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STEM-Based Innovation and Practice in Battery Science Outreach for High School Students: A Teaching Case Study on Energy Technology Education

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Abstract: Against the backdrop of global energy transition and rapid advances in new energy technologies, integrating cutting-edge scientific content into basic education has become a key direction of science education reform. As a core technology in energy storage and conversion, battery technology plays an important role in transportation, renewable energy utilization, and smart devices. However, current high school curricula mostly remain at the level of basic electrochemistry, leaving students with little systematic understanding of the development and real-world applications of modern batteries. Taking a battery science outreach lecture for high school students as a case study, this paper designs a STEM-based course model that integrates hands-on practice, theoretical instruction, and discussion of technological applications. The course engages students in a solar–nickel-metal hydride battery-powered fan activity, introduces battery history and principles of typical battery systems, and expands into battery testing techniques and energy application scenarios. Using classroom observation and teaching reflection, the study analyzes implementation and educational outcomes. Observations during the course suggest that the hands-on activities helped engage students and provided them with opportunities to connect basic battery concepts with real-world applications. This study offers a practical curriculum design for integrating cutting-edge science into secondary education.

Keywords: STEM education; Battery technology; Science outreach; Secondary education; Teaching practice

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1. Introduction

Against the backdrop of the global energy transition and the growing emphasis on low-carbon development, new energy technologies have become an increasingly important area of scientific and technological development. As a core component of energy storage and conversion systems, battery technology plays a critical role in electric vehicles, renewable energy storage, mobile electronic devices, and other sectors. In recent years, new battery technologies represented by lithium-ion batteries have achieved continuous progress; meanwhile, new-generation energy storage technologies such as solid-state batteries and aqueous batteries have increasingly become research hotspots. Battery science has evolved into a highly interdisciplinary subject integrating electrochemistry, materials science, physics, and engineering technology [1].

However, within the current science curriculum system at the senior high school level, the battery knowledge acquired by students mainly focuses on fundamental electrochemical principles, such as the basic reaction mechanisms of galvanic cells and electrolytic cells. Although such knowledge provides a theoretical foundation for understanding the working mechanisms of batteries, students often struggle to connect these abstract concepts with energy technologies in real life. Therefore, how to introduce the achievements of modern scientific and technological development into classroom teaching in a form suitable for high school students' cognitive level has become an important issue in the current reform of science education.

In recent years, the concept of STEM education has attracted extensive attention in the international education community. STEM education emphasizes the interdisciplinary integration of Science, Technology, Engineering and Mathematics (STEM) [2], and promotes the development of students' comprehensive competencies through practical activities and real-world problem scenarios. Guided by this philosophy, taking modern energy technologies as the teaching theme and adopting a teaching approach that combines practical activities with technical cases helps broaden students' scientific horizons and enhance their overall literacy.

Against the aforementioned background, this paper takes a battery science popularization course designed for first-year senior high school students as the research object. It systematically analyzes the curriculum design philosophy, teaching implementation process, and teaching effectiveness, aiming to provide practical references for the effective integration of cutting-edge scientific and technological content into high school classrooms.

2. Current status of science outreach lectures for adolescents

With the increasing national emphasis on science education and the cultivation of innovative scientific and technological talents, various science outreach lectures for high school students have gradually increased. Universities, research institutes, and science and technology venues have been disseminating cutting-edge scientific and technological knowledge to teenagers through special lectures and popular science activities, playing a positive role in broadening students' scientific horizons [3]. However, in practice, current science outreach lectures still exhibit several limitations in terms of instructional philosophy and implementation methods.

2.1. Lectures are dominated by one-way knowledge transmission with insufficient interactivity and student participation

Most popular science lectures still adopt the traditional classroom lecture model centered on expert lecturing, where students remain in a passive receptive state [4,5]. Although this one-way mode of information transmission can convey a large amount of knowledge in a short period of time, it may not sufficiently engage students or support their understanding of complex scientific concepts. Especially for highly abstract topics such as battery technology, explanations lacking specific situational support often fail to achieve satisfactory teaching outcomes.

2.2. There is a certain disconnect between popular science content and students' cognitive level

On the one hand, some lecture content is overly specialized, involving numerous cutting-edge research details and technical jargon that may exceed the developmental and cognitive level of high school students. On the other hand, some popular science content remains at a superficial introductory level, lacking systematicity and logicality, and thus failing to help students construct a complete knowledge framework. This imbalance at two extremes weakens the educational effectiveness of popular science activities to a certain extent.

2.3. Practical experience sessions are generally lacking, making it difficult to embody the core characteristics of STEM education

STEM education emphasizes learning through hands-on activities and real-world problem situations [6]. However, constrained by time, equipment, and organizational arrangements, most popular science lectures offer very few hands-on experiments and engineering experience sessions. Deprived of opportunities for personal involvement, students struggle to understand scientific principles and technical processes through concrete operation, thereby restricting the development of their comprehensive abilities.

2.4. Popular science lectures are insufficiently closely connected with real-life application scenarios

In terms of content design, some lectures focus excessively on the explanation of scientific principles while paying inadequate attention to the practical application of technologies in daily life, making it difficult for students to recognize the practical value of scientific knowledge. This is particularly true for fields closely related to social development, such as new energy and battery technology. Without the support of application scenarios, students often fail to form a holistic understanding of relevant technologies.

These limitations indicate that there is significant room for improvement in the design and implementation of science outreach lectures. Therefore, under the guidance of STEM education principles, it is necessary to develop more systematic instructional models that integrate hands-on practice, structured knowledge construction, and application-oriented learning. The battery science outreach course presented in this study represents an exploratory attempt in this direction.

3. Course design philosophy and overall structure

In the course design process, this study was guided by the principles of STEM education, emphasizing the organic integration of knowledge acquisition and practical experience. Unlike traditional, lecture-based science popularization sessions, this course attempts to introduce learning scenarios through practical activities, enabling students to form a preliminary understanding of energy conversion processes through hands-on operations. This is followed by theoretical explanations to establish a systematic knowledge framework, and finally, the integration of technical application case studies to guide students towards comprehensive thinking.

In terms of overall structure, the course adopts a teaching approach of hands-on experience, conceptual understanding, and application and extension (**Figure 1**). The initial stage of the course uses small-scale engineering activities to stimulate students' interest, allowing them to experience energy conversion processes in real-world contexts; subsequently, through systematic explanations of the development history of battery technology and the principles of typical battery systems, students are helped to establish a comprehensive understanding of battery science; finally, by introducing battery testing techniques and real-world application cases, students are guided to understand the relationship between technological development and societal needs.

The course lasts approximately two hours and involves around 30 students. During the practical session, students work in pairs to assemble, test, and adjust the system. This group-based approach not only enhances classroom engagement but also helps cultivate students' teamwork skills and problem-solving abilities.

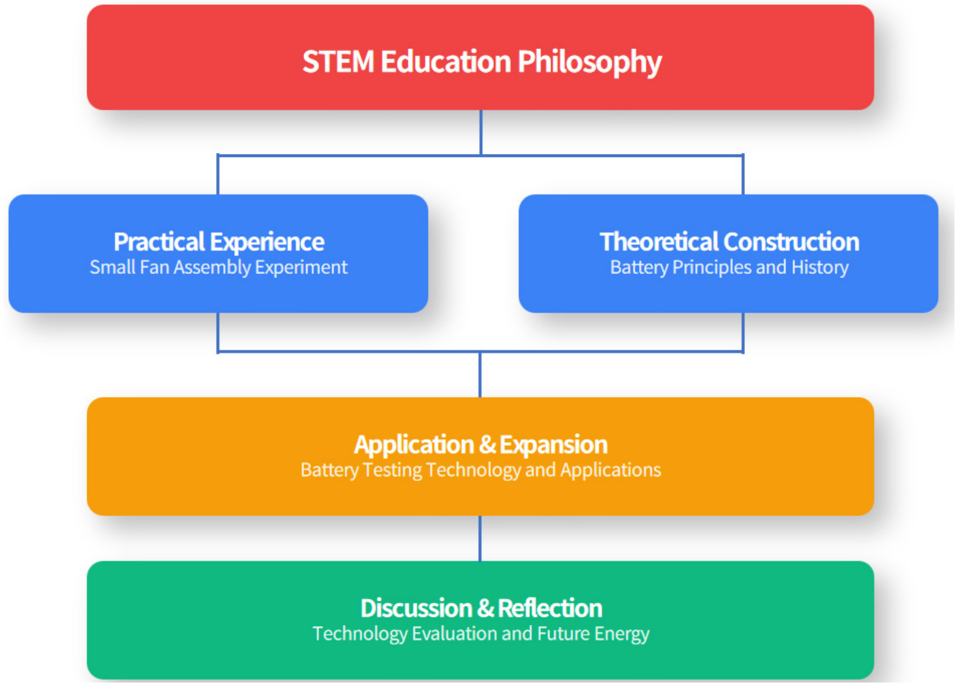

Figure 1. Teaching structure of a battery science outreach course based on the STEM approach

4. Teaching implementation process

The course commenced with a practical introduction. The teacher provided students with experimental materials including nickel-metal hydride batteries, solar panels, small DC motors, fan blades, and connecting wires, and organized them to assemble a solar-powered nickel-metal hydride battery-driven small fan. Students were required to connect the battery, motor, and solar panel to form a simple circuit, enabling the motor to drive the fan blades to rotate (**Figure 2**).

During this process, students can observe the fundamental process of energy conversion first-hand. The chemical energy provided by the battery is converted into electrical energy via the circuit, driving the motor to rotate and further converting this into mechanical energy; simultaneously, the solar panel generates electrical energy under sunlight, providing additional energy input to the system. Through this hands-on experience, students are able to understand the basic concepts of energy conversion within a concrete context.

Once the practical session is complete, the course moves on to the theoretical explanation phase. First, the history of battery technology is introduced, from the invention of the Voltaic pile to the widespread application of modern lithium-ion batteries, with the development process of battery technology presented using a timeline. Through this historical perspective, students can understand that technological development is characterized by continuous accumulation and constant innovation.

Figure 2. Students carrying out hands-on activities

Subsequently, the course focuses on explaining the fundamental principles of several typical battery systems, including lead-acid batteries, nickel-metal hydride batteries and lithium-ion batteries. The explanations cover both electrode materials and basic reaction mechanisms, whilst also illustrating these concepts through real-world application scenarios. For example, when discussing lead-acid batteries, their use in automotive starting systems is highlighted; when discussing nickel-metal hydride batteries, the topic is linked to hybrid vehicles; and when discussing lithium-ion batteries, the focus is on common devices such as smartphones and electric vehicles.

In the final section of the course, the lecturer introduced basic methods for evaluating battery performance, such as capacity testing, cycle life testing, and rate performance testing. By presenting typical charge-discharge curves, students were able to understand how technical performance is assessed through experimental data in scientific research. This content not only helped students grasp research methodologies in battery technology but also fostered a fundamental understanding of scientific data.

5. Analysis of teaching outcomes

Classroom observations suggested that the hands-on activities helped engage students during the course. During the experimental sessions, the majority of students actively participated in connecting and debugging the equipment, and attempted to resolve connection issues through group discussions. When the fan successfully operated, the students demonstrated clear interest and a sense of achievement, which fostered a positive learning atmosphere for subsequent theoretical study.

During the theoretical explanation phase, students asked questions regarding battery charging principles, battery capacity, and the safety of electric vehicle batteries. The nature of these questions suggested that students were interested not only in technical principles but also in the practical applications of battery technologies. This suggests that the course has, to some extent, encouraged students to link scientific knowledge with real-world technology.

Furthermore, during the discussion session following the course, some students also asked about degree programs related to new energy and future developments in battery technology, suggesting that the course stimulated interest in further learning in this area. Through the combination of practical activities and technical case studies, students are able to gain a more intuitive understanding of the vital role scientific knowledge plays in the real world.

From a pedagogical perspective, the course has also contributed to the development of students' engineering thinking. During the assembly of the small fan, students had to follow the basic process of "assembly–testing–adjustment," which bears a certain resemblance to the iterative process in engineering design. Although this practical activity was relatively simple, it nevertheless helped students gain a preliminary understanding of the fundamental approach to engineering practice.

6. Discussion

This teaching case suggests several potential benefits of integrating emerging energy technologies into secondary science education. Firstly, such content bridges the gap between the pace of textbook updates and the speed of technological advancement, enabling students to form a more comprehensive understanding of modern technological developments. Secondly, by incorporating real-world application cases into instruction, the practical relevance of scientific learning is enhanced, thereby increasing students' enthusiasm for acquiring scientific knowledge.

Furthermore, battery technology itself possesses distinct interdisciplinary characteristics; during the teaching process, it can simultaneously cover content from multiple fields, including the principles of chemical reactions, the conversion of physical energy, and materials science. This interdisciplinary integration aligns with the fundamental principles of STEM education and helps cultivate students' ability to apply knowledge comprehensively to solve problems.

Of course, certain challenges exist in teaching practice. For instance, battery science involves a substantial amount of specialist knowledge; if explanations are too in-depth, they may exceed the cognitive level of secondary school students. Therefore, when designing the curriculum, content needs to be appropriately simplified, and analogies and case studies should be used to help students understand complex concepts.

7. Conclusion

This paper takes a popular science course on battery science delivered to secondary school students as a case study to explore a STEM-based teaching model for cutting-edge technology. This teaching case illustrates how a combination of hands-on activities, conceptual instruction, and application-oriented discussion can be used to introduce battery science within a STEM-based outreach context. Classroom observations suggest that this approach provided students with opportunities to engage with battery concepts through practical experience and real-world applications.

This teaching practice demonstrates that cutting-edge scientific content can be fully integrated into secondary school classrooms through appropriate pedagogical adaptation, thereby broadening students' scientific horizons and fostering their overall literacy. Future research could conduct a more systematic analysis of the educational effectiveness of this teaching model, based on larger-scale teaching practices and utilizing methods such as questionnaire surveys and assessments of learning outcomes.

Disclosure statement

The authors declare no conflict of interest.

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