2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #50053

Building Engineering Self-Efficacy Across the Pipeline: Outcomes from Three NSF-Funded Summer Programs in Sustainable Refrigerant Technology

Dr. Casey Michael Williams Ph.D., The University of Kansas

Casey Williams, Industry Liaison Officer at the University of Kansas Haiying Long, Professor of Educational Psychology at University of Kansas

Dr. Haiying Long

Haiying Long is a professor in the Department of Educational Psychology at the University of Kansas.

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Funding acknowledgment:
This material is based upon work supported by the National Science Foundation under Grant No. 2330175. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Abstract

Engineering workforce development requires interventions that build technical competence and engineering self-efficacy (confidence in performing engineering-relevant tasks). Grounded in social cognitive theory and Social Cognitive Career Theory (SCCT), this short paper reports outcomes from three pipeline-aligned, NSF Engineering Research Center (ERC) summer programs implemented by the Environmentally Applied Refrigerant Technology Hub (EARTH) in Summer 2025: FROST Research Experiences for Undergraduates (REU; 10 weeks; n=6), HEART Research Experiences for Teachers (RET; 4 weeks; n=6), and a Summer Venture pre-college experience (3.5 days; n=10). Evaluation combined role-appropriate self-efficacy measures for REU and RET participants (pre/post) with satisfaction and open-ended feedback across all programs; Summer Venture used an end-of-program survey because the short duration limits interpretability of traditional pre/post change estimates. Participants across small, demographically diverse cohorts reported increased HVACR and sustainable engineering knowledge, high mentoring value, and strengthened confidence communicating technical ideas. Pre/post patterns indicated meaningful gains in REU research self-efficacy (notably presenting findings and independent project work) and RET engineering-teaching self-efficacy (guiding design processes and integrating engineering into curricula), with comparatively smaller gains in experimental design (REU) and facilitating hands-on design activities and STEM-career preparation (RET). Summer Venture participants reported strong mentoring and peer learning but only moderate confidence regarding engineering pathways, aligning with lower ratings for hands-on HVACR engineering exposure. Implications are provided for designing short-duration programs to strengthen self-efficacy through explicit mastery cycles, structured mentoring, and SCCT-informed pathway scaffolding.

Keywords: engineering self-efficacy, SCCT, summer programs, REU, RET, HVACR workforce development, NSF ERC

Introduction and Motivation

National workforce priorities in heating, ventilation, air conditioning, and refrigeration (HVACR) include accelerating the adoption of sustainable refrigerants and building a workforce capable of designing, operating, and maintaining next-generation systems. Across STEM domains, persistence through key transitions is shaped not only by preparation but by self-efficacy—domain- and task-specific beliefs about one's capability to perform required actions. In Bandura's social cognitive theory, self-efficacy develops through mastery experiences, vicarious learning, social persuasion, and affective or physiological states. SCCT extends this framework to educational and career trajectories, specifying how learning experiences influence interests and choice goals through self-efficacy in interaction with outcome expectations and contextual supports and barriers [1]–[3].

Summer programs are widely used to provide authentic, mentored engineering experiences, yet evaluation often occurs program-by-program rather than as coordinated pipeline systems. In Summer 2025, EARTH implemented three aligned education and workforce development programs targeting distinct roles—high school students, undergraduates, and educators—with a shared theory of change: repeated opportunities to perform meaningful engineering tasks, paired with mentoring and community belonging, would strengthen engineering self-efficacy, particularly in communication and applied problem solving, and support next-step educational choices. This paper summarizes activities and outcomes across the three programs and highlights actionable design implications for short-duration interventions.

Program Overview

Program	Audience and duration (Summer 2025)	Core experiences	Evaluation measures
FROST REU	Undergraduates; 10 weeks; n=6 (paired n=5)	HVACR and sustainable refrigerant research with faculty and graduate mentoring; poster and oral presentation deliverables	15-item research self-efficacy pre/post; post-program satisfaction and open-ended feedback
HEART RET	Educators; 4 weeks; n=6 (paired n=6)	Hands-on research and prototype-oriented work with classroom translation; graduate mentor support	12-item engineering-teaching self-efficacy pre/post; post-program satisfaction and open-ended feedback; mentor survey (n=5)
Summer Venture	High school students; 3.5 days; n=10 (survey n=9)	College readiness and engineering pathway exposure; near-peer mentoring; community building	End-of-program perceived gains and satisfaction; open-ended feedback

Methods

Design

A multi-program evaluation approach combined pre/post self-efficacy measurement (where feasible) with end-of-program satisfaction and open-ended feedback. Given small cohort sizes typical of intensive summer programs, findings are interpreted as program-level evidence for continuous improvement rather than population-generalizable estimates.

Participants

REU participants (n=6) completed surveys; paired pre/post analyses used matched responses (n=5). The REU cohort included participants from both in-state and out-of-state institutions and represented a mix of genders and racial and ethnic backgrounds. Demographic characteristics are reported only in aggregate to protect confidentiality.

RET educators (n=6) completed pre/post measures. The cohort included four HVACR instructors from local community colleges and two secondary-level STEM teachers. Participants included both male and female educators and reflected varied professional backgrounds; all educators were based within the regional Midwest workforce ecosystem served by the ERC.

Summer Venture enrolled ten high school students, with nine completing the end-of-program survey. Participants were drawn primarily from the local Kansas region, with intentional recruitment of students from groups historically underrepresented in engineering. As with the other programs, demographic reporting is aggregated due to small sample size.

Five graduate mentors participating in the RET program completed a mentor survey.

Measures

REU self-efficacy was assessed using a 15-item, 5-point confidence scale adapted from validated undergraduate engineering self-efficacy instruments (e.g., Mamaril et al.) and contextualized to HVACR research tasks and deliverables [4]. RET self-efficacy used a 12-item, 5-point scale adapted from the Teaching Engineering Self-Efficacy Scale and related engineering-teaching efficacy work (e.g., Yoon et al.) [5], [6]. Summer Venture used an end-of-program survey assessing perceived gains and satisfaction; a pre/post design was not employed because the 3.5-day duration risks novelty-driven noise and limited interpretability of change estimates.

Analysis

Results are summarized descriptively at the item level (direction and relative magnitude of change) and triangulated with open-ended feedback to identify consistent strengths, constraints, and opportunities for refinement.

Results

Cross-Program Patterns

Across programs, participants reported (a) increased HVACR and sustainable engineering knowledge, (b) strengthened confidence communicating technical ideas, and (c) high value placed on mentoring and peer collaboration. These outcomes indicate that the programs successfully met primary learning and engagement goals. In contrast, longer-horizon pathway intentions (e.g., engineering major selection or advanced degree interest) showed more modest movement, suggesting the need for explicit SCCT-informed pathway scaffolding.

FROST REU

Paired pre/post results indicated increases on nearly all research self-efficacy items (paired n=5), with the largest gains in communication-linked mastery tasks, including creating a poster or presentation, presenting findings, and working independently on an engineering research project. Smaller gains were observed in experimental design and early-stage research ownership (identifying problems, designing experiments, conducting experiments). Post-program feedback emphasized mentor availability and encouragement and recommended clearer expectations, a poster rubric, and scheduling final presentations later in the program.

HEART RET

Educators increased on all measured engineering-teaching self-efficacy items (paired n=6). The largest gains clustered around guiding the engineering design process, integrating engineering principles into curricula, conducting hands-on research, and developing sustainability-focused STEM lessons. Smaller gains were observed in facilitating hands-on design activities in classrooms and preparing students for STEM careers. Overall satisfaction was high; comparatively weaker ratings related to program organization and opportunities to connect with industry partners. Graduate mentors reported developmental benefits, particularly growth in teaching and communication skills, while noting that clearer expectations and improved organization would increase willingness to mentor again.

Summer Venture

End-of-program responses (n=9) indicated strong mentoring and peer learning experiences and increased knowledge of college applications and financial aid. Reported gains in engineering pathway confidence were moderate, and the lowest ratings related to the amount of hands-on HVACR engineering exposure. These findings aligned with participant suggestions for more structured scheduling and additional build-and-test activities.

Discussion and Design Implications

Interpreting Outcomes Through Self-Efficacy Theory

The strongest gains appeared in domains tightly coupled to observable performance tasks and feedback cycles, particularly communication deliverables such as posters and presentations and facilitation of the engineering design process. This pattern aligns with Bandura's emphasis on mastery experiences as the most influential source of self-efficacy beliefs, supported by vicarious learning and social persuasion through mentoring.

Explaining Modest Pathway-Intention Shifts via SCCT

SCCT posits that self-efficacy contributes to interests and goals, but that educational and career intentions also depend on outcome expectations and contextual supports and barriers. High satisfaction alongside modest shifts in longer-horizon intentions may reflect informed realism about fit or insufficient pathway scaffolding to translate near-term confidence into choice goals.

Actionable Refinements

Three cross-cutting refinements emerge from the evidence: (1) design explicit mastery cycles around two to three target competencies with planned checkpoints and rubrics; (2) formalize mentoring as a program deliverable through clearer role expectations, onboarding, and weekly structures; and (3) embed pathway supports, such as career maps, panels, financial aid guidance, and next-step action planning, to influence outcome expectations and reduce perceived barriers. Program-specific refinements include additional experimental design scaffolding and later poster timing for REU; a classroom facilitation module and STEM-career toolkit for RET; and a compact build–test–iterate challenge to increase hands-on intensity in Summer Venture.

Limitations and Future Work

Cohorts were small (REU n=6, RET n=6, Summer Venture n=10), limiting statistical power and generalizability. Measures were adapted from validated scales; future cycles should more fully document adaptation procedures and report internal consistency. The evaluation focused on short-term self-report outcomes; follow-up at 6–12 months is recommended to assess persistence indicators such as continued research engagement, course-taking, and classroom implementation of engineering design.

Future work will also explore alignment with emerging ERC-wide quantitative assessment efforts, including recently published work on common self-efficacy instruments and shared web-based platforms designed to support cross-ERC comparison and longitudinal tracking [7]. Such alignment would strengthen comparability while preserving sensitivity to program-specific contexts.

Conclusion

Across three coordinated EARTH summer programs spanning high school students, undergraduates, and educators, participants reported increased HVACR and sustainable engineering knowledge, high satisfaction, and strengthened confidence communicating technical ideas. Pre/post evidence supports meaningful self-efficacy gains in research communication and design-process teaching while highlighting constraints related to time, organization, and hands-on intensity. These findings suggest that short-duration programs can effectively strengthen engineering self-efficacy when structured around authentic performance tasks, frequent feedback, and well-supported mentoring. Translating these gains into longer-horizon educational and career choices likely requires intentional, SCCT-informed pathway supports.

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