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Citizen science projects: an effective approach for cultivating the core chemistry literacy of middle school students

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Abstract. In recent years, citizen science has become an important way for the public to engage in scientific inquiry in Europe and North America. It has gradually evolved into school-based citizen science projects that integrate with school education. Currently, citizen science projects in China are still in their early stages, mainly focused on fields such as ecology and astronomy, with very few citizen science projects in the field of chemistry. In the existing citizen science projects in China, public participation is still at the early stage of simple data collection, with little integration with school education. This paper explores the important role of citizen science in enhancing middle school students' core chemistry literacy and aims to provide a platform for students to participate in scientific inquiry through citizen science projects, with the goal of offering a new approach to cultivating core chemistry literacy in middle school students.

Keywords: citizen science, school citizen science, core chemistry literacy

1. Introduction

Citizen science, as an emerging form of scientific practice, shifts the role of the public from passive recipients of scientific knowledge to active participants in scientific research. By involving the public in real scientific studies, it strengthens the connection between science and society. In school education, citizen science projects offer students a platform to apply scientific knowledge and skills. These projects not only promote students' understanding of knowledge and enhance their practical skills but also increase their understanding of and interest in scientific careers through collaboration with scientists, thereby cultivating students' scientific attitudes and values. Given the potential of citizen science to improve scientific literacy, it is particularly important to explore its application in middle school chemistry education, as chemistry is a critical component of the scientific field. This study aims to investigate how citizen science can serve as a tool to promote the development of middle school students' core chemistry literacy.

2. Overview of citizen science

2.1. Origins and definition of citizen science

The concept of citizen science originated in the late 1980s and was first mentioned in the 1989 edition of MIT Technology Review, particularly in the context of describing the Audubon Society's acid rain project [1]. This project recruited volunteers to participate in scientific research, not only demonstrating how the public could engage in the collection of scientific data but also illustrating how such data could be used to drive policy changes and social action. The project highlighted the potential and value of public involvement in scientific research. This historical example marked the important role of citizen science in both scientific research and social action, laying the groundwork for subsequent citizen science projects worldwide.

Therefore, citizen science, in a broad sense, refers to the active participation of the public in scientific research tasks. It is a form of research collaboration that allows the public to engage in scientific studies aimed at solving real-world problems, with scientists and citizens working together to create new knowledge for both science and society. In recent years, citizen science has gained attention for its potential to strengthen the relationship between science and society. Through citizen science projects, public scientific literacy has been improved, the boundaries of scientific research have been expanded, and scientists have been able to obtain more data necessary for their studies, thus driving the development of scientific research [2].

2.2. Key features of the implementation of citizen science

In the early stages of citizen science development, scientists and the public formed the cornerstone of project implementation. Scientists played the role of planners and mentors, while the public acted as participants, allowing the projects to reach wider geographic areas and engage with a more diverse range of phenomena, enriching the content and depth of the research. However, due to the lack of research experience among the public, simple participation often led to poor data quality, posing challenges to the accuracy and reliability of scientific research. As scientists' pursuit of precise data grew and the public's desire to engage in scientific research and knowledge acquisition increased, the participation model of citizen science gradually evolved. This change is reflected in the diversification of collaboration methods. Based on the degree of public involvement, Hakla categorized these collaborative methods into several levels: crowdsourcing, cognitive crowdsourcing, participatory science, and extreme citizen science [3].

"Crowdsourcing" is the most basic form of participation in citizen science, typically involving simple data collection tasks. Although participants are willing to engage in scientific projects, their cognitive potential is not fully utilized. This limits their growth and development within citizen science projects. Due to the lack of deep engagement and professional guidance, participants often struggle to provide precise and reliable data, which poses a challenge to the accuracy and validity of scientific research. In contrast, under the "cognitive crowdsourcing" model, scientists provide training materials, requiring participants to complete basic training. This not only increases their contribution to the project but also enhances their personal capabilities. However, the public's involvement still remains relatively superficial, mainly performing tasks assigned by scientists without deeply understanding the significance and goals of the project. In the "participatory science" model, participants not only engage in data collection but also collaborate with scientists to define research questions and design data collection methods. Although expert involvement is still required for data analysis and interpretation, this model enables participants to engage more deeply in scientific research. "Extreme citizen science" involves participants and scientists jointly deciding on the research direction and possibly participating in the entire process from data collection to analysis and publication. In this model, scientists play a dual role as both experts and facilitators.

2.3. Current development of citizen science

"Public Science" projects have proven to be highly effective in practice. Not only have they positively impacted scientific research and public scientific literacy, but these projects also tend to focus on fields such as the environment, air, and water resources, enabling governments to efficiently address local environmental issues at low costs. In this model, the public contributes through labor, while scientists provide technical support. Governments can act as coordinators and communicators, driving the development of "public science," saving resources, enhancing public environmental awareness, and promoting scientific popularization and social progress. As a result, in the 21st century, governments in Europe and North America have increasingly paid attention to the development of "citizen science." The European Commission established the European Citizen Science Association (ECSA) to provide large-scale support for public participation in science across Europe. Approximately €234 million was invested in the "Horizon 2020" program, launching the Citizen Science online platform (EU-Citizen.Science), which offers knowledge, tools, and training courses related to citizen science for participants, practitioners, researchers, and policymakers across Europe [4]. In terms of policy, the launch of the White Paper on Citizen Science for Europe provided significant reference and policy support for the development of citizen science projects [5].

The U.S. federal government has provided legal support for the development of citizen science. In 2016, the U.S. Congress passed the Crowdsourcing and Citizen Science Act, which defined citizen science and encouraged federal agencies to utilize citizen science in research. As of December 2024, the citizen science service platform SciStarter, supported by the National Science Foundation (NSF), has recorded over 3,000 citizen science projects, both formal and informal. The U.S. citizen science website (citizenscience.gov) lists 503 ongoing projects that have been verified by federal employees, covering 31 fields such as birds, climate, and chemistry, with funding and personnel support from over 30 institutions including NASA, NOAA, EPA, and USDA. Volunteer participation is open globally, or specific to the U.S. or certain U.S. regions, depending on the project. In the development of citizen science, the world's largest citizen science platform—Zooniverse—has also emerged. Since its launch in 2007, Zooniverse has expanded across fields including art, biology, language, weather, medicine, nature, physics, and astronomy, with nearly 2.8 million registered volunteers. It connects professional researchers with global volunteers, having completed over 850 million different tasks.

With government funding support and policy promotion, citizen science has gradually evolved from a "crowdsourcing" model to one involving deeper public participation. The high-quality and diverse data contributed by the public, after professional training, has greatly expanded the scope of scientific research and changed many scientists' previous views that science popularization would take up research time. At the same time, this approach has encouraged the public to actively explore rather than merely accept scientific knowledge, giving rise to a new incentive model for public participation in scientific research. "Public science" projects have also enhanced the scientific cultural atmosphere of society, promoting the democratization of science. They allow the public to participate in the creation and dissemination of scientific knowledge, deepen their understanding of science, and build a scientific atmosphere. Public participation has also increased trust in science and laid the foundation for public involvement in science policy-making. In short, through public participation, public science projects have not only promoted the dissemination of

scientific knowledge but also strengthened the democratic nature of scientific decision-making. Overall, citizen science projects, led by scientists and involving the general public in actual research activities, have gradually formed a strong trend in Europe and North America [6].

2.4. Exploration of citizen science in China

Citizen science projects in China are still in their early stages. In fields such as ecology and astronomy, some Chinese scientists have begun exploring this new approach that combines science popularization with scientific research. In ecology, Chinese scientists have made significant achievements in various research areas by utilizing citizen science data, including bird community structure [7], waterfowl habitat conservation [8], species protection [9], wildlife distribution patterns [10], birds' response to urbanization [11], and urban bird diversity [12]. The Public Supernova Search Project (PSP), launched by Xingming Observatory in collaboration with the China Virtual Observatory, is the largest astronomical citizen science project in China, having attracted more than 20,000 participants since 2015 [13]. However, compared to the more comprehensive policies and funding support in other countries, citizen science projects in China are still in the "crowdsourcing" stage, lacking systematic participation from research institutions and stable funding guarantees.

3. Citizen science and the development of scientific literacy

Citizen science projects play a significant role in enhancing public scientific literacy. By providing opportunities for active participation in scientific research, these projects promote the development of participants' abilities across several key dimensions. These initiatives allow participants to directly experience and apply scientific concepts, thereby deepening their understanding of scientific knowledge. In terms of scientific processes and methods, participants engage in real-world data collection and analysis activities, which allows them to practice scientific inquiry firsthand and improve their understanding of the scientific research process. In regard to scientific attitudes and values, citizen science projects address real-world issues such as the greenhouse effect and environmental pollution, which enhances participants' recognition of the value of science. Moreover, citizen science projects often involve communication between scientists and the public. Many citizen science networks and platforms have opened pathways for collaboration, thereby helping participants develop their scientific communication skills. In the areas of scientific thinking and problem-solving, participants are often faced with complex scientific questions. During their involvement, they frequently need to employ critical thinking and logical reasoning to analyze data, which significantly enhances their ability to solve problems. At the same time, by addressing practical problems, participants gain a tangible understanding of how scientific discoveries and technological advancements affect individuals and society, thus deepening their comprehension of the impact of science and technology. This also promotes public participation in scientific decision-making and fosters greater civic engagement. These projects encourage participants to continue learning new knowledge and adapt to changes in science and technology, cultivating habits of lifelong learning. Overall, citizen science projects, through public involvement in scientific initiatives, lay a solid foundation for the public's understanding of science, participation in scientific decision-making, and commitment to lifelong learning, effectively enhancing public scientific literacy.

4. Citizen science and the development of core chemistry literacy in students

Citizen science projects often focus on fields such as environmental protection, atmospheric studies, and water resources. Knowledge of chemistry plays a crucial role in explaining and addressing environmental issues. Furthermore, chemistry often serves as a useful tool in citizen science projects, acting as a bridge that enhances the interdisciplinary nature of these initiatives [14]. Developing citizen science projects centered on chemistry can provide students with a learning platform that is distinct from traditional classroom teaching. Students can apply chemical knowledge in real-world scientific research, and this mode of learning not only strengthens their understanding of chemical principles but also cultivates their critical thinking and problem-solving skills through active participation in scientific inquiry. Especially in comparison with traditional classroom teaching, participation in citizen science projects has clear advantages in developing students' core chemistry literacy, including evidence reasoning and model cognition, scientific inquiry and innovation awareness, as well as scientific attitudes and social responsibility.

4.1. The role of citizen science projects in the development of evidence reasoning and model cognition

A citizen science project in the United States called the "Youth Forest Monitoring Program" provides a clear example. In this project, students monitor soil and water pH levels, collect data, and formulate hypotheses about forest health and ecological balance. In a water quality monitoring project, students track water quality and analyze changes in data, reasoning and verifying the causes of pollution, thereby establishing logical connections between viewpoints, evidence, and conclusions [14]. These practical activities not only deepen students' understanding of chemical concepts but also improve their ability to apply theoretical knowledge to solve real-world problems, highlighting the significant educational value of citizen science projects. By participating in these projects, students directly collect and analyze data, form evidence-based hypotheses, and use logical reasoning to confirm

or refute these hypotheses, all of which contribute to the development of their core chemistry literacy in evidence reasoning and model cognition.

4.2. The role of citizen science projects in the development of scientific inquiry and innovation awareness

Citizen science projects also play an important role in fostering scientific inquiry and innovation awareness in students. Citizen science, by nature, is a scientific inquiry activity that involves collaboration between scientists and the public, aimed at solving real-world problems and creating new knowledge for both science and society. In a school science project in Portugal centered on chemistry for secondary school students, teachers commonly reported in interviews that students who participated in the project showed significant improvements in debate, reflection, and critical thinking skills. During the project activities, students needed to express their views, listen to others, and engage in discussions and debates. Such interactions not only improved their communication abilities but also enhanced their logical thinking and argumentative skills [15]. At the same time, citizen science projects offer students a platform to showcase their creativity and innovation. Compared to near-transfer activities in the classroom, citizen science projects often present students with complex scientific issues. In unfamiliar contexts, students are required to think of solutions to problems and translate these ideas into actual scientific research activities, thereby continually developing their innovation awareness.

4.3. The role of citizen science projects in the development of scientific attitudes and social responsibility

Chemistry knowledge provides a unique perspective and tools for addressing environmental pollution, a contribution that is difficult to match by other disciplines. Through chemical analysis techniques, we can precisely identify and measure harmful substances in the environment, such as heavy metals, organic pollutants, and excess nutrients, thereby assessing the extent of pollution and developing targeted remediation strategies. When students participate in these projects, they not only apply their chemistry knowledge to solve real-world problems but also cultivate scientific attitudes and social responsibility, which are key components of core subject literacy. In citizen science projects, students have the opportunity to directly engage in environmental monitoring and research. This sense of involvement and hands-on experience is crucial for the development of their scientific attitudes. For example, students may take part in water quality monitoring projects, where they can collect samples in the field, conduct laboratory analyses, and interpret data. This experience allows them to directly observe how chemical analysis is applied in environmental management. Not only does this deepen their understanding of chemical principles, but it also enhances their awareness of the importance of environmental protection.

Additionally, when scientists share their professional knowledge and experiences with middle and high school students, young people often envision themselves as engineers or scientists, which can positively influence their motivation for engaging in science and their future career choices [16]. Moreover, citizen science projects typically involve interdisciplinary collaboration, with chemistry often serving as a practical tool to solve real-world problems. By participating in these projects, students explore the connections between chemistry and other fields such as environmental science, materials science, and medicine. They experience firsthand how chemical knowledge can be applied in different domains and how it integrates with other disciplines to address complex scientific problems. This interdisciplinary learning experience helps students discover the application of chemistry in real-world research, sparks their interest in specific fields, and provides guidance for their academic and professional development, which is significant for their future career choices [17].

5. Implementation recommendations for school citizen science projects

First, increase national support and provide policy guarantees. Citizen science projects in China are still in the early stages, and there is a lack of widespread advocacy within the academic community [1]. To effectively implement citizen science projects, the government needs to increase support and promote awareness by formulating relevant policies. This should include providing financial support for citizen science projects to alleviate the burden on research institutions and schools. Additionally, a cross-departmental cooperation mechanism should be established, along with the creation of citizen science organizations to bridge the gap between scientific research and citizen science. Furthermore, an evaluation and feedback mechanism should be set up to assess the effectiveness of the projects, ensuring continuous improvement and maximizing their impact.

Second, carry out interdisciplinary academic activities with clear teaching objectives. Citizen science is typically conceived and implemented in informal science education contexts. However, within formal education settings, school citizen science projects provide students and teachers with the opportunity to participate in real research processes, making it an important means of enhancing student literacy and fostering teacher professional development [18]. Nevertheless, when citizen science enters middle and high school classrooms, aligning the goals of scientists with those of school education becomes more challenging, as there is a gap between the research topics of scientists and the learning objectives that students are required to achieve under educational standards [19]. Coordinating the scientific research goals with educational objectives poses a significant challenge for frontline teachers. Since 2014, the Science and Society Research Group at the School of Education, Trinity College Dublin, has visited 20 schools, with 500 students participating in citizen science activities. By creating a citizen science group consisting of

"scientists-educators-teachers-students," the group has effectively integrated scientific research, educational research, and practical teaching. This project has received 20 independent research grants and published over 50 papers. Therefore, by combining scientific research with educational research and carrying out interdisciplinary academic activities, aligning the goals of scientists with educational objectives provides teachers with clear teaching goals, which can effectively enhance students' literacy development in citizen science activities.

Third, carry out teacher training to enhance professional knowledge and skills. Teachers play a bridging role in integrating citizen science projects into formal educational environments, and their professionalism is crucial for the success of the projects. Because real scientific research requires a substantial amount of specialized subject knowledge, teachers may lack confidence in their overall understanding of this content, which can significantly hinder the achievement of both the goals of citizen science and educational objectives. However, through professional development activities, teachers can be guided on how to lead students in formulating appropriate research questions and analyzing data, which can help address these gaps [20]. During the training process, it is necessary to focus on both subject knowledge and teaching objectives. Such training will help teachers overcome any lack of confidence in scientific content, ensuring that the citizen science projects can successfully achieve their educational goals.

As technology advances and educational needs evolve, the application of citizen science projects in secondary school chemistry education will become more widespread, offering students more learning opportunities and research experiences. Educational policymakers and resource managers need to provide necessary funding and policy support. Scientific researchers and educational researchers should collaborate to carry out interdisciplinary academic activities, clarify goal alignment, and set clear teaching objectives. At the same time, teachers must receive professional training and development opportunities to ensure the quality of citizen science projects. Through these efforts, we can expect citizen science projects to play an increasingly significant role in secondary school chemistry education and contribute more substantially to the cultivation of students' core chemistry literacy.

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