IJRES International Journal of Research in Education and Science

www.ijres.net

Empowering Future Engineers: The Impact of the Online iDRONE Camp on Students' STEM Affinity and Electrical Engineering Learning

Jiyoon Yoon [1] *, Jae Hyeon Ryu [2]

[1] Associate Professor, Department of Teacher and Administrator Preparation, College of Education, University of Texas Arlington, USA, 0000-0002-1268-5604
[2] Professor, Department of Soil and Water Systems, College of Agricultural and Life Sciences, University of Idaho Boise, USA, 0000-0002-4686-4723
* Corresponding author: Jiyoon Yoon (jiyoon@uta.edu)

Article Info

Article History

Received:
26 December 2025

Revised:
5 March 2026

Accepted:
5 May 2026

Published:
1 July 2026

Keywords

STEM identity
Project-based learning
Culturally-responsive pedagogy
Electrical engineering education
Drone technology

Abstract

Engaging middle and high school students in meaningful, hands-on STEM experiences is essential for nurturing future innovators in science, technology, engineering, and mathematics. This study examines the effects of the 2025 iDRONE National Youth Online Camp, a culturally responsive, project-based, inquiry-driven program designed to develop electrical engineering competencies through drone construction, circuit integration, and Arduino programming. Involving 53 diverse students across multiple regions, the camp employed scaffolded, hierarchical instruction aligned with laboratory principles of electrical engineering. Quantitative analyses of pre- and post-camp surveys revealed significant improvements in students' STEM identity ($\Delta = 0.35$) and self-concept of ability ($\Delta = 0.38$), alongside modest gains in STEM value and personal interest. Qualitative feedback underscored increased enthusiasm, confidence in technical skills, and a deeper understanding of STEM careers and applications. The findings demonstrate that immersive, culturally responsive online STEM programs combining active learning and real-world relevance can effectively foster STEM engagement, identity, and inclusion among youth. This scalable model holds promise for expanding high-quality STEM education and nurturing diverse future STEM professionals, particularly in underserved populations.

Citation: Yoon, J. & Ryu, J. H. (2026). Empowering future engineers: The impact of the online iDRONE camp on students' STEM affinity and electrical engineering learning. *International Journal of Research in Education and Science (IJRES), 12*(3), 680-695. https://doi.org/10.46328/ijres.6751

Introduction

Equipping students with meaningful engineering experiences is essential for fostering the development of future engineers and innovators. In particular, electrical engineering education benefits from pedagogical strategies that promote active, inquiry-based learning, and integration of real-world technological applications. Recent advances in engineering education emphasize the importance of experiential, project-based, and culturally responsive pedagogies that support diverse learners' engagement, identity development, and practical skills essential for the 21st-century workforce (Barron & Darling-Hammond, 2008; Gay, 2018; Liu et al., 2023; Tyson et al., 2007).

This study introduces and evaluates an innovative pedagogical model rooted in constructivist and inquiry-based learning theories (Siller, Nitzan-Tamar, & Kohen, 2023), tailored specifically for electrical engineering education within a scalable, online STEM camp—the iDRONE program. The approach aligns with established engineering education frameworks such as the Engineering Design Cycle and systems thinking models, emphasizing hands-on construction, iterative troubleshooting, and integration of hardware and software systems—core components necessary for authentic engineering practice (Helden, Zandbergen, Specht, & Gill, 2023; Ertugrul & Govindaraju, 2021).

Moreover, this research advances the pedagogical discourse by integrating culturally responsive teaching strategies (Aronson & Laughter, 2016; Ladson-Billings, 1995), addressing inclusivity and equity—long-standing goals shared by engineering educators worldwide. The intervention specifically targets the development of engineering identity, self-efficacy, and motivation among diverse youth populations, areas identified as critical for broadening participation in engineering fields (Liu et al., 2023; Tyson et al., 2007).

By systematically examining the impacts of project-based, inquiry-driven pedagogies within a digital, culturally inclusive environment, this study contributes to the growing body of engineering education research that seeks to innovate pedagogical approaches, improve student engagement, and foster the next generation of engineers with a strong sense of belonging and technical competence (Yosso, 2005; Zhao et al., 2024). It offers insights into scalable models that leverage emerging technologies such as drone systems—a rapidly evolving area within electrical and systems engineering—underscoring the potential for such approaches to transform engineering curricula and workforce preparation in the digital age.

Pedagogical Approach

The 2025 iDRONE National Youth Online Camp employed a pedagogical framework rooted in established engineering education research, emphasizing hands-on, inquiry-based, and scaffolded learning techniques aligned with best practices in electrical engineering instruction (Dym, Agogino, Eris, Frey, & Leifer, 2005; Hmelo-Silver & Barrows, 2006). The use of project-based, inquiry-driven models aligns with constructivist theories underpinning engineering education, which emphasize active engagement and authentic problem-solving as means to deepen understanding and foster professional identity formation (Jonassen, 2000; Papert, 1993).

Specifically, the curriculum incorporated hierarchical instructional strategies that reflect cognitive apprenticeship approaches, facilitating progressive mastery of complex electrical engineering skills through scaffolded tasks (Collins, Brown, & Newman, 1989). This tiered structure supports differentiated learning, ensuring a personalized trajectory where students construct knowledge incrementally, aligning with principles of guided inquiry that promote reflective thinking and iterative design—core to engineering practices (Vygotsky, 1978).

Moreover, integrating culturally responsive pedagogy within this technical framework is supported by research indicating that acknowledging students' cultural backgrounds enhances engagement and self-efficacy, thereby advancing inclusivity in engineering education (Aronson & Laughter, 2016; Ladson-Billings, 1995). The camp's emphasis on real-world applications and contextual relevance embodies an engineering design-based pedagogy that bridges theoretical concepts with practical, industry-relevant scenarios (Dym et al., 2005; Mohsin, Ali, & Usman, 2022).

The instructional model also drew on recent advances in virtual and remote engineering labs, emphasizing embodied cognition and collaborative inquiry via online platforms (Brehm, Rosenkrands, & Madsen, 2021; Korte & Crick, 2020). This approach not only aligns with current trends in remote engineering education but also expands access and inclusivity, which are critical for scaling engineering pedagogy beyond traditional settings (Herrington & Kervin, 2007; Korte & Crick, 2020).

In sum, the pedagogical approach exemplifies a synthesis of inquiry-based learning, hierarchical scaffolded instruction, culturally responsive strategies, and authentic engineering design, contributing to the advancement of engineering education methodologies that prioritize equity, active learning, and real-world relevance (Herrington & Kervin, 2007; Vygotsky, 1978).

Research Questions

This research study was conducted based on the following research questions:

1) How does participation in the iDRONE 2 Camp influence students' STEM identity, self-concept of ability, and personal interest in STEM?
2) In what ways do hands-on, project-based activities, such as drone construction, coding, and problem-solving, enhance students' technical skills, confidence, and engagement in STEM?
3) How does exposure to real-world STEM applications and expert seminars shape students' understanding of STEM careers and their future aspirations in science and engineering?
4) How do culturally responsive strategies, including peer collaboration and shared cultural experiences, impact students' engagement, confidence, and sense of belonging in STEM learning environments?

Method

This study was conducted using a mixed-methods research design, integrating quantitative measures from structured surveys with qualitative data derived from open-ended responses, observations, and student reflections.

This triangulation approach enhances the validity of the findings by cross-verifying evidence across multiple data sources (Creswell & Plano Clark, 2017).

Participants and Hierarchical Engagement

The study involved 53 middle and high school students who enrolled in the 2025 iDRONE National Youth Online Camp (INOC) conducted in May 2025. Participants were recruited nationally through partner schools and STEM outreach networks and represented diverse geographic regions across the United States, including Washington, D.C., Texas, California, Illinois, Minnesota, New York, Washington, Ohio, Florida, and Oregon. All participants and their guardians provided informed consent prior to participation in accordance with institutional research guidelines. Figure 1 presents a representative screenshot of student group configurations used during INOC.

Figure 1. Group Photo of the iDRONE Camp

To support rigorous instructional alignment and equitable access to learning, the camp employed a hierarchical and scaffolded instructional design, in which students were grouped into tiered cohorts based on self-reported prior experience with electronics, programming, and robotics, corroborated by a brief pre-camp diagnostic survey. Differentiated grouping is well established in STEM education research as an effective approach for addressing learner variability while maintaining high cognitive demand (Tomlinson, 2014; Vygotsky, 1978; Siller, Nitzan-Tamar, & Kohen, 2023). This structure enabled instructors to tailor pacing, instructional supports, and task complexity while preserving shared learning objectives across groups.

Instruction progressed sequentially from foundational to advanced competencies. During the initial phase, students engaged in guided instruction on basic electronics, circuit assembly, and safety protocols, emphasizing core electrical engineering concepts such as current flow, resistance, and circuit logic. Subsequent modules focused on hands-on drone construction and wiring, reinforcing principles of circuit design and systems integration. In the advanced phase, students completed programming and coding tasks using Arduino IDE and Python to implement autonomous flight behaviors and sensor-based control, consistent with constructionist and experiential learning models shown to enhance engineering learning outcomes (Kolb, 2015; Papert, 1993; Hmelo-Silver, Duncan, & Chinn, 2007).

The online camp spanned four consecutive days, with approximately four hours of instruction per day, combining synchronous instructor-led sessions, collaborative breakout activities, and asynchronous self-paced modules. This blended structure was intentionally designed to support sustained engagement while accommodating diverse learning needs, a practice supported by prior research in online and informal STEM learning environments (Means, Bakia, & Murphy, 2014; National Academies of Sciences, Engineering, and Medicine, 2018).

Project Overview & Electrical Engineering Focus

The iDRONE camp employed a tiered, multidisciplinary instructional design integrating hardware, software, and systems engineering principles. The curriculum was guided by a student-centered, goal-driven pedagogy grounded in established research on active learning, scaffolding, and engineering design-based instruction (Ertuğrul & Govindaraju, 2021; Hmelo-Silver & Barrows, 2006; Lou et al., 2021). This framework emphasized progressive skill development, where instructional complexity increased as students demonstrated conceptual and procedural mastery. Such hierarchical and scaffolded designs are widely recognized as effective in engineering education for supporting diverse learners while maintaining rigorous learning outcomes (Siller, Nitzan-Tamar, & Kohen, 2023).

The instructional sequence followed a structured engineering design cycle, including problem definition, design, implementation, testing, and iteration, consistent with best practices in undergraduate and pre-college engineering education (Dym et al., 2005; Kolodner, 1997). Figure 2 presents a representative instructional page used during guided drone assembly:

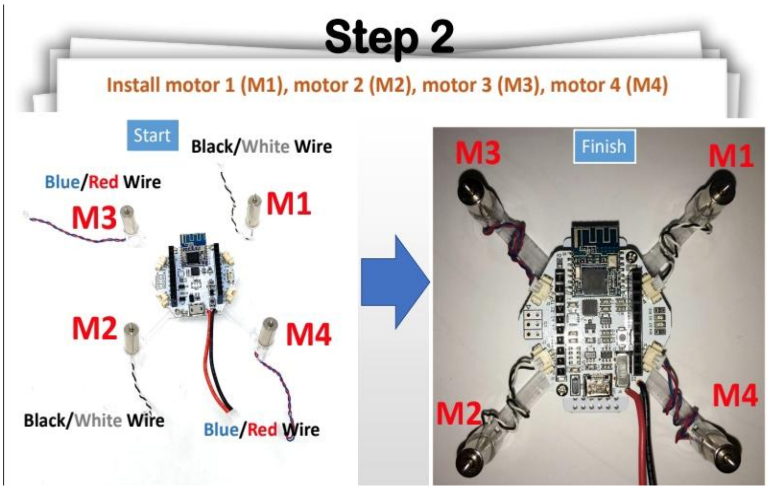

Figure 2. Sample Instruction Page for Assembling Drones Using the iDRONE Development Kits

- *Drone Construction & Electrical Design:* Participants constructed quadcopter drones using standardized iDRONE development kits, with a primary emphasis on electrical circuitry and power systems. Students assembled and wired motors, electronic speed controllers (ESCs), GPS modules, and onboard sensors (e.g., ultrasonic sensors, accelerometers, and gyroscopes). Instruction focused on power distribution design, electrical load management, and safe wiring practices to ensure reliable operation. Troubleshooting activities required students to diagnose wiring faults, improper grounding, and voltage inconsistencies, reinforcing core electrical engineering concepts related to circuit safety and system reliability (Ertuğrul & Govindaraju, 2021).

- *Electronics & Wiring:* Following mechanical assembly, students engaged in circuit analysis, sensor calibration, and controller configuration. Instruction centered on the use of Arduino-based microcontrollers, selected for their widespread adoption in engineering education and industry prototyping (Ertuğrul & Govindaraju, 2021). Students examined how microcontrollers manage power regulation, sensor data acquisition, and motor control, applying key electrical engineering concepts such as pulse width modulation (PWM), signal conditioning, and mitigation of electromagnetic interference. These activities supported conceptual understanding of embedded systems and real-time control architectures (Ertuğrul & Govindaraju, 2021).
- *Programming & Coding:* Students developed embedded programs using the Arduino IDE, writing and debugging C/C++ code to control motors and sensors. Instruction included implementation of closed-loop feedback systems, most notably PID (Proportional–Integral–Derivative) controllers, to stabilize drone flight. Through guided tutorials and experimentation, students adjusted PID gains and analyzed system responses, applying foundational principles of control systems engineering (Doyle et al., 2015; Åström & Hägglund, 2006). Figure 3 illustrates a sample motor-testing demonstration used to support this learning phase.

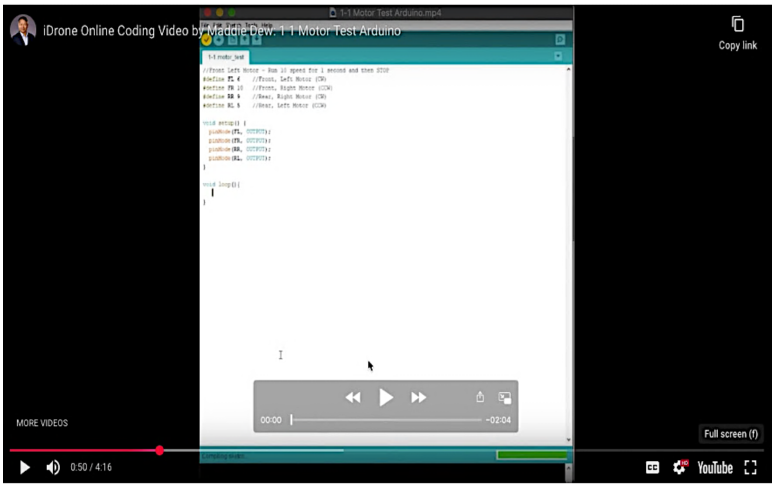

Figure 3. Coding Demonstration Video for Motor Test Arduino

- *Experimentation & Technical Problem-Solving:* Participants conducted iterative testing cycles, analyzing sensor outputs, refining wiring configurations, and tuning control parameters to optimize flight performance. This experimentation mirrored authentic engineering practice by emphasizing data-driven decision making, fault isolation, and performance optimization. Such iterative design experiences have been shown to significantly enhance students' engineering reasoning, persistence, and problem-solving abilities (Dym et al., 2005; Kolodner, 1997).
- *Team Collaboration & Technical Communication:* Students worked in tiered teams, completing tasks that progressed from basic circuit assembly to full system integration (Figure 4). Each team produced technical posters and oral presentations documenting their design rationale, challenges, and solutions

(Loughran et al., 2014). These collaborative and communicative components were intentionally embedded to develop professional engineering competencies, including teamwork and technical communication, which are core outcomes emphasized in engineering education research (Dym et al., 2005).

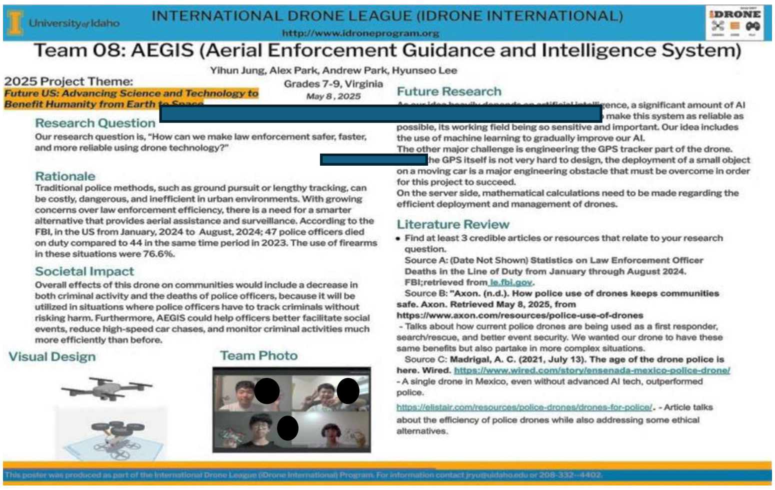

Figure 4. iDRONE Posters by Team 8

- *Expert Seminars & Industry Integration:* To contextualize learning, the camp included expert seminars led by professionals from NASA, industry partners, and regulatory agencies. These sessions connected camp activities to real-world applications such as precision agriculture, environmental monitoring, and autonomous navigation systems. Integrating industry perspectives has been shown to strengthen students' understanding of engineering relevance and career pathways (Liu, et al., 2023).

Assessment & Hierarchical Progression

Consistent with the camp's hierarchical instructional framework, student learning was evaluated using a tiered assessment system aligned with progressive skill development in electrical engineering and computing. Advancement to more complex project tasks was contingent upon demonstrated mastery of prerequisite competencies, including electrical wiring accuracy, circuit logic comprehension, and functional coding implementation. This criterion-based progression allowed instructional resources and mentoring support to be allocated responsively, ensuring that learners engaged with appropriately challenging tasks while minimizing cognitive overload. Prior research indicates that such mastery-oriented, hierarchical assessment structures promote deeper conceptual understanding and learner confidence in engineering contexts (Biggs & Tang, 2011; Mahoney & Hall, 2017).

Student performance evidence included successful completion of wiring checkpoints, functional motor tests, verified sensor integration, and execution of stable control code. These checkpoints served both formative and summative purposes, providing immediate feedback while documenting learning progression across instructional phases (Kier et al., 2013; Liu et al., 2023).

Data Collection

A mixed-methods research design was employed to capture both measurable changes in students' STEM-related dispositions and rich contextual insights into their learning experiences. Combining quantitative and qualitative data sources enhanced methodological triangulation and strengthened the credibility of findings (Creswell & Plano Clark, 2017).

Quantitative data were collected using a pre–post STEM Affinity Survey, administered at the beginning and conclusion of the camp. The instrument measured four theoretically grounded constructs:

- STEM Identity, reinforced through team-based poster presentations and public articulation of engineering ideas; • Self-Concept of Ability, developed through successful drone construction, wiring, and coding tasks using the Arduino IDE;
- STEM Value, emphasized through expert seminars highlighting societal applications of drones, robotics, and AI;
- Attitudes Toward STEM, shaped through collaborative problem-solving and peer interaction that framed STEM as engaging and meaningful.

The survey was adapted from previously validated instruments, including the STEM Career Interest Survey (Kier et al., 2013), the SIC-STEM framework (Roller et al., 2018), and established STEM identity measures (Liu et al., 2023). Internal consistency reliability was assessed using Cronbach's alpha, with coefficients ranging from 0.84 to 0.91 across subscales, exceeding commonly accepted thresholds for educational research reliability (Tavakol & Dennick, 2011). Pre–post comparisons were conducted to examine changes in STEM affinity over the duration of the camp.

Qualitative data were gathered from open-ended survey responses, facilitator field notes, and student reflections generated during poster sessions. These data sources were analyzed using a thematic analysis approach, involving iterative coding, category refinement, and cross-source comparison to identify recurring patterns related to STEM engagement, problem-solving strategies, and perceptions of engineering learning (Braun & Clarke, 2006). This qualitative strand provided explanatory depth, contextualizing quantitative trends and illuminating how instructional features influenced student experiences.

Results

To better understand the impact of the iDRONE camp on students' perceptions and attitudes towards STEM, both quantitative and qualitative data were systematically analyzed. The quantitative analysis focused on measuring changes in specific constructs such as STEM identity, self-concept of ability, STEM value, and personal interest in STEM through pre- and post-surveys. Complementary qualitative data provided contextual insights into students' experiences, capturing their reflections on learning, confidence, and engagement. Together, these data sources allowed for a comprehensive evaluation of the program's effectiveness in fostering STEM-related dispositions and identifying areas for future improvement.

Quantitative Findings from Pre-and Post STEM Affinity Survey

Based on a comparison of the Pre- and Post-STEM Affinity Survey data and student interviews from the iDRONE 2 Camp, notable growth was observed in how youth scientists and engineers perceive and engage with STEM. The findings, summarized in Table 1, demonstrate measurable improvement across five key areas.

Table 1. Quantitative Summary

Category	Pre-Survey Score	Post-Survey Score	Change	t-statistic	P-value
STEM Identity	3.63	3.98	0.35	2.9235	0.0431
Self-Concept of Ability	3.87	4.25	0.38	2.9235	0.0431
STEM Value	4.4	4.47	0.07	2.9235	0.0431
Personal Interest	3.98	4.11	0.13	2.9235	0.0431
Attitudes Toward STEM	3.31	3.38	0.07	2.9235	0.0431

The average scores from the pre- and post-surveys were compared using the bar graph shown in Figure 5.

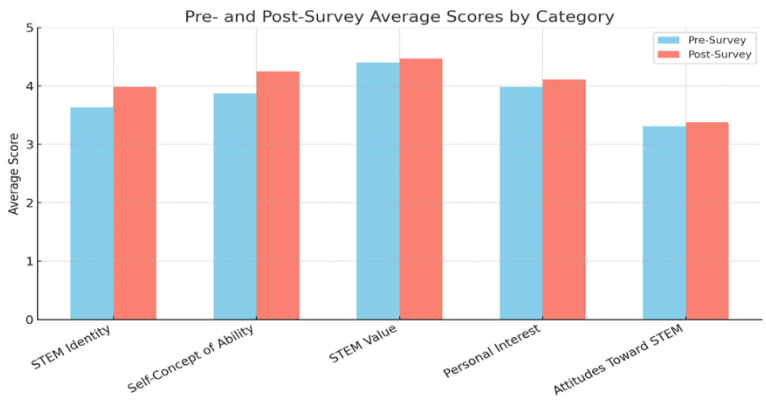

Figure 5. Bar Graph for the Differences in Mean Scores before and after the iDRONE2

Based on the table and bar graph, the study shows that participation in the program led to modest but meaningful improvements in students' STEM-related perceptions:

- Mean scores for *STEM Identity* increased from 3.63 to 3.98, representing a gain of 0.35. This change suggests that, following the intervention, students more strongly identified themselves as capable participants in STEM contexts.
- Similarly, *Self-Concept of Ability* showed an increase from 3.87 to 4.25 (Δ = 0.38), indicating enhanced confidence in students' STEM-related skills and problem-solving abilities after completing the camp's hands-on engineering tasks.
- Measures of *STEM Value and Attitudes Toward STEM* remained high at both pre- and post-test, with small increases of 0.07 in each construct. These relatively modest gains likely reflect a ceiling effect, as students entered the program with already positive perceptions of STEM.
- *Personal Interest in STEM* increased from 3.98 to 4.11, demonstrating a slight but positive growth in curiosity and engagement with STEM topics. Inferential analysis indicated that the overall pre–post

differences were statistically significant, $t = 2.92$, $p = .043$, meeting the conventional $\alpha = .05$ threshold.

This finding suggests that observed improvements were unlikely to be due to random variation alone. Although the magnitude of change was moderate, these results are notable given the short duration of the intervention and the already high baseline levels of STEM affinity among participants. Collectively, the quantitative findings indicate that the camp's project-based, inquiry-driven, and culturally responsive instructional design contributed to measurable gains in students' STEM confidence and identity.

Qualitative Findings from Open Responses

Qualitative analyses of open-ended survey responses and student reflections provided convergent evidence supporting the quantitative trends. Several salient themes emerged:

- *Increased Interest in STEM.* Students frequently described heightened enthusiasm for drones, robotics, coding, and engineering. One participant noted, *"I liked coding and building drones. It helped me understand how drones work and made me want to learn more about engineering."* Another shared, *"I loved the STEM activities and wish we could do this longer."* These responses reflect not only enjoyment but sustained interest in continued STEM learning.
- *Confidence and Skill Development.* Many students reported increased confidence in their technical abilities and a clearer understanding of STEM careers. As one student explained, *"This camp helped me realize how drones can be used in real jobs, like search and rescue or helping the environment."* Such reflections align with observed gains in self-concept of ability.
- *Career Awareness and Real-World Relevance.* Participants frequently referenced the application of drone technology to real-world challenges, particularly environmental monitoring and disaster response. One student remarked, *"I didn't know science could help save lives like that."* These statements underscore the importance of authentic, context-rich learning experiences in shaping students' STEM aspirations.
- *Cultural Relevance and Sense of Belonging.* Students also emphasized the value of learning alongside peers who shared similar cultural backgrounds. Comments such as *"I felt more comfortable and confident"* and *"It made learning feel more personal"* highlight how culturally responsive structures supported engagement and participation.

Taken together, the quantitative and qualitative findings indicate that the iDRONE camp produced meaningful short-term gains in students' STEM identity, confidence, and engagement, particularly through hands-on engineering activities, real-world applications, and culturally inclusive learning environments. However, these findings should be interpreted in light of several limitations. The study relied on immediate post-program data and did not include longitudinal follow-up to assess the durability of observed gains. Additionally, the absence of a control or comparison group limits causal attribution.

Future research should incorporate longitudinal designs and comparative analyses to examine whether improvements in STEM perceptions persist over time and translate into sustained participation in STEM coursework or career pathways. Despite these limitations, the present results provide promising evidence that integrated, culturally responsive, project-based STEM programs can positively influence students' perceptions and experiences in engineering education.

Discussion

The second iteration of the iDRONE Camp demonstrated a more pronounced impact on students' STEM affinity compared to the first, underscoring the effectiveness of enhancements made in the program's design. Key improvements included more structured support for coding tasks, the integration of culturally relevant pedagogy, and explicit connections to real-world STEM careers. These modifications contributed to measurable gains in students' STEM identity, self-concept of ability, and personal interest, as evidenced by statistically significant changes in pre- and post-survey scores.

Importantly, the incorporation of culturally responsive pedagogy played a pivotal role in fostering a sense of belonging and engagement among students. Research indicates that culturally relevant contexts and informal STEM experiences can enhance learners' self-efficacy, identity development, and persistence in STEM fields, particularly for underserved student populations (Gay, 2018; Ladson-Billings, 1995). Summer camps and informal STEM interventions are shown to increase STEM interest, motivation, and perceived relevance of STEM careers by providing authentic, hands-on learning that aligns with students' lived experiences (Barajas-Salazar et al., 2025; Boone et al., 2024).

The second iteration's emphasis on active, project-based learning and real-world applications aligns with broader evidence from engineering and STEM education research. Project-based learning has been linked to gains in self-efficacy, deeper conceptual understanding, and sustained interest in STEM disciplines across grade levels and educational contexts (Guo et al., 2020; National Academies of Sciences, Engineering, and Medicine, 2021). Furthermore, such design principles are consistent with recommendations for engineering curricula that integrate culturally responsive frameworks and experiential learning to strengthen student engagement and retention (LaCosse et al., 2025; Samsudin et al., 2020).

Despite positive short-term effects, challenges such as occasional instruction clarity were noted by students. These were mitigated by peer collaboration and instructor support, highlighting the importance of scaffolding and social learning in facilitating STEM learning environments (Ertugrul & Govindaraju, 2021; Hmelo-Silver et al., 2007).

Conclusion

The second iteration of the iDRONE Camp demonstrates that thoughtfully designed, active, and culturally responsive STEM programs can yield significant short-term improvements in students' STEM identities, confidence, and interest. By emphasizing project-based learning, real-world relevance, and cultural inclusion, the program effectively engaged diverse students and fostered a sense of belonging and motivation toward STEM careers (Barajas-Salazar et al., 2025; Boone et al., 2024).

These findings support calls to integrate culturally relevant, project-based learning within formal engineering education. Incorporating such approaches into curricula—such as through engineering design projects grounded in community contexts or augmenting introductory engineering courses with culturally inclusive challenges—may enrich student engagement and better prepare learners for real-world problem solving (Guo et al., 2020; National Academies of Sciences, Engineering, and Medicine, 2021). Educators can adapt elements of scalable online, culturally responsive designs—such as modular project sequences, industry mentors, and flexible collaboration frameworks—to complement traditional coursework and broaden participation in engineering pathways (LaCosse et al., 2025; Samsudin et al., 2020).

At the systems level, these results align with recommendations for aligning STEM educational experiences with workforce development goals. Programs that intentionally connect learners to authentic engineering design practices and culturally relevant contexts can build competencies sought by employers while also expanding access for underrepresented groups in the engineering pipeline (Gay, 2018; Ladson-Billings, 1995). Policymakers and institutional leaders should consider supporting infrastructures that promote such scalable and integrative STEM interventions across K–12 and postsecondary settings (Barajas-Salazar et al., 2025; Boone et al., 2024).

To fully understand the lasting impact of programs like iDRONE, future studies should adopt longitudinal designs to track students' continued STEM engagement and career interests over time. Longitudinal evidence has been shown to provide richer insights into how early interventions influence persistence and identity formation across educational transitions (National Academies of Sciences, Engineering, and Medicine, 2021). Additionally, comparative research that includes control or alternative intervention groups will enhance causal inference regarding program effectiveness and clarify which pedagogical features most powerfully shape outcomes (Guo et al., 2020; Samsudin et al., 2020). Exploring such comparisons with formal classroom engineering programs or other informal STEM initiatives would contribute to evidence-based educational innovation.

For broader implementation, refining instructional protocols and extending program duration or post-camp reinforcement (such as mentorship or follow-up projects) may strengthen the impact. The adaptability of online and hybrid models also offers opportunities for wider dissemination across varied geographic and socio-economic contexts (LaCosse et al., 2025; Boone et al., 2024). Ultimately, integrating authentic, culturally responsive, and hands-on STEM experiences holds great promise for cultivating the next generation of diverse, capable STEM innovators prepared for an era of artificial intelligence and automation (Gay, 2018; Ladson-Billings, 1995).

Recommendations

Based on the findings of this study, the following recommendations are proposed to inform future research and strengthen educational practice related to the iDRONE Camp and similar STEM interventions:

- *Implement Longitudinal Studies* Future research should adopt longitudinal designs to assess the sustained impact of the iDRONE program on students' STEM identities, interests, and career pathways. Tracking participants over time will provide insights into the long-term effectiveness of culturally responsive, project-based STEM interventions (National Academies of Sciences, Engineering, and Medicine, 2021).

- *Incorporate Control or Comparison Groups* To strengthen causal claims about the program's effectiveness, future studies should include control groups or compare different pedagogical approaches. This will help determine which specific elements—such as culturally responsive pedagogy, hands-on activities, or industry engagement—most significantly influence outcomes (Guo et al., 2020; Samsudin et al., 2020).
- *Expand Program Duration and Follow-up Support* Extending the length of the camp or integrating follow-up activities such as ongoing mentorship, project continuation, or peer networks could reinforce learning gains and sustain engagement. This approach aligns with evidence that extended or reinforced interventions are more likely to produce durable impacts (Boone et al., 2024; LaCosse et al., 2025).
- *Explore Diverse Demographic and Geographic Contexts* To increase generalizability, future research should involve participants from varied socio-economic, cultural, and geographic backgrounds. Examining program effects across diverse populations can help identify specific needs and tailor strategies for inclusive engagement (Barajas-Salazar et al., 2025; Ladson-Billings, 1995).
- *Assess Long-term Career and Educational Outcomes* Studies should investigate whether participation in programs like iDRONE influences students' actual pursuit of STEM coursework, postsecondary degrees, and careers. Such data will clarify the program's effectiveness in contributing to pipeline development (Gay, 2018; National Academies of Sciences, Engineering, and Medicine, 2021).
- *Refine and* **Scale Instructional Models** Further research is needed to optimize the hierarchical, scaffolded instructional strategies and culturally responsive elements to maximize engagement and learning outcomes. Evaluating different models and scalability options can facilitate broader dissemination in formal and informal settings (Siller et al., 2023; Guo et al., 2020).
- *Integrate Industry and Community Partnerships* Deepening connections with industry professionals, community organizations, and local stakeholders can enrich contextual relevance and provide authentic mentorship opportunities. Future designs should embed such partnerships to enhance relevance and career awareness (Ertugrul & Govindaraju, 2021; Gay, 2018).
- *Assess Impact on Underrepresented and Disadvantaged Groups* Prioritize examining how culturally responsive, project-based programs influence participation, confidence, and persistence among underrepresented youth in STEM. Identifying effective culturally inclusive strategies can inform policies and practices aimed at reducing disparities (Ladson-Billings, 1995; Boone et al., 2024).
- *Develop Clear Metrics and Standardized Assessment Tools* Enhance the measurement of program impacts using validated, reliable instruments and clear benchmarks related to STEM identity, self-efficacy, and motivation. Consistent metrics will enable more robust comparison across studies and programs (Kier et al., 2013; Liu et al., 2023).
- *Disseminate Best Practices and Scale-up Strategies* Finally, sharing successful instructional elements, culturally responsive strategies, and scalable models through publications, workshops, and online platforms will support wider adoption and adaptation of effective STEM interventions globally.

Statements and Declarations

Acknowledgments/Notes: During the preparation of this manuscript, the author used AI-assisted technology

(ChatGPT) for language editing and proofreading support. Following this assistance, the author reviewed, revised, and finalized all content and assumes full responsibility for the accuracy, integrity, and originality of the work.

Supplementary Materials: Not applicable.

Author Contributions: All authors contributed equally. All authors have read and agreed to the published version of the manuscript

Funding: This work was supported by the Korean-American Scientists and Engineers Association (KSEA), which provided funding and organizational support for the iDRONE Youth Camp. Additionally, in-kind contribution was made by iDRONE program at https://www.iDRONEprogram.org.

Data Availability: Not applicable.

Ethics Approval: The study was approved by the IRB Committee of the University of Texas Arlington. All methods were performed in accordance with the study protocol and ethical guidelines and regulations.

Informed Consent: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflicts of interest.

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