

Interdisciplinary Teaching in the American Next Generation Science Standards: Research Findings and Implications for China

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Abstract: The Next Generation Science Standards (NGSS) represent a significant reform in American science education. These standards emphasize the deep integration of scientific practices, conceptual understanding, and systems thinking, aiming to cultivate comprehensive scientific literacy among students. This initiative offers valuable insights for global science education reform. This paper, through an analysis of the theoretical foundations, implementation strategies, and positive impacts of interdisciplinary teaching in NGSS, reveals that such an approach can effectively enhance students' critical thinking, creativity, and problem-solving skills. Consequently, the implementation of interdisciplinary teaching in China's science education should focus on the integration of interdisciplinary curricula, student-centered learning methods, an emphasis on practical and inquiry-based learning, transformation in the role of teachers, and the application of diverse assessment methods.

Keywords: Next Generation Science Standards, Interdisciplinary Teaching, Educational Reform, Science Education, Creativity

1. Introduction

Since its introduction in 2013, the implementation of the Next Generation Science Standards (NGSS) in the United States has marked a fundamental shift in the field of science education, prompting a profound reevaluation of traditional teaching methods worldwide [1]. The interdisciplinary teaching approach advocated by the NGSS, along with its emphasis on scientific practices, has had a significant impact on international education and is widely regarded as an innovative practice in science education. These standards have not only redefined the content and methods of science education but have also inspired educators to explore new ways of teaching science, particularly in integrating disciplines and encouraging students to use multidisciplinary knowledge to solve complex problems [2, 3].

Current trends in the field indicate that interdisciplinary teaching is becoming a key direction in educational reform [4]. Numerous scholars have pointed out that this approach not only breaks down traditional boundaries between disciplines but also fosters the comprehensive development of students in areas such as critical thinking, creativity, and problem-solving skills [5]. However, despite the widespread attention that the concept and practice of interdisciplinary teaching have received globally, several areas require further exploration. These include effectively integrating knowledge and methods from different disciplines, assessing its impact on student learning outcomes, and incorporating these principles and practices into the educational systems of different countries and cultures. The United States has accumulated valuable experience and achieved notable success in the development of interdisciplinary teaching within the framework of the NGSS. These experiences and outcomes are crucial for global science education and have particular relevance for science education in China. They not only introduce new educational concepts but also present new perspectives and challenges for the reform of science education in China [6].

2. The Development and Main Objectives of NGSS

The release of the Next Generation Science Standards (NGSS) represents a proactive response to the

challenges of 21st-century science education. Aimed at providing all students with a science education that meets international standards, NGSS integrates three core dimensions of science education to establish a new set of educational standards. The development of NGSS began in 2010, spearheaded by a collaboration of 26 states and key organizations including the National Science Teachers Association, the American Association for the Advancement of Science, the National Research Council, and the nonprofit organization Achieve. The foundational document for NGSS, the "Framework for K-12 Science Education," was published by the National Research Council in 2012. This framework introduced the three core dimensions that underpin NGSS: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. These dimensions form the basis of NGSS, which was developed with input from experts across education, science, engineering, and policy, and was subjected to public review before the final draft was released in April 2013.

The NGSS provides a comprehensive educational framework designed to enhance students' understanding and application of scientific principles. It consists of three main components: Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEPs), and Crosscutting Concepts (CCCs). Together, these components aim to cultivate students' integrated thinking and problem-solving abilities. DCIs cover fundamental theories in life sciences, Earth and space sciences, physical sciences, and engineering and technology. SEPs promote scientific inquiry and thinking through activities like questioning, experimental design, and data analysis. CCCs guide students to understand universal concepts across disciplines, such as causality and systems modeling. The standards encourage teachers to use an integrated teaching approach, allowing students to deeply understand complex phenomena and apply this knowledge to real-world problems. For example, studying climate change within the context of Earth science, physics, and biology enables a holistic understanding and application.

The main objective of NGSS is to improve students' understanding and interest in science, preparing them to work and learn more effectively in the fields of science, technology, engineering, and mathematics (STEM). By integrating content knowledge with practical skills, NGSS fosters innovative thinking and problem-solving abilities in students. The standards emphasize the close connection between science education and real-world applications, aiming to help students understand the role of science in daily life and its impact on societal and technological advancements. NGSS encourages the combination of science learning with social and environmental issues, prompting students to understand and address real-world challenges through scientific inquiry. For instance, second-grade students learn about Earth's surface features, differences between Earth and other planets, and various aspects of life sciences. As they progress, students explore motion and reactions, studying how energy is transferred not only through organisms, food chains, and food webs but also through inanimate objects and physical systems. By the end of the school year, students can construct circuits, balance boats, and design houses, transitioning from acquiring scientific knowledge and skills to solving problems as engineers ^[7, 8].

3. Implementation of Interdisciplinary Teaching in NGSS

(1) Case Overview

The selected case involves a comprehensive learning project aimed at helping students understand and integrate knowledge from multiple disciplines, including biology, geography, chemistry, and political science, through the exploration of the complex issue of climate change. This case serves as a concrete example of how interdisciplinary teaching is implemented within the framework of the Next Generation Science Standards (NGSS) in the United States.

(2) Project Theme and Objectives

Theme: An in-depth study of climate change and its impact on biodiversity.

Learning Objectives: The project aims for students not only to acquire scientific knowledge about climate change but also to understand its socio-political implications and explore possible actions to mitigate its negative effects.

(3) Integration of Curriculum Content

Biology: Examining the effects of climate change on ecosystems and biodiversity.

Chemistry: Understanding the chemical properties of greenhouse gases and how they contribute to global warming.

Geography: Studying the impact of climate change on different geographical regions.

Political Science: Analyzing the policies and stances of various countries and organizations in response to climate change.

(4) Teaching Methods and Activities

Inquiry-Based Learning: Students engage in group research, experiments, and data analysis to explore the scientific principles and societal impacts of climate change.

Project-Based Learning: Students work in groups to investigate specific topics related to climate change, such as the chemical processes behind greenhouse gas emissions or the impact on specific ecosystems.

Community Engagement: Students are encouraged to participate in community activities to raise public awareness and understanding of climate change.

Interdisciplinary Collaboration: Through group discussions and presentations, students exchange ideas and are encouraged to analyze problems from multiple disciplinary perspectives.

(5) Implementation Steps

Problem Definition and Exploration: Initially, guided by teachers, students define specific topics to explore, such as the impact of climate change on biodiversity. This phase mainly involves foundational knowledge from biology and geography.

Data Collection and Analysis: Students then collect relevant data, such as global temperature changes and species distribution, and use chemical principles to understand changes in atmospheric greenhouse gases. This stage integrates methods and knowledge from biology, geography, and chemistry.

Policy Understanding and Discussion: Subsequently, students study how different countries address climate change through policies, requiring them to understand basic political science principles and practices. Students learn to analyze policies and comprehend their environmental and social impacts.

Integrated Application and Presentation: Finally, students design an interdisciplinary solution based on their research, such as a plan to reduce greenhouse gas emissions. This requires them to synthesize knowledge from various disciplines and present their solutions to the class.

This case study provides insight into the specific implementation details of interdisciplinary teaching within the NGSS framework. This teaching approach not only enhances students' understanding of scientific principles but also promotes deeper consideration of societal issues, increasing their ability to apply knowledge from different disciplines to solve real-world problems. Interdisciplinary teaching has proven to be an effective way to achieve the integrated thinking and innovation skills advocated by NGSS. To further understand how the concept of interdisciplinary teaching within the NGSS is supported and promoted in actual policies and educational documents, Table 1 summarizes relevant policies and documents issued since 2001. These documents clearly articulate the importance of interdisciplinary teaching and demonstrate its growing influence across the educational system.

Table 1: Summary of U.S. Policies and Documents Related to Interdisciplinary Teaching.

Year	Issuer	U.S. Education Policy and Document	Statements on Interdisciplinary Teaching
2001	George W. Bush	No Child Left Behind Act (NCLB)	Emphasizes the importance of foundational subjects, indirectly promoting the exploration of interdisciplinary connections and integrated scientific skills
2010	National Governors Association and the Council of Chief State School Officers	Common Core State Standards	Indirectly supports interdisciplinary teaching through skills in reading comprehension, data analysis, and evidence use
2011	National Academy of Sciences, National Academy of Engineering, National Academy of Medicine, and National Research Council	Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas	Emphasizes crosscutting concepts and approaches to help students see connections between different scientific fields, promoting integrated understanding

2013	National Science Teachers Association and National Research Council	Next Generation Science Standards (NGSS)	Includes multidisciplinary content, emphasizes connections between science, technology, engineering, and mathematics, aiming to promote understanding and application through interdisciplinary learning
2015	Barack Obama	Every Student Succeeds Act (ESSA)	Encourages the implementation of more comprehensive learning approaches, including enhanced STEM education and promotion of interdisciplinary learning programs
2016	U.S. Department of Education	STEM 2026 Vision Report	Highlights the importance of interdisciplinary teaching, advocating for the integration of science, technology, engineering, and mathematics education to promote holistic student development
2017	U.S. Department of Education	National Education Technology Plan	Utilizes digital tools and resources to create richer, interdisciplinary learning environments, encouraging project-based learning, collaborative learning, and problem-solving activities
2018	Committee on STEM Education of the National Science & Technology Council	2018-2023 STEM Education Strategic Plan	Emphasizes the importance of interdisciplinary learning, advocating for hands-on learning projects and solving real-world problems to integrate science, technology, engineering, and mathematics education, thus fostering students' innovation and problem-solving skills

4. Core Elements of Interdisciplinary Teaching

Through the analysis of specific cases, it is evident that the success of interdisciplinary teaching hinges on effective curriculum design and the professional development of teachers. These factors significantly influence student learning outcomes, particularly in enhancing critical thinking and problem-solving abilities.

(1) Interdisciplinary Knowledge and Skills

Teachers need to acquire the knowledge and skills necessary for interdisciplinary teaching. This includes understanding fundamental concepts across different disciplines, the ability to integrate these concepts, and the skills to design and implement interdisciplinary learning activities. For instance, the "Climate Change and Sustainable Agriculture Project" illustrates how interdisciplinary teaching can deepen students' understanding of scientific concepts. In this case, teachers must possess knowledge in environmental science, biology, geography, and economics, and be capable of applying this knowledge to real-world problem-solving.

(2) Teaching Methods and Strategies

Teachers must be proficient in employing new teaching methods and strategies, such as project-based learning, inquiry-based learning, and cooperative learning, to help students make connections across disciplines^[9]. For example, in the "Urban Sustainability Program," teachers use these methods to help students apply knowledge from various disciplines, thereby enhancing their subject knowledge, critical thinking, and teamwork skills. These methods encourage students to engage actively with the content, ask questions, conduct investigations, and collaborate with peers, leading to a deeper understanding and retention of interdisciplinary knowledge.

(3) Assessment Skills

Teachers need to be adept at designing and implementing tools and methods to assess students' interdisciplinary learning. The "Environmental Change and Social Impact Project" requires teachers to use a variety of tools and methods, such as comprehensive project portfolios, reflective journals or learning logs, oral presentations, and group discussions, to evaluate students' performance in interdisciplinary learning comprehensively. These assessment methods provide a more holistic view of student progress and understanding, beyond traditional testing, by capturing a range of skills and knowledge applications.

(4) Continuous Learning and Professional Growth

Ongoing professional development is crucial for teachers to continually enhance their knowledge and skills. Participation in workshops, online courses, and peer learning groups is essential for keeping abreast of new developments in educational technology and interdisciplinary teaching. The "Education Technology and Innovation in the Digital Age" program, for instance, highlights how teachers improve their expertise in educational technology and interdisciplinary teaching through such professional development activities. These opportunities enable teachers to learn about the latest tools and techniques, share best practices, and collaborate with colleagues, fostering a culture of continuous improvement and innovation in teaching practices.

5. Outcomes and Impact Assessment of Interdisciplinary Teaching

5.1. Learning Outcomes

Interdisciplinary teaching, as implemented under the NGSS framework in the United States, aims to enhance students' overall learning outcomes ^[10]. This approach has significantly improved student performance in several key areas:

(1) **Scientific Understanding:** Interdisciplinary learning enables students to gain a deeper understanding of scientific concepts by exploring them within the context of multiple disciplines. For instance, in the "Energy Transformation and Climate Change Project," students explored the impact of energy transformation on climate change, integrating knowledge from physics, chemistry, environmental science, and economics. This comprehensive approach allows students to understand the fundamental concepts of energy transformation and its environmental and economic implications from multiple perspectives.

(2) **Critical Thinking Skills:** Through interdisciplinary learning, students are encouraged to examine issues from various angles, thereby enhancing their critical thinking skills. For example, in the "Urban Planning and Sustainable Development Challenge," students analyzed the complexities of urban development by integrating perspectives from urban planning, environmental science, sociology, economics, and political science. This multidimensional analysis fosters their ability to think critically about complex issues.

(3) **Problem-Solving Skills:** Interdisciplinary projects require students to apply knowledge and skills from different disciplines to solve problems, thereby improving their comprehensive problem-solving abilities. In the "Global Water Resources Crisis Project," students utilized knowledge from environmental science, geography, economics, and political science to address global water resource issues. This interdisciplinary application strengthens their ability to analyze and innovate in addressing real-world problems.

(4) **Innovation Capability:** Interdisciplinary learning encourages innovative thinking as students explore new ways to connect knowledge from different fields. In the "Smart City Design Challenge" project, students combined engineering, environmental science, information technology, and sociology to design innovative solutions for smart cities. This fusion of disciplines enhances their creativity and innovation skills.

(5) **Collaboration Skills:** Working on interdisciplinary projects often requires students to collaborate with peers, which helps improve their teamwork and social skills. For instance, in the "Climate Change Response Plan" project, students worked in teams, integrating perspectives from environmental science, political science, economics, and public administration to develop strategies for addressing climate change. This teamwork enhances their ability to communicate, coordinate, and collaboratively solve problems.

5.2. Impact Assessment

The evaluation of student outcomes in interdisciplinary teaching under the NGSS goes beyond traditional exams and quizzes, adopting a multifaceted approach to comprehensively assess students' understanding and application of interdisciplinary knowledge ^[11].

(1) **Comprehensive Assessment:** This method emphasizes overall student learning outcomes through various forms, such as project reports, oral presentations, and portfolios. For example, students might be required to complete a comprehensive research project that covers environmental science and sociology, presenting their findings and solutions through oral presentations. Such comprehensive assessments not only measure students' grasp of interdisciplinary concepts but also evaluate their problem-solving abilities, reflecting their innovative thinking, information integration skills, and communication capabilities.

(2) **Reflective Assessment:** This approach encourages students to engage in self-reflection, serving as a crucial means of evaluating their experiences, challenges, and growth in interdisciplinary learning. Through journals, learning logs, or reflective reports, students can reflect on their learning experiences, including the challenges they faced, the strategies they employed to solve problems, and how they integrated knowledge from different disciplines. This form of assessment helps teachers gain insights into students' learning processes while promoting students' self-awareness and lifelong learning skills.

(3) **Peer Assessment:** As an interactive and reciprocal assessment method, peer assessment enriches the evaluation process. In this model, students are not only participants in learning but also assessors. Through peer evaluations, students receive diverse feedback from their peers, which not only deepens their understanding of the content but also enhances their critical thinking and communication skills. For instance, in group research projects, members can evaluate each other's contributions and performance, providing constructive feedback and fostering team learning and development.

(4) **Teacher Observation:** Teacher observation is another critical component in assessing the effectiveness of interdisciplinary learning. By closely observing students' participation, interaction, and learning dynamics during classroom discussions, group collaborations, and experimental activities, teachers can more accurately assess students' engagement levels, social interactions, problem-solving abilities, and displays of innovative thinking. This observation extends beyond academic performance to include social skills and leadership potential, which can be evaluated through students' communication styles and teamwork during group activities.

In summary, interdisciplinary teaching under the NGSS framework not only enhances students' academic abilities but also develops a wide range of critical life skills. These outcomes are achieved through a well-rounded approach that includes effective curriculum design, innovative teaching methods, diverse assessment strategies, and continuous professional development for teachers. This comprehensive educational model provides a robust foundation for students to navigate and contribute meaningfully to an increasingly complex and interconnected world.

6. Implications for Enhancing Science Education in China

The comprehensive analysis of the NGSS provides valuable insights into the theoretical underpinnings of interdisciplinary teaching. For China, understanding these foundational theories is crucial, but the key challenge lies in applying these theories to practical teaching contexts. Chinese educators can draw lessons from the interdisciplinary teaching models advocated by NGSS to develop educational programs that enhance students' overall scientific literacy and problem-solving abilities.

(1) Integration of Interdisciplinary Curricula

NGSS emphasizes the interconnectedness of science, technology, engineering, and mathematics (STEM) disciplines, advocating for an integrated approach to enrich and deepen students' learning experiences. For instance, in a course on climate change, students not only learn the fundamental concepts of climate science but also employ methods from technology, engineering, and mathematics to analyze and solve problems. Through experiments, group discussions, and practical projects, this curriculum design encourages students to apply and synthesize knowledge across various disciplines, fostering integrated thinking and problem-solving skills. For the Chinese education system, this implies a need to create environments that facilitate the integration of these disciplines, allowing students to apply knowledge and skills from multiple subjects within a single project. Such integration helps students better understand the real-world applications and significance of scientific knowledge.

(2) Student-Centered Learning Approaches

NGSS promotes student-centered learning approaches that encourage students to actively explore and engage in the learning process. For example, in an ecosystem inquiry project, students independently conduct research, collect and analyze data, with teachers acting as facilitators and guides. In renewable energy exploration activities, students independently investigate and evaluate, making decisions while teachers provide necessary support and feedback. These activities not only promote active learning and inquiry but also strengthen critical thinking and problem-solving abilities. For China, this suggests a shift from teacher-centered to student-centered teaching models, emphasizing active student engagement and exploration. This could involve methods such as group collaboration, project-based learning, or problem-based learning, where students delve deeply into scientific concepts. Encouraging students to engage in hands-on activities and research allows them to not only acquire scientific knowledge but also develop the skills needed to address real-world challenges, which are crucial for their future education and careers.

(3) Emphasis on Practical and Inquiry-Based Learning

NGSS encourages learning through practical activities, allowing students to actively participate in and experience scientific processes. For example, in a river ecosystem study, students explore environmental impacts through fieldwork, and in a solar vehicle design challenge, they learn about energy transformation and engineering design by building and testing models. These activities not only foster active exploration but also deepen students' understanding of scientific principles and develop their innovation and problem-solving skills. For China, this highlights the need to provide more opportunities for experiments and hands-on activities, allowing students to learn scientific principles through practical experience. This approach encourages students to pose questions, conduct experiments, and seek answers independently, cultivating a spirit of scientific inquiry and innovation. Practical activities encourage students to think critically, analyze data, and evaluate results, skills that are crucial for their academic and professional development.

(4) Transformation of the Teacher's Role

In the NGSS framework, the teacher's role shifts from a traditional knowledge transmitter to a facilitator and coordinator of learning. For example, in implementing project-based learning, teachers design courses that allow students to conduct independent research and design while providing necessary guidance and resources. In inquiry-based science experiments, teachers guide students in understanding experimental design and pose questions to stimulate thinking, while also coordinating teamwork. This transformation highlights the critical role of teachers in promoting student-centered learning and interdisciplinary understanding. For China, this suggests the need to enhance teacher professional development and training to adapt to this role change, helping them master new teaching methods and interdisciplinary knowledge to better guide and inspire student learning. Strengthening teacher training helps them transition from traditional lecturers to facilitators and coordinators of learning. Developing specialized professional development courses and workshops can help teachers master interdisciplinary teaching methods and practice-oriented learning strategies. Encouraging closer interactions between teachers and students can foster a more engaging and supportive learning environment, promoting independent learning and inquiry among students.

(5) Application of Diverse Assessment Methods

NGSS advocates for the use of various assessment methods, including project reports, oral presentations, and reflective assessments. For instance, in an oral presentation on climate change research, assessment focuses not only on the understanding of climate change knowledge but also on students' communication skills and teamwork abilities. In reflective assessments through scientific experiment logs, teachers focus not only on the correctness of experimental results but also on students' analysis of data and reflections on the experimental process. These diverse assessment methods provide a more comprehensive evaluation of students' learning outcomes and overall skills. For China, this suggests a shift beyond traditional pen-and-paper exams to develop more varied assessment methods, providing a more holistic evaluation of students' comprehensive abilities and innovative thinking. Encouraging the use of diverse assessment methods allows for a broader evaluation of students' capabilities, beyond mere memorization and recall. Through these assessment approaches, students are encouraged to develop critical thinking, innovation, and effective communication skills, all of which are essential competencies for the 21st century.

In conclusion, the NGSS framework offers a comprehensive model for interdisciplinary education that can significantly enhance science education in China. By integrating STEM curricula, adopting student-centered learning approaches, emphasizing practical and inquiry-based learning, redefining the

teacher's role, and employing diverse assessment methods, China can foster a more holistic and effective science education system that equips students with the skills and knowledge needed to thrive in a complex, interconnected world.

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References

- [1] Wang, B., Feng, Y. *Analysis of the Next Generation Science Standards in the United States*[J]. *Journal of Chinese Education*, 2015(04): 96-100.
- [2] Calmer, J. M. *Teaching Physics within a Next Generation Science Standards Perspective*[J]. *Pedagogical Research*, 2019, 4(4): em0041.
- [3] Hapsari, L., Rosana, D. *Adapting Next Generation Science Standard to Improve Using Mathematics–Computational Thinking in Science Learning*[C]//6th International Conference on Educational Research and Innovation (ICERI 2018). Atlantis Press, 2019: 121-125.
- [4] Yang, W., Xu, Q. *Integrating "Big Concepts" in STEAM Interdisciplinary Research: Model Construction and Practical Cases*[J]. *Journal of Distance Education*, 2021, 39(02): 103-112.
- [5] Chen, P. *Deconstruction and Reconstruction: Innovation Ideas and Practical Exploration of Interdisciplinary Course Teaching under the Perspective of "New Liberal Arts"*[J]. *Heilongjiang Research on Higher Education*, 2023, 41(01): 156-160.
- [6] Hoeg, D. G., Bencze, J. L. *Values Underpinning STEM Education in the USA: An Analysis of the Next Generation Science Standards*[J]. *Science Education*, 2017, 101(2): 278-301.
- [7] Comfort, K. B., Timms, M. *A Twenty-First Century Skills Lens on the Common Core State Standards and the Next Generation Science Standards*[J]. *Assessment and Teaching of 21st Century Skills: Research and Applications*, 2018: 131-144.
- [8] Kuhn, M. *Encouraging Teachers to WAIT Before Engaging Students in Next Generation Science Standards STEAM Activities*[J]. *The STEAM Journal*, 2015, 2(1): 15.
- [9] Harris, K., Sithole, A., Kibirige, J., McCarthy, P. *The Next Generation Science Standards and the Quest Towards Culturally Responsive Pedagogy: Perceptions of K-12 Educators*[J]. *American Academic Scientific Research Journal for Engineering, Technology, and Sciences*, 2018, 49(1): 192-208.
- [10] Caylor, K. *The Next Generation Science Standards: Saving K-12 Science Education*[J]. *WWU Honors College Senior Projects*, 2019, 302.
- [11] Roseman, J. E., Fortus, D., Krajcik, J., et al. *Curriculum Materials for Next Generation Science Standards: What the Science Education Research Community Can Do*[C]//NARST Annual International Conference, Chicago, IL. 2015.