missing or inaccurate.	Students accurately and completely recorded the experimental data and were able to analyze the changes in the data.

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Teamwork and communication skills	Whether students can effectively communicate and express their ideas in group cooperation.	Students are not actively involved in the discussion or are unclear in the group.	Students are able to participate in group discussions but do not express themselves clearly enough or support the discussion adequately.	Students actively participate in discussions, clearly express their own views and support others.

4. Implementation strategies of STEM courses based on real engineering scenarios

4.1 Create real situations and drive students to think deeply

In engineering design-based STEM education, context plays a crucial role in stimulating students 'interest and fostering higher-order thinking (Park et al., 2019). For instance, in the South-to-North Water Diversion Project, teachers can present engineering scenarios and construction challenges to help students understand the complexity and significance of engineering design. This approach encourages students to think deeply about complex issues, promoting higher-order thinking and enhancing their initiative and depth of learning. To develop students' scientific higher-order thinking, teachers should transform engineering design tasks into structured and logical questions. In the design of the South-to-North Water Diversion Project, teachers can start by guiding students to consider the key factors for efficient water transmission from a macro perspective, then delve into the selection criteria for water transmission technologies under different terrains, and finally encourage students to think about how to optimize these technologies to reduce costs and environmental impact. Through a series of progressive questions, students can apply higher-order thinking skills to complete engineering design tasks.

4.2 Strengthen experimental investigation and group cooperation to verify the design scheme

Experimental inquiry is a crucial method for fostering students' advanced scientific thinking. In engineering design education, using the inverted siphon technology of the South-to-North Water Diversion Project as an example, this teaching approach aims to explore how factors such as water level differences and pipe diameters affect water transmission through design simulation experiments. Students are required to use various types of thinking to propose hypotheses, design procedures, and collect and analyze data. If the collected data does not match expectations, students must critically review and improve their experiments (QIN et al., 2023). This learning method helps students understand engineering principles, enhances their problem-solving skills, and fosters a scientific attitude and advanced thinking. Group cooperative learning is of great significance in engineering design STEM education. In the South-to-North Water Diversion Project, students are divided into groups with clear roles, and through group discussions, they share their ideas (Majolo & Maréchal, 2017). The interaction of different perspectives and disciplines can spark creativity, improve systematic and innovative thinking, and enhance teamwork and communication skills—essential qualities for future engineers.

4.3 Introduce multiple evaluation, and teachers guide to cultivate higher-order thinking

The development of advanced scientific thinking requires timely and effective feedback and evaluation. In engineering design-oriented STEM education, a variety of evaluation methods should be employed, including teacher evaluations, self-assessments, and peer assessments (Li, 2024). For instance, when evaluating a specific phase of the South-to-North Water Diversion Project designed by students, teachers should not only assess the feasibility and innovation of the plan but also focus on the high-level thinking skills demonstrated by students during the design process, such as the depth of problem analysis and the rigor of logical reasoning (Humanities & Social Sciences Communications, 2025). Through self-assessment and peer assessment, students can gain insights into their own and others' work from different perspectives, learn from others' strengths, and identify their weaknesses. For example, during peer assessment, students can evaluate whether their classmates' water conveyance system models have adequately considered various practical engineering factors. Through diverse evaluations, students can continuously reflect on their learning processes and design ideas, adjust their learning strategies in a timely manner, enhance their high-level thinking skills, and promote the continuous development of their engineering design abilities.

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