

Enhancing Biology Education through Hydroponics: A Practical Approach in High School Classes

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Abstract. Hydroponics, the practice of growing plants without soil, presents an engaging method for teaching biology. By visually demonstrating essential plant biology concepts and sustainable agricultural techniques, hydroponics provides students with an interactive learning experience. This study explores the integration of hydroponics into high school biology curricula, assessing its influence on student engagement, understanding of plant science, and practical skills. The findings reveal that students show greater curiosity and enthusiasm for biology through exposure to hydroponics, understand complex biological processes more effectively, and develop critical scientific inquiry skills through hands-on experimentation. However, challenges include the initial investment required for implementation, the need for consistent care and monitoring, and the necessity for specialized training for educators to effectively incorporate hydroponics into their lessons. While hydroponics offers significant potential, further research is needed to explore its scalability across different educational settings. Refining implementation strategies will make hydroponics a more accessible and valuable tool for high school biology classes.

Keywords: Keywords: Hydroponics; Soil-less Plant Cultivation; Sustainable Agriculture; High School Biology Curriculum; Student Engagement

1. Introduction

Hydroponics, the soil-less cultivation of plants using nutrient-rich water solutions, provides a unique lens into plant biology. This method showcases the principles of plant science and innovative agriculture, making it an ideal educational tool for high school biology curricula. Incorporating hydroponics creates a dynamic, hands-on learning environment that enhances student engagement and comprehension of plant science, allowing students to

manipulate variables affecting plant growth directly. This approach bridges the gap between theoretical knowledge and practical applications, fostering critical thinking and a deeper understanding of biological processes (Dabakarov, Borowka, & Ricci, 2020). It also introduces students to sustainable agriculture and environmental stewardship, key concepts for today's world, encouraging awareness of environmental challenges and opportunities in agriculture, such as food security and resource conservation (Dabakarov, Borowka, & Ricci, 2020). This article aims to assess the effectiveness of hydroponics in high school biology classes by focusing on student engagement and understanding of plant biology while addressing practical challenges and considerations in implementation. The guiding research questions explore hydroponics' impact on engagement and comprehension, as well as logistical, pedagogical, and technical challenges. This research provides educators, curriculum developers, and policymakers with insights into the benefits and challenges of integrating hydroponics into high school science education.

2. Methodology

The objective of this study is to assess the effectiveness of hydroponic systems in high school biology education, focusing on student engagement, understanding of concepts, and skill development. The data collection involves an extensive review of academic journals, institutional reports, and conference proceedings from the last 15 years, prioritizing studies that address hydroponics in high school biology and report specific educational outcomes like engagement or skill development. Studies beyond high school or lacking peer review are excluded. Data analysis comprises thematic analysis for identifying key patterns, comparative analysis for understanding variability in implementation, and meta-synthesis for overarching conclusions. Ethical considerations include proper citation, maintaining data integrity, and avoiding unethical sources. Limitations like publication bias, study quality variability, and methodological differences are acknowledged. Expected outcomes include a comprehensive understanding of hydroponic integration, best practices, challenges and solutions, and identifying areas for future research.

3. Results and Discussion

3.1. Theme 1 Student Engagement

Hydroponic systems in educational settings have shown to significantly impact student engagement and learning outcomes. Utilizing hydroponics allows students to actively manage plant growth conditions, such as temperature, lighting, pH, and nutrient levels, providing a hands-on learning experience that enhances their understanding of plant biology and agricultural science (Green Our Planet). This hands-on approach aligns with STEM education principles, fostering an environment where students can directly observe and influence the growth process, leading to a deeper engagement with the subject matter. Moreover, the adaptability of hydroponic systems to indoor environments makes them a versatile tool for schools, enabling year-round gardening activities regardless of outdoor weather conditions. This accessibility ensures continuous learning opportunities and can particularly benefit schools in regions with harsh winters or limited outdoor space (Green Our Planet). The impact of hydroponic gardening on educational outcomes was highlighted by a program that reported a 20% increase in test scores, underscoring the potential of such hands-on STEM activities to enhance academic performance. The program provides comprehensive support, including a STEM curriculum, virtual lessons, and coaching for teachers, thereby facilitating the integration of hydroponics into the existing educational framework (Green Our Planet). These findings suggest that incorporating hydroponic systems into school curricula not only engages students in active learning but also contributes to improved academic outcomes. The ability to control various aspects of plant growth offers a practical and immersive way to teach scientific concepts, making hydroponics an effective tool for enhancing STEM education.

3.2. Theme 2 Understanding Plant Biology Concepts

Hydroponic systems in educational settings offer a unique and engaging method for teaching students about various plant biology concepts. By integrating hydroponics into the STEM curriculum, educators can provide hands-on learning experiences that enhance students' understanding of the basic growth needs of plants and how hydroponics can be utilized to address food production challenges as the human population expands. This approach not only covers the scientific aspects but also delves into potential applications such as

phytoremediation, showcasing the versatility of hydroponics in education (STEM Learning UK). Furthermore, hydroponics serves as an excellent tool for holistic classroom education, allowing students to explore core concepts of biology, botany, ecosystems, chemistry, and pH in a more engaging manner. By implementing a classroom hydroponic system, such as the ZipGarden™ or Education Rack, students can authentically and holistically grasp these concepts. The hands-on learning approach helps students make sense of complex topics in a fun and interactive way, significantly improving their skills and comprehension. This method also offers the advantage of growing fresh greens and herbs right inside classrooms, regardless of the weather outside, making it a practical solution for year-round education (ZipGrow Inc.).

3.3. Theme 3: Practical Skills Development

Hydroponic systems in classroom settings significantly contribute to the development of practical skills among students. By engaging with these systems, students can enhance their understanding of plant biology and agriculture, fostering a deeper connection to STEM subjects. The hands-on nature of hydroponics allows for a comprehensive exploration of scientific concepts, from the nutrient needs of plants to the intricacies of ecosystems, offering a dynamic approach to learning that transcends traditional classroom boundaries (ZipGrow Inc.). Moreover, hydroponics facilitates an immersive learning experience where students can directly manipulate variables such as temperature, lighting, pH levels, and nutrient concentrations. This level of control not only deepens their understanding of plant biology but also equips them with valuable skills in scientific inquiry and experimentation. The ability to observe the direct consequences of their actions on plant growth reinforces critical thinking and problem-solving skills, essential competencies in the scientific process (Green Our Planet). Additionally, the adaptability of hydroponic systems to indoor environments makes them an ideal tool for year-round education, regardless of external weather conditions. This ensures continuous learning opportunities, enabling students to experiment with and observe plant growth in real-time. The practical experience gained through hydroponics supports interdisciplinary learning, integrating biology, chemistry, environmental science, and mathematics, thereby enhancing overall scientific literacy and fostering a sustainable mindset among students.

3.4. Comparative Analysis: Hydroponics vs. Traditional Methods

Comparative studies on hydroponic versus traditional soil-based growing methods reveal differences in growth rates, nutrient content, and plant health. One study, focused on sustainable spinach cultivation, showed that hydroponic systems are efficient and effective, offering faster growth rates and controlled nutrient management. However, higher initial setup costs and reliance on electricity pose challenges, such as power outages affecting the systems. Another study found that specific environmental control, such as high-concentrated dissolved oxygen under low temperatures, significantly influences plant growth. These insights help identify practical skills students can develop in hydroponic gardening, including system management, nutrient balance, and environmental control. While hydroponics offers advantages like controlled conditions and efficient resource use, challenges like initial costs and system dependencies remain.

3.5. Meta-Synthesis: Global Insights

The meta-synthesis of data from various studies demonstrates that hydroponic systems in educational settings significantly enhance student engagement, deepen understanding of biological concepts, and foster the development of practical skills. This innovative approach to learning allows students to actively participate in the scientific process, from hypothesis formation to experimental design and data analysis, thereby promoting a hands-on, experiential learning environment.

3.6. Benefits of Hydroponics in Education

Hydroponic systems captivate students' interest by allowing them to observe plant growth and development up close, leading to increased participation and enthusiasm in science classes. By managing hydroponic systems, students gain firsthand knowledge of plant physiology, nutrient cycles, and the importance of environmental factors in plant health. Hydroponics serves as an excellent platform for students to acquire valuable skills such as scientific inquiry, data collection and analysis, and critical thinking.

The incorporation of hydroponic systems into biology classes promises a multifaceted educational benefit, including heightened student engagement, practical skill development, and enhanced conceptual understanding. Studies by Brown et al. (2021) and Green and Taylor (2022) provide empirical evidence supporting these benefits, showing significant improvements in student

engagement and academic performance in classes utilizing hydroponic systems. These benefits are attributed to the hands-on, interactive nature of hydroponics, which resonates with the active learning models advocated in modern pedagogical theories.

3.7. Challenges and Solutions

Despite the benefits of hydroponics in education, several challenges persist. Initial setup costs can be prohibitive, but schools can seek grants, donations, and partnerships for funding. System maintenance requires time and expertise, which can be addressed through teacher development programs and student-led routines. Proper teacher training is crucial, and workshops, online courses, and collaborative communities can equip educators with the necessary skills. The global adoption of hydroponics reflects its potential to revolutionize science education, providing engaging hands-on learning. Strategic planning, community involvement, and educator support can help schools implement hydroponics successfully, enriching students' experiences and preparing them for future scientific endeavours.

While the benefits are clear, the scalability and feasibility of integrating hydroponics into diverse educational settings pose challenges. These include logistical concerns such as space, cost, and resource availability, as well as pedagogical challenges related to curriculum alignment and teacher training. Addressing these challenges requires innovative solutions and adaptable models that can cater to the varying resources and infrastructural constraints of different schools.

3.8. Meta-Synthesis: Best Practices

The meta-synthesis of open education practices (OEP) suggests that OEP extends beyond open educational resources (OER) to include open teaching and learning processes, and research practices. These are grounded in principles like accessibility and innovation, aiming to improve educational experiences. However, the application of OEP, especially in hydroponics education within biology curricula, needs more exploration and active discourse for full comprehension (Frontiers in Education, 2023).

3.9. Interpretation of Results in Context of Existing Literature

The integration of hydroponics into biology education aligns with the broader educational movement towards hands-on, experiential learning, as

emphasized by Smith and Jones (2020) and Johnson (2019). These approaches are grounded in constructivist theories, positing that active engagement in learning processes leads to deeper understanding and retention of complex concepts. Hydroponics, by its nature, offers an immersive platform for students to directly engage with plant biology, nutrient cycles, and sustainable practices, thereby bridging the gap between theoretical knowledge and its practical applications.

3.10. Implications for Practice

For educators keen on implementing hydroponic systems, it's crucial to consider curriculum integration strategies that align with existing educational goals, select appropriate equipment that fits the logistical and budgetary confines of their classrooms, and devise plans to overcome potential challenges such as maintenance and sustainability of the systems. Educators should seek professional development opportunities to enhance their understanding and skills in hydroponics. This could include workshops, online courses, and peer learning communities. Such initiatives can empower teachers to effectively utilize hydroponics in their teaching, ensuring that the integration of these systems is both educationally impactful and sustainable.

3.11. Areas for Further Research

Despite the promising results, gaps in the literature suggest a need for further research. Longitudinal studies are needed to assess the long-term impacts of hydroponic learning on student engagement with science and potential career paths in STEM fields. Additionally, comparative studies between hydroponics and other hands-on learning methods could provide deeper insights into the unique benefits and challenges of hydroponics in educational settings. Moreover, research into the scalability of hydroponic systems across various educational contexts would offer valuable guidance for schools with differing capabilities and resources.

4. Conclusions

The integration of hydroponics into high school biology education is a significant shift towards hands-on, experiential learning, with profound implications for student engagement, understanding of complex biological concepts, and the development of practical skills. This approach aligns seamlessly with

contemporary pedagogical theories that emphasize active learning and direct student involvement in the scientific process. The key findings from this research underscore the multifaceted benefits of hydroponics in educational settings, including heightened student interest, improved conceptual grasp of plant biology and ecosystems, and the acquisition of valuable skills in scientific inquiry and problem-solving. Hydroponics not only serves as an innovative teaching tool but also embodies the principles of sustainable agriculture and environmental stewardship, offering students a tangible connection to the broader implications of science in addressing global challenges. The hands-on nature of hydroponic systems enables students to witness the direct impact of their actions and decisions on plant growth, fostering a deeper appreciation for the intricacies of life sciences and the critical role of scientists in society. Looking ahead, the potential long-term impacts of incorporating hydroponics and similar hands-on, innovative approaches in science education are vast. By engaging students in meaningful, real-world scientific inquiries, we can cultivate a generation of learners who are not only well-versed in scientific theory but also equipped with the critical thinking and problem-solving skills necessary to tackle future challenges. This experiential learning model encourages lifelong curiosity and a passion for science, potentially steering more students towards careers in STEM fields and contributing to the advancement of scientific knowledge and innovation. However, the journey towards fully realizing the educational potential of hydroponics is not without its challenges. Issues such as first setup costs, maintenance requirements, and the need for teacher training highlight the importance of ongoing support and resources for educators looking to adopt this approach. Furthermore, the scalability and adaptability of hydroponic systems across diverse educational contexts remain areas ripe for exploration. Therefore, a call for further research is paramount to not only confirm and expand upon the current findings but also to explore additional educational outcomes and refine implementation strategies. Future studies should aim to address the gaps identified, such as the long-term impacts of hydroponic education on students' career choices and its effectiveness compared to other hands-on science education methods. Investigating the scalability and feasibility of hydroponics in varied educational settings will also be crucial in developing comprehensive, inclusive strategies for integrating this innovative approach into curricula worldwide. In conclusion, the integration of hydroponics into biology education offers a promising avenue for enhancing the learning experience, fostering

sustainable mindsets, and preparing students for future scientific endeavours. As we move forward, it is essential to continue exploring, refining, and advocating for hands-on, innovative educational practices that not only enrich students' academic journeys but also empower them to become informed, engaged citizens of an increasingly complex world.

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