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Transcending Silos: An Interdisciplinary Project-Based Learning Approach to Science Education

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Abstract: In an era defined by complex, interconnected challenges like climate change, pandemics, and resource depletion, the traditional siloed approach to science education is proving increasingly insufficient. Interdisciplinary project-based learning represents a promising path forward in science education, fostering integrated and holistic learning experiences that move beyond isolated subject learning. Grounded in philosophical ideas of holism, pragmatism, constructivism, and transcendentalism, this article presents a case project illustrating the practical application of interdisciplinary project-based learning. This project engages students in integrating concepts from biology, chemistry, earth science, engineering, and social studies. Through phased activities—research and planning, data collection, implementation, and presentation—students develop a decent understanding of real-world problems while fostering skills in collaboration, problem-solving, and a sense of civic responsibility. Additionally, strategies are proposed to navigate the challenges associated with implementing interdisciplinary project-based learning, including aligning projects with standards, investing in professional development, leveraging community resources, and building support from stakeholders.

Keywords: Interdisciplinary; Project-based learning; Science education; Practical activities; Disciplinary integration

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1. Introduction

The real world is defined by its intricate web of interconnected challenges. From the looming threat of climate change to the pervasive impacts of global pandemics, from the escalating crisis of resource depletion to the persistent inequalities that plague societies worldwide, the problems humanity faces are multifaceted and demand integrated science solutions. However, China's science education in primary and middle schools is not well-positioned to foster students to address those interconnected challenges. For decades, science education in China's primary and middle schools has largely been compartmentalized into discrete subject areas, such as biology, chemistry, physics, and earth science, studied in silos. While each discipline provides valuable knowledge and skills, this disintegration often leaves students struggling to see the connections between them and is increasingly insufficient for preparing students to grapple with the complexity of the real world. Real-world problems rarely fall neatly within the boundaries of a single discipline. For example, fully understanding photosynthesis entails not only knowledge of biology but also an understanding of the underlying chemical reactions in chemistry and the principles of light absorption in physics. As this example informs, addressing real-world problems demands a holistic understanding that integrates perspectives and methodologies from multiple scientific fields. Hence, interdisciplinary science education is not merely a desirable and optional enhancement but a fundamental necessity for equipping the next generation with the knowledge, skills, and ethics needed to navigate and shape a rapidly evolving world. The need for interdisciplinary approaches in science education has been highlighted by numerous educational researchers and policymakers. The National Science Education Standards, for example, emphasize the importance of connecting science to students' lives and fostering an understanding of the interrelationships among different scientific disciplines [1]. Similarly, a practical guide from the American Association for the Advancement of Science (AAAS) advocates for a more interdisciplinary approach to science education [2].

Interdisciplinary science teaching and learning offer a powerful alternative to the siloed approach. By intentionally integrating concepts, methodologies, and perspectives from multiple scientific disciplines, interdisciplinary learning creates a more holistic, relevant, and engaging educational experience. The profound insights will emerge from the synthesis of diverse perspectives. Interdisciplinary learning in science can take various forms. Interdisciplinary project-based learning (ID-PBL) has emerged as one of the promising pedagogical strategies for promoting interdisciplinary learning in science. ID-PBL is a student-centered approach that engages students in extended, inquiry-driven projects focused on addressing real-world problems and challenges or answering complex questions. Through ID-PBL, students develop a deeper understanding of scientific concepts, enhance their problem-solving and critical thinking skills, and learn to collaborate effectively with others. Students work together over an extended period to investigate and respond to questions through in-depth inquiry, research, and creation of a tangible product or presentation. When thoughtfully designed, ID-PBL promotes interdisciplinary learning by requiring students to draw upon knowledge and skills from multiple scientific fields.

In this article, we explore an interdisciplinary project-based approach to science education. In the following sections, we begin by examining the philosophical underpinnings related to interdisciplinary science education. We then present an example that showcases how science educators can design and implement ID-PBL projects in local contexts. Next, we discuss the challenges possibly encountered in ID-PBL implementation. Finally, we conclude by asserting the imperative of embracing an interdisciplinary approach in order to build a more scientifically literate and engaged citizenry in China's primary and middle school science education.

2. The philosophical underpinnings

The rationale for interdisciplinary science education is not merely a pragmatic one, based on the practical benefits it offers. It is also grounded deeply in philosophical principles that transcend the assumptions of traditional siloed science education and offer a compelling vision for a more holistic and integrated approach to learning.

2.1. Holism

Traditional science education in China's primary and middle schools often relies on a reductionist approach, which seeks to understand complex phenomena by breaking them down into their simplest components. While reductionism has been a powerful tool for scientific discovery, it can also lead to a fragmented and incomplete understanding of the world. Interdisciplinary science education transcends reductionism by embracing holism, the philosophical principle of which posits that the whole is greater than the sum of its parts and provides an underpinning for interdisciplinary science education. Holism emphasizes the importance of context in understanding scientific phenomena, arguing that scientific concepts cannot be fully understood in isolation but must be considered in relation to their broader social, environmental, historical, and cultural contexts [3–5]. For example, understanding the science of climate change requires not only reductionist knowledge of atmospheric physics and chemistry but also an understanding of the social, economic, and political factors that contribute to greenhouse gas emissions and the ethical considerations that guide our responses to the crisis. By situating scientific knowledge in a holistic perspective, interdisciplinary education fosters a deeper and broader understanding of the world.

2.2. Pragmatism

Another philosophical underpinning supporting interdisciplinary science education is pragmatism, which views knowledge as a tool for effective action and problem-solving. Pragmatism emphasizes experiential learning, inquiry, and the practical consequences of ideas. The pragmatic tradition, rooted in the works of philosophers like John Dewey [6], aligns well with active, project-based, and inquiry-driven pedagogies characteristic of interdisciplinary education. It encourages students to engage with real-world problems, test ideas through experimentation and reflection, and continuously revise their understanding based on outcomes. Pragmatism advocates for designing learning experiences that are relevant, contextualized, and oriented towards empowering learners to make meaningful contributions to society. This orientation naturally dissolves disciplinary boundaries, as practical problems often require integrating knowledge from multiple fields.

2.3. Constructivism

Constructivism, a dominant learning theory influenced by philosophers such as Jean Piaget, provides a crucial underpinning for interdisciplinary education. Constructivism holds that learners actively construct their own understanding through experience, reflection, and social interaction, rather than passively absorbing facts [7]. In interdisciplinary science education, constructivist approaches emphasize inquiry, collaboration, and the co-creation of knowledge. Students engage in authentic tasks that require synthesizing concepts from multiple domains, such as biology, chemistry, and physics, constructing integrated understandings that are personally meaningful. This learner-centered philosophy supports pedagogies that nurture cognitive flexibility and metacognition—skills essential for interdisciplinary problem-solving and lifelong learning.

2.4. Transcendentalism

The Transcendentalist movement, with key figures such as Ralph Waldo Emerson and Henry David Thoreau [8,9], offers a philosophical vision that resonates deeply with interdisciplinary education. Transcendentalism emphasizes the unity and interconnectedness of all knowledge, the inherent goodness of nature and humanity, and the importance of integrating intellectual, ethical, and spiritual insight. Emerson's call to move beyond narrow specialization to embrace a comprehensive and interconnected view of learning parallels the goals of interdisciplinary science education. Thoreau's integration of scientific observation with philosophical reflection and a profound appreciation for the natural world exemplifies the holistic mindset that interdisciplinary approaches seek to cultivate. Transcendentalism also highlights the ethical dimension of knowledge, encouraging students to consider the moral implications of scientific inquiry and to develop a sense of responsibility as stewards of the environment and society.

3. Interdisciplinary project-based learning

ID-PBL is a pedagogical approach that emphasizes student-led investigation and discovery. It encourages students to ask questions, explore different resources, conduct their own research, and construct their own understandings of complex phenomena. It is particularly well-suited for interdisciplinary science education because it allows students to explore topics from multiple perspectives and to integrate knowledge from different disciplines. A few cases of ID-PBL have demonstrated the potential of this interdisciplinary approach, offering valuable insights and inspiration for science educators seeking to implement interdisciplinary learning in their own contexts [10–13]. These cases serve as beacons, illuminating the path forward and providing concrete examples of how to create engaging and effective interdisciplinary learning experiences.

In this section, we present an example of this approach, which is a project called ‘river restoration’. This project, spanning an entire academic year, brings together concepts from biology, chemistry, earth science, social studies, and engineering to address the complex challenge of restoring a local river ecosystem while fostering civic responsibility. The primary goal was to engage students in restoring a section of the river through scientific inquiry, community collaboration, and hands-on action, thereby developing a deep understanding of ecological systems, environmental chemistry, social dynamics, and practical engineering solutions. The rationale for this project was multifaceted. First, it aimed to break down the traditional disciplinary silos in science education by demonstrating the interconnectedness of scientific and social issues. Second, it sought to make learning relevant by connecting classroom concepts to a tangible, local problem that students could directly impact. Third, it was designed to cultivate essential skills such as critical thinking, problem-solving, collaboration, and communication. Finally, it was intended to instill a sense of civic responsibility and environmental stewardship in students, empowering them to see themselves as agents of change. The project was divided into four distinct phases: research and planning, data collection and analysis, implementation of restoration strategies, and reflection and presentation.

In the first phase, students were introduced to the historical and ecological significance of the local river through a series of interdisciplinary lessons. In biology, they studied river ecosystems, learning about aquatic biodiversity, food webs, and the impact of pollution on native species. In chemistry, they explored water quality parameters such as pH, dissolved oxygen, and nutrient levels, understanding how agricultural runoff and industrial waste contribute to eutrophication and habitat degradation. In earth science, the focus is on rivers’ geological history, watershed dynamics, and the effects of urbanization on erosion and sedimentation. Meanwhile, social studies examined the river’s cultural and economic importance to the local population through document analysis, interviews, and the study of relevant policy decisions. This phase culminated in small student groups formulating research questions and designing a plan to assess the river’s current state, integrating scientific and social perspectives to identify key areas for restoration.

The second phase shifted the focus to hands-on fieldwork and laboratory work. Students visited the river site periodically, working in teams to collect water samples, monitor biodiversity, and assess physical characteristics like streamflow and sediment composition. Biologically, students identified macroinvertebrates as indicators of water quality. Chemically, students analyzed samples in the lab for pollutants such as nitrates and heavy metals. Geologically, students mapped erosion patterns, assessed the riverbank's stability, and visualized data. Sociologically, students conducted surveys and interviews with community members to understand local perceptions of the river and identify stakeholders' views regarding restoration efforts. This phase emphasized collaboration across disciplines, as students shared data and insights to build a comprehensive picture of the river's health and the social context surrounding it. Science teachers facilitated discussions where students synthesized their findings, identifying key challenges such as high nutrient levels, loss of native species, and community distinct views about the restoration.

During the third phase, implementation of restoration strategies, students applied their knowledge to design and execute actionable solutions. Drawing on engineering principles, students collaborated to develop small-scale interventions such as planting native vegetation along the riverbank to reduce erosion, constructing biofilters to improve water quality, and creating fish habitats using natural materials. From a biological perspective, students selected plant species based on their ecological benefits, while from a chemical perspective, they ensured that interventions wouldn't introduce harmful substances into the ecosystem. Applying geological principles, students focused on stabilizing the riverbank, using their erosion data to guide planting and construction efforts. With a sociological approach, students led community outreach, educating residents about the project and soliciting volunteer support for planting days. This phase was particularly impactful, as students saw the direct results of their efforts—plants taking root, water clarity improving slightly, and community members supporting the work—reinforcing the real-world relevance of their learning.

The final phase provided an opportunity for students to evaluate their project's impact and share their findings with a broader audience. Students compiled their data into comprehensive reports, integrating scientific results with social insights to propose long-term restoration strategies for the river. They reflected on their learning through written essays and group discussions, considering questions such as 'How did integrating different disciplines enhance our understanding of the river's challenges?' and 'What responsibilities do we have as community members to sustain this work?' The project culminated in a showcase event at the school, where students presented their findings through posters, multimedia presentations, and live demonstrations of their biofilters and habitats. Local stakeholders provided students with feedback and recognition for their efforts. This phase not only reinforced communication skills but also fostered a sense of agency and ownership in their contributions to the community.

This project exemplifies several key pedagogical strategies that underpin successful interdisciplinary science education. First, it employs agency and interdisciplinarity as its core ideas, allowing students to take ownership of their learning, from formulating research questions to designing solutions and presenting outcomes, ensuring that they see the connections between disciplines and the relevance of their work in an authentic, extended inquiry into a real-world problem. Science teachers acted as facilitators, guiding students through the process while encouraging autonomy and interdisciplinary thinking. Second, the project integrates inquiry and collaborative learning, particularly in the data collection phase, where students posed questions about the river's health and designed methods to answer them. This approach fostered curiosity and scientific reasoning, as students had to navigate uncertainties such as variable water quality data or conflicting community opinions. The inquiry was complemented by collaborative learning, as students worked in teams to share expertise and solve problems collectively, mirroring real-world scientific and social collaboration. Third, the project leverages community partnerships to enhance authenticity and civic impact. Partnering with the local community offered practical insights into designing sustainable interventions. These partnerships not only enriched the curriculum but also broadened their understanding of civic engagement.

A tentative 4-point assessment rubric can be used to evaluate student learning outcomes from the project. The rubric can be organized into key learning areas, each with a specific score, criteria, and description of performance level. It provides differentiation between performance levels and helps teachers recognize student achievements. Student outcomes can be individually scored against the rubric, with scores ranging from 1 to 4 for each learning area. To emphasize certain areas, science teachers could weight them, for example, Interdisciplinary Knowledge Integration (30%), Scientific Inquiry and Data Analysis (25%), Implementation and Problem-Solving (20%), Social and Civic Engagement (15%), and Communication and Reflection (10%). Total scores can be calculated by multiplying each area's score by its weight and summing them. Science teachers can customize criteria based on grade level or specific project variations. Evidence of learning outcomes can be gathered from observations, written reports, presentations, reflective essays, fieldwork notes, group contributions, etc. To promote student growth, teachers can provide specific, constructive feedback alongside scores, highlighting both strengths and areas for improvement in each learning area. Assessment can be conducted at multiple points throughout the project (e.g., after data collection, during implementation, and at the final presentation) to track progress, or as a summative assessment at the project's conclusion. For illustrative purposes, here we only present the two learning areas assessment rubric (**Table 1**).

Table 1. A tentative 4-point assessment rubric for assessing student learning outcomes

Learning Area: Interdisciplinary Knowledge Integration	
Score	**Description**
4 (Excellent)	Students masterfully synthesize all disciplines (biology, chemistry, earth science, social studies, engineering) into a cohesive understanding, innovatively applying insights to propose novel restoration strategies and address real-world complexities.
3 (Good)	Students effectively integrate 3–4 disciplines (e.g., linking chemical analysis of nutrients to earth science erosion patterns and social studies community impacts), with clear application to research questions and solutions.
2 (Fair)	Students identify basic connections between 2–3 disciplines (e.g., biology and chemistry on pollution), but explanations are incomplete or lack depth in applying to restoration planning.
1 (Poor)	Students show little awareness of how disciplines connect; they focus on one area (e.g., only biology) with inaccurate or superficial links to the river ecosystem or social issues.
Learning Area: Scientific Inquiry and Data Analysis	
Score	**Description**
4 (Excellent)	Students design sophisticated research questions; excel in comprehensive data collection and advanced analysis (e.g., statistical trends in nutrient levels), insightfully navigating complexities and contributing original interpretations to group understanding.
3 (Good)	Students formulate focused research questions; conduct thorough data collection (e.g., chemical testing, erosion mapping) and analyze it logically, addressing uncertainties and synthesizing findings across teams.
2 (Fair)	Students develop simple research questions; collect basic data (e.g., some biodiversity monitoring), but analysis is superficial, with limited handling of challenges like conflicting results.
1 (Poor)	Students exhibit vague or absent research questions; data collection is minimal or inaccurate (e.g., incomplete water samples); analysis shows little reasoning or ignores uncertainties like variable data.

The project yielded significant outcomes for students, demonstrating the potential of interdisciplinary science education via ID-PBL. Academically, most students exhibited a good understanding of scientific concepts, as embodied by their ability to explain complex ecological and chemical processes in their reports and presentations. Their ability to integrate knowledge across disciplines was shown in their analyses of the river's health, which considered biological, chemical, geo-physical, and social factors in tandem. Science teachers noted improved critical thinking and problem-solving skills, as students navigated real-world challenges with creativity and resilience. Beyond academics, the project fostered essential skills, as students worked in diverse teams, learning to negotiate differences, delegate tasks, and communicate effectively. Their presentations honed public speaking and multimedia skills, while their outreach efforts developed interpersonal abilities. The hands-on nature of the restoration work instilled a sense of agency, as students saw tangible results from their efforts, such as reduced erosion along the riverbank and increased community awareness of environmental issues, as well as a sense of environmental and civic responsibility.

4. Navigating the challenges

While the benefits of ID-PBL are compelling, implementing this approach effectively can be challenging. Curriculum constraints, standardized testing pressures, teacher training needs, institutional barriers, and resource constraints can all pose obstacles to the wider adoption of interdisciplinary practices. Overcoming these challenges requires careful planning, collaboration, a commitment to ongoing professional development, as well as a willingness to transcend traditional educational norms.

4.1. Curriculum constraints and standardized testing pressures

One of the most significant challenges to implementing ID-PBL is the pressure to cover a large amount of content in a limited amount of time, particularly in the context of standardized testing in China. Many teachers feel constrained by the need to "teach to the test," which can limit their ability to engage in more innovative and interdisciplinary approaches. To address this challenge, science educators can carefully align interdisciplinary projects with existing curriculum standards, ensuring that students are exposed to the required content in a meaningful and engaging way. Assessment strategies can be integrated into the projects themselves, providing students with opportunities to demonstrate their understanding of the content through authentic tasks. It is also crucial to advocate for changes in assessment practices, reducing the emphasis on standardized testing and promoting more holistic and performance-based measures of student learning. This requires a collective effort from teachers, administrators, policymakers, and parents to reimagine the purpose of assessment and to prioritize deeper understanding, sensemaking, and critical thinking over rote memorization.

4.2. Teacher training and professional development

ID-PBL demands that teachers possess expertise in multiple disciplines and be comfortable working collaboratively. Many science teachers in China's primary and middle schools, however, have been trained in specific disciplines and may lack the knowledge and skills needed to effectively integrate different perspectives and methodologies. To deal with this challenge, schools and districts must invest in ongoing teacher training and professional development opportunities focused on interdisciplinary teaching strategies, project-based learning techniques, collaborative planning models, and effective assessment practices. These professional development programs should be designed to empower teachers to become confident and skilled facilitators of interdisciplinary learning experiences. Furthermore, creating dedicated time for teachers to collaborate on curriculum development, project design, and assessment strategies is essential. This allows teachers to share their expertise, learn from each other, and build a strong sense of collective ownership over the interdisciplinary curriculum.

4.3. Resource constraints

Implementing ID-PBL may require additional resources, such as technology, project materials, and access to community partners. However, many schools face significant resource constraints, making it difficult to implement ID-PBL. To solve this challenge, science educators must be creative and resourceful, seeking ways to maximize existing assets and to leverage community resources. This may involve applying for grants, partnering with local organizations, utilizing open educational resources, and engaging volunteers in the learning process. Furthermore, it is essential to prioritize the allocation of resources to support interdisciplinary teaching, recognizing its importance in preparing students for the challenges of the real world. This may involve reallocating funds from traditional programs to support ID-PBL.

4.4. Institutional barriers

Implementing ID-PBL in China often requires overcoming deeply entrenched institutional barriers and resistance to change. Traditional school structures, departmental silos, and rigid curriculum frameworks can all hinder the adoption of more integrated and innovative approaches. To tackle these challenges, it is crucial to build support among administrators, policymakers, and community members by demonstrating the benefits of ID-PBL through pilot projects, data collection, and compelling narratives. Engaging community members in the process of transforming science education can also help to build momentum and to create a shared vision for the future. Starting with small-scale interdisciplinary projects and gradually expanding the scope over time can be a more manageable and sustainable approach than attempting to implement sweeping changes all at once. Celebrating successes and highlighting the positive impact of interdisciplinary learning on student engagement, achievement, and attitudes towards science can also help to build support and to encourage others to get involved. Fostering a culture of collaboration, innovation, and continuous improvement is essential for creating a learning environment that embraces interdisciplinary approaches and empowers teachers and students to thrive.

5. Conclusion

It is recognized that the world is complex, interconnected, and constantly evolving, and that our understanding of it must be equally dynamic and integrated. ID-PBL offers a transcendental approach to siloed science education and prepares students to understand the complexity and challenges of the real world. By transcending disciplinary silos and embracing real-world problems, ID-PBL creates a science education that is truly interdisciplinary and authentic and enables a more holistic, engaging, and relevant learning experience which equips students with the knowledge, skills, and ethics needed to navigate the complexities of the real world and empowers students to become critical thinkers, problem-solvers, and collaborators—the very skills needed to thrive in an increasingly interconnected world. ID-PBL is not simply a pedagogical trend; it is a shift in how we understand and approach learning, teaching, and the very purpose of science education itself. Science teachers shall embrace this approach and must understand it is not just a pedagogical choice, but a crucial step towards building a more scientifically literate and engaged citizenry.

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Disclosure statement

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