Decarbonization Education for K-12: A Pilot Study on Transforming Student Perceptions and Career Trajectories in Clean Energy

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Abstract

Abstract
This paper presents a pilot study of an immersive, one-week summer camp aimed at fostering interest in clean energy careers among high school and middle school students from underserved minority backgrounds. Conducted at Florida Agricultural and Mechanical University (FAMU) in collaboration with the Stanford Building Decarbonization Learning Accelerator, the camp engaged students in a range of hands-on activities focused on building decarbonization, renewable energy technologies, and robotics. Participants, primarily from Title I schools, were introduced to clean energy concepts through a combination of lectures, lab sessions, and interactive projects. The camp's curriculum emphasized practical applications, including the use of solar panels, robotic assembly, and strategies for energy efficiency in buildings. Pre- and post-surveys, along with qualitative data from instructor observations and student reflections captured through word clouds, were analyzed to assess shifts in student interest, understanding, and career aspirations in the fields of renewable energy and STEM more broadly. Preliminary results indicate notable improvements in both interest and understanding of clean energy concepts, with the percentage of students expressing a strong interest in renewable energy careers increasing from 44% to 78%. Similarly, familiarity with decarbonization concepts rose from 27% to 64%. Furthermore, the hands-on activities were found to be the most effective in maintaining engagement and promoting deeper learning. The study highlights the importance of experiential learning in enhancing STEM education for underrepresented communities and provides a framework for future iterations of the camp, with a focus on scaling the program and incorporating additional industry partnerships. This paper contributes to the body of knowledge on STEM education outreach, offering valuable insights into the design and implementation of programs that aim to diversify the clean energy workforce and address equity gaps in education.

Keywords: Clean Energy, STEM Education, Career Trajectories, Hands-On, Summer Camp

Introduction

The escalating impacts of climate change and the need for sustainable practices underscore the urgent global push towards a low-carbon economy. Clean energy and decarbonization are pivotal in mitigating greenhouse gas emissions and ensuring long-term environmental stability. Derived from renewable, zero-emission sources such as solar and wind, clean energy minimizes harm to the environment while ensuring resource sustainability. Decarbonization complements this effort by employing strategies and technologies to reduce CO_2 emissions and the carbon footprint of energy production [1, 2]. However, despite advancements in clean energy technologies, underrepresentation persists among minority groups in the STEM and clean energy sectors. Addressing this disparity is critical to fostering a diverse and innovative workforce that drives clean energy solutions [3, 4].

Research underscores the role of early exposure to STEM education in shaping students' academic interests and career aspirations, particularly through hands-on, experiential learning [5-7]. Summer camps have proven to be effective platforms for fostering STEM engagement, combining structured curricula with interactive activities to enhance interest and confidence among participants. These programs are especially impactful for students from underrepresented backgrounds, offering them opportunities to connect theoretical knowledge with practical applications [8, 9]. Recognizing this potential, Florida Agricultural and Mechanical University (FAMU) launched "EmpowerEd: A Sustainable Future through Clean Energy Education," a one-week pilot summer camp funded by the Department of Energy through the HBCU Clean Energy Prize. This program aimed to inspire middle and high school students from underserved backgrounds to explore careers in clean energy and STEM. By leveraging experiential learning principles, the camp provided students with immersive activities such as solar panel assembly, robotics integration, and workshops on building decarbonization. This paper presents the design, implementation, and outcomes of this pilot program, with a focus on its impact on student interest and knowledge of clean energy concepts.

Background and Literature Review

The transition to sustainable energy practices is crucial for mitigating climate change and achieving long-term environmental stability. Clean energy sources like solar, wind, and geothermal play a pivotal role in this transition by offering renewable, zero-emission alternatives to traditional energy sources [1]. Decarbonization strategies further enhance this effort by minimizing the carbon footprint associated with energy production and consumption [2]. However, despite the growing demand for clean energy technologies, the sector faces a significant challenge in diversifying its workforce. Only 9% of the STEM workforce comprises Black and Hispanic professionals, highlighting systemic barriers such as limited access to quality education, mentorship, and STEM opportunities [3-5]. Addressing these disparities is essential to building a skilled and diverse workforce that can meet the demands of the renewable energy sector.

Research consistently shows that early exposure to STEM education is a key determinant in shaping students' academic interests and career aspirations. Programs that engage students with hands-on, experiential learning opportunities have been particularly effective in enhancing students' interest, confidence, and performance in STEM fields [10, 11]. Experiential learning, as outlined by Kolb [12], emphasizes the importance of active engagement with the material, allowing students to connect theory to practice through real-world applications. This approach is especially beneficial for students from underrepresented backgrounds, who may otherwise lack access to quality STEM education and related resources. Summer camps focused on STEM have emerged as impactful platforms for delivering experiential learning. Their intensive, immersive nature provides an environment conducive to deep learning, sustained engagement, and skill development. For instance, Yilmaz, et al. [13] highlight that STEM-focused summer camps can spark long-term interest in scientific fields, while Hammack, et al. [14] found that participants in such programs are more likely to pursue STEM majors and careers. Additionally, Alexander, et al. [15] indicate that minority students who participate in STEM outreach programs demonstrate higher levels of academic self-efficacy and are better positioned for future STEM success.

Despite significant advancements in renewable energy technologies and growing public awareness, clean energy education has not fully reached all segments of society [16]. Existing literature suggests that targeted educational outreach remains critical for addressing these gaps [17-20]. Ikevuje, et al. [5] note that while general STEM outreach has expanded, specialized programs focusing on clean energy and sustainability are less common, particularly those that cater to underrepresented student populations. This gap is particularly concerning given the projected growth of the renewable energy sector and the need for a skilled, diverse workforce to support it [2, 18]. Moreover, while there are numerous STEM initiatives aimed at broad science education, fewer programs incorporate comprehensive clean energy and decarbonization topics. This is a missed opportunity, as early exposure to clean energy concepts not only enhances scientific understanding but also motivates students to consider careers in fields essential for a sustainable future. The integration of real-world applications in educational content increases student engagement and fosters a more profound, lasting interest in STEM [21, 22].

FAMU's EmpowerEd program addresses these gaps through a comprehensive curriculum that combines theoretical knowledge with practical application. Funded by the Department of Energy as part of the HBCU Clean Energy Prize, the program aligns with Kolb [12] experiential learning principles. Activities such as solar panel assembly, robotics integration, and building decarbonization workshops provide students from underserved backgrounds with opportunities to engage directly with clean energy technologies. By focusing on mentorship, interactive projects, and real-world problem-solving, the EmpowerEd program equips students with the skills and inspiration needed to pursue careers in renewable energy and STEM fields. This comprehensive approach contributes to addressing educational equity and diversifying the clean energy workforce.

Methodology

The EmpowerEd summer camp was meticulously designed to provide a comprehensive educational experience focused on clean energy and decarbonization. The camp was structured as a one-week immersive program, aligning with best practices in experiential learning [12]. The curriculum combined theoretical instruction with hands-on activities to bridge the gap between academic concepts and real-world applications. The program targeted middle and high school students from underserved and minority backgrounds, particularly those attending Title I schools in the Tallahassee area. Recruitment strategies included distributing flyers at local schools, leveraging community partnerships, and promoting the camp during FAMU's STEM Day event. Out of 16 registered participants, 11 students attended, creating a diverse group with a balanced gender representation of 57.1% female and 42.9% male. The participants were predominantly juniors (52.4%), followed by freshmen (38.1%) and seniors (4.8%). Although the program was designed for both middle and high school students (grades 6-12), all 11 students who attended were high school students. Recruitment efforts were initially broad; however, most of the interest came from high school students, likely due to greater alignment with their academic and career considerations. Future iterations of the program may explore separate activities tailored for middle and high school students to better differentiate learning experiences for each group.

Curriculum and Activities

The structured curriculum provided a blend of lectures, interactive activities, and hands-on lab sessions each day, ensuring a comprehensive learning experience for all participants. The

detailed schedule of the camp activities is shown figure 1. These activities ensured that the students were not only learning theoretical concepts but also applying them practically through engaging activities and lab sessions. The highlight of the camp was the graduation ceremony, where all students received certificates for their participation, marking a successful completion of the camp. The lecture materials used in the camp was developed by Stanford Building Decarbonization Learning Accelerator. Each day involved a mix of lectures, interactive activities, and hands-on lab sessions, ensuring a comprehensive learning experience as shown in the breakdown and the Figure 2 below.

- Day 1: Introduction to Clean Energy and Sustainability
  - Morning: Welcome session and pre-survey, followed by a lecture on building decarbonization.
  - Afternoon: Interactive session on renewable energy fundamentals.
- Day 2: Low-Carbon Materials and Energy Efficiency
  - Morning: Lecture on low-carbon construction materials.
  - Afternoon: Workshop on residential energy efficiency strategies.
- Day 3: Solar Energy and Robotics
  - Morning: Session on solar energy applications and geothermal technologies.
  - Afternoon: Hands-on robotics lab, emphasizing practical applications of clean energy.
- Day 4: Robotics Integration and Industry Insight
  - Morning: Robotics assembly and motion planning exercises.
  - Afternoon: Guest lecture by the City of Tallahassee's clean energy representative.
- Day 5: Operational Carbon and Closing
  - Morning: Workshop on operational and embodied carbon, followed by solar panel assembly.
  - Afternoon: Post-survey, graduation ceremony, and distribution of certificates.

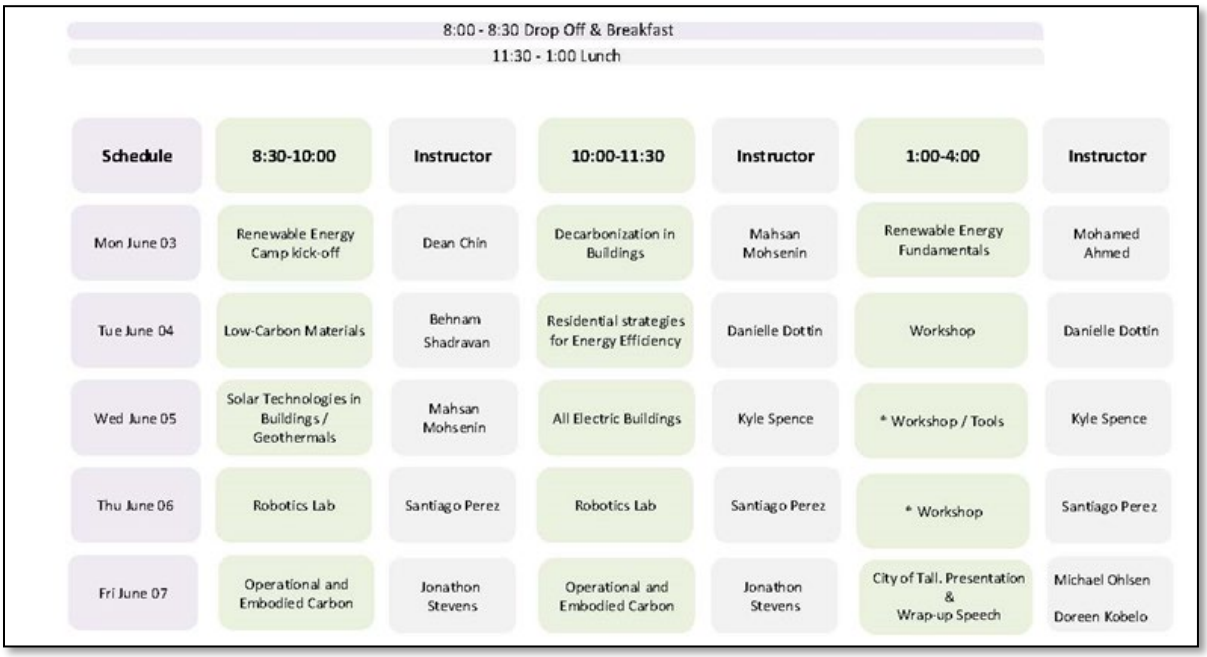

Figure 1. Empowered Clean Energy Summer Camp Schedule

Data Collection Tools and Techniques

To assess the camp's impact, data collection included both quantitative and qualitative methods:

- Pre- and Post-Surveys: Students completed surveys at the start and end of the camp, designed to measure changes in their interest in clean energy and understanding of key concepts.
- Daily Feedback Mechanisms: At the end of each day, students were asked to reflect on what they found most interesting or impactful during the day's activities. Responses were collected and visualized using word clouds to identify recurring themes and measure engagement with different concepts.
- Observation and Instructor Notes: Instructors documented engagement levels, student interactions, and any challenges faced during the activities.

Data Analysis

Survey data were analyzed to determine shifts in students' attitudes and knowledge. Pre- and post-survey responses were compared using descriptive statistics to highlight changes in interest and familiarity with clean energy topics. Qualitative feedback from word clouds and instructor observations provided additional context, helping to identify which activities resonated most with students and where improvements could be made. This multi-faceted approach to data collection and analysis ensured a comprehensive evaluation of the camp's effectiveness in achieving its educational goals and fostering student interest in clean energy careers.

Results

The results of the EmpowerEd summer camp were measured through pre- and post-camp surveys, observational data, and feedback collected from both participants and instructors. This section presents the findings related to participant engagement, shifts in knowledge and interest, and qualitative feedback on the program's impact. Pre- and post-surveys (shown in Figure 2) were administered to evaluate changes in students' knowledge, interest in clean energy concepts, and career aspirations in STEM fields. The surveys included questions on familiarity with renewable energy technologies, understanding of decarbonization, and interest in pursuing STEM careers. The pre-survey revealed that only 44% of participants rated their interest in renewable energy careers as high (4 or 5 on a 5-point scale). Post-camp survey results demonstrated improvements, with 78% of students expressing a strong interest in clean energy careers. Similarly, understanding of decarbonization concepts saw notable improvements. Before the camp, only 27% of participants reported familiarity with decarbonization, while post-camp results showed that 64% felt knowledgeable about the topic. These shifts underscore the effectiveness of the camp's curriculum in enhancing students' understanding and sparking interest in renewable energy.

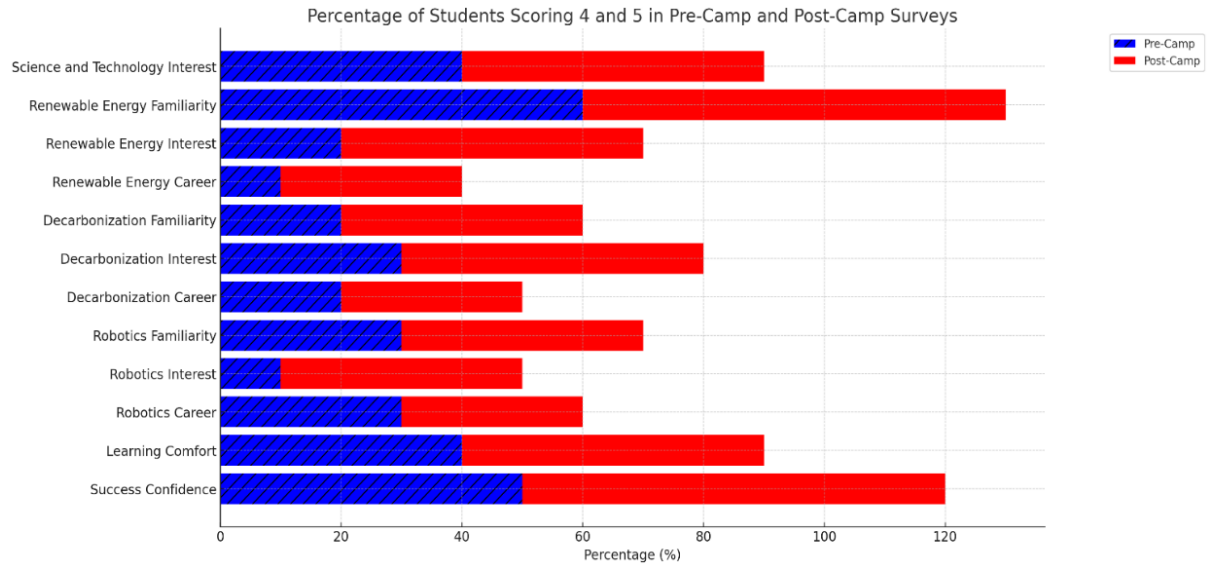

Figure 2. Pre- and Post-survey Data Showing Increases in Interest and Understanding

Observational Data and Engagement

Instructors noted high levels of engagement, particularly during hands-on activities such as solar panel assembly and robotics workshops. The robotics sessions were particularly impactful, with students showing increased enthusiasm and participation. Observations indicated that interactive and practical exercises contributed to sustained attention and deeper learning. Word clouds, as shown in Figure 3, generated from daily feedback captured students' key takeaways and highlighted the most resonant concepts. Terms such as 'solar energy,' 'robotics,' and 'sustainability' appeared frequently, reflecting the students' positive reception to these core topics.

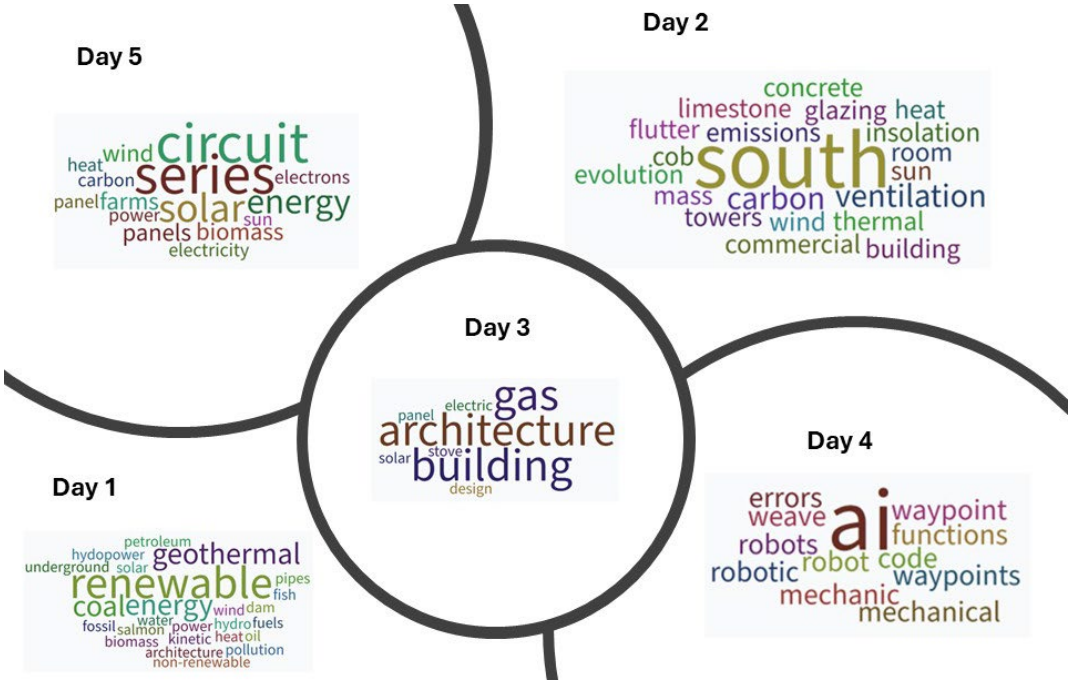

Figure 4. Word Cloud Showing Key Takeaways from Each Day of the Camp

Qualitative Feedback

Qualitative data from post-camp reflections and instructor notes provided further insight into the camp's impact. Many students shared that the hands-on activities made learning more relatable and enjoyable, with one participant noting, "I never thought building solar panels could be so interesting. It made me think about engineering as a real career path." Another student expressed increased confidence, stating, "I feel more prepared to take on STEM courses in school now." Instructors emphasized that the real-world applications demonstrated in the workshops helped bridge theoretical concepts and practical use. This alignment with Kolb's experiential learning model validated the camp's approach, reinforcing the importance of applying knowledge through doing.

Discussion

The discussion of the EmpowerEd summer camp results highlights its significant role in enhancing students' knowledge and interest in clean energy and STEM careers. The notable improvements in pre- and post-survey results underscore the effectiveness of the camp's curriculum, which combined theoretical instruction with hands-on activities. This method aligns with the growing body of research emphasizing the importance of experiential learning in STEM education [12]. Experiential learning frameworks assert that knowledge is best acquired through active engagement, allowing students to apply concepts in a practical context and reflect on their experiences. The improvements in familiarity and interest, as evidenced by survey data, demonstrate that this approach can be transformative, particularly for underrepresented groups.

The camp's ability to foster gains in renewable energy interest (from 44% to 78%) and decarbonization understanding (from 27% to 64%) is consistent with findings in related educational interventions. For example, a study by Alexander, et al. [15] found that project-based learning experiences significantly increased students' engagement and motivation to pursue STEM fields. These findings are also supported by Hiğde and Aktamış [8], who noted that hands-on activities can lead to deeper comprehension and sustained interest, particularly when learners see real-world applications of the knowledge they acquire. Student feedback from the EmpowerEd program reinforced these findings, as many participants expressed newfound enthusiasm for STEM disciplines and confidence in their abilities. This aligns with Salto, et al. [21], who identified a strong correlation between hands-on STEM learning experiences and increased self-efficacy among students from minority backgrounds. The camp's focus on practical projects, such as solar panel assembly and robotics integration, not only made complex topics more approachable but also fostered a sense of accomplishment that can be pivotal in shaping career aspirations.

Moreover, the positive reception of robotics sessions illustrates how specific content areas can resonate more strongly with students. As observed in the work by Yilmaz Yilmaz, et al. [13], incorporating robotics and technology into STEM programs can elevate student interest due to the interactive and dynamic nature of these subjects. The EmpowerEd camp's approach to integrating robotics as a core component of its curriculum validated these insights, showcasing its potential to attract students who might otherwise feel disconnected from more traditional STEM content.

Despite these successes, areas for improvement remain. The small sample size of 11 participants, although sufficient for initial findings, limits the generalizability of the results. Future expansions should aim for larger cohorts to bolster the reliability of the data and provide a more comprehensive understanding of the program's impact. Additionally, logistical constraints, such as limited time for each session, hindered the delivery of all planned content. Extending the duration of the camp or incorporating more preparatory sessions could enhance the depth of learning and allow students to engage with the material more thoroughly. These logistical considerations align with Ikevuje, et al. [5], who noted that the scalability of educational programs requires careful planning and additional resources to maintain quality and depth. Furthermore, certain areas of the survey results were lower than others, indicating potential areas of the curriculum that may need to be reinforced or adjusted to maximize student engagement and comprehension.

The significance of the EmpowerEd camp extends beyond its immediate outcomes; it represents a broader effort to address systemic disparities in STEM education for minority students. The underrepresentation of these groups in the clean energy workforce is well-documented [4], and programs like EmpowerEd play a crucial role in bridging this gap by providing early exposure and building foundational interest. Rhodes, et al. [6] emphasized that targeted educational outreach can mitigate some of the barriers faced by underrepresented students, such as limited access to resources and mentorship. Feedback mechanisms such as daily word clouds provided valuable insights into what resonated most with students, allowing for real-time adjustments to the curriculum. This adaptive strategy not only kept engagement high but also ensured that content delivery was student-centered, aligning with best practices in STEM education as noted by Kong, et al. [7]. Continuous feedback and iterative improvement are essential for the sustainability and effectiveness of such programs, pointing to a need for future camps to maintain these practices and possibly expand them to include more detailed assessments and follow-up studies. Additionally, tracking participants beyond the camp to evaluate their continued interest in STEM and clean energy fields would strengthen the assessment of long-term program impact.

In summary, the EmpowerEd summer camp demonstrated that immersive, hands-on learning experiences are effective in increasing interest and understanding of clean energy and STEM among underserved students. The alignment of the program's outcomes with established research underscores the importance of experiential education in fostering both interest and confidence. Addressing the noted challenges and expanding the program will be key steps in maximizing its impact and contributing to a more inclusive and diverse clean energy workforce. These findings add to the growing body of evidence supporting the role of targeted, interactive STEM outreach programs in shaping future educational and career pathways.

Conclusions

The EmpowerEd pilot summer camp effectively demonstrated the potential of targeted educational interventions to enhance interest and understanding of clean energy and STEM careers among underrepresented students. The significant increases observed in students' familiarity with renewable energy and decarbonization concepts, as well as their interest in STEM-related career paths, underscore the program's impact. This aligns with prior research showing that experiential learning approaches can foster greater engagement and knowledge

retention [12, 21]. The hands-on activities and real-world applications incorporated into the camp were particularly effective in maintaining student attention and promoting deeper learning, as evidenced by both survey data and qualitative feedback.

Despite the successes, the pilot also highlighted areas for improvement. The challenges related to sample size and session duration indicate the need for extended programming and broader recruitment efforts to enhance the scalability and impact of future camps. Addressing these limitations can further strengthen the program's ability to inspire and prepare students for academic and career pursuits in clean energy and STEM fields. Additionally, refining survey methodologies and incorporating follow-up assessments could provide a more comprehensive evaluation of long-term program effectiveness. Furthermore, expanding industry partnerships and mentorship opportunities could enhance student exposure to real-world applications and career pathways within the clean energy sector. Providing alumni tracking mechanisms and longitudinal studies on participant outcomes would allow for a deeper understanding of how early STEM interventions influence future academic and career decisions.

In conclusion, programs like EmpowerEd play a crucial role in bridging educational gaps and fostering diversity within the clean energy workforce. By providing immersive, hands-on learning experiences, such initiatives not only enhance students' technical knowledge but also build confidence and aspirations for future STEM careers. Expanding similar outreach efforts can contribute significantly to diversifying and strengthening the pipeline of future leaders in renewable energy and sustainability. Continued commitment to refining and scaling these programs is essential for fostering long-term interest and participation in clean energy education among underrepresented communities.

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