General Science Course Use of Inquiry-Guided Learning to Develop Near-Space Experiments

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Abstract

Science, Technology, Engineering, and Mathematics (STEM) literacy and practices are important to workforce development. STEM literacy and practices are also contributing factors to undergraduate students' enrollment and retention in STEM fields of study. Therefore, schools and faculty are challenged to find means to educate, engage, and empower their students to be competent and impactful participants in their local, state, and national workforce. As a result, first- and second-year college students have been afforded a general science course to conceive, develop, build, and conduct near-space experiments based on their own perspectives about our world using weather balloons to deliver their student-generated experiments to near-space. These near-space experiments are developed using science and engineering practices found in educational and professional settings and foster students' curiosities, discovery, and expression.

This article provides a longitudinal report of the science and engineering self-efficacy of 102 undergraduate students in a 17-week general education Science course at a metropolitan university in the United States Midwest over four academic semesters. Qualitative, ordinal data were collected for students' self-efficacy perceptions using the Engineering Skills Self-Efficacy Scale (ESSES). The ESSES identifies an individual's self-efficacy for performing specific engineering skills: experimental, tinkering, and design. Two of the ESSES subscales were administered (Experimental Self-Efficacy Scale and Design Self-Efficacy Scale) at the start and end of the course. The Experimental Self-Efficacy subscale was used to identify students' science perceptions, and the Design Self-Efficacy subscale was used to identify students' engineering perceptions. The ESSES subscales were administered as pre-tests and post-tests over four semesters for the general education Science course.

Inquiry-Guided Learning | Self-efficacy | Near-space experiments

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1. Introduction

The University of Nebraska at Omaha (UNO) is a metropolitan university founded in 1908 and is comprised on six colleges which have impacted the city, state, region, nation, and world and whose impact is a result of UNO's mission and vision to transform and improve the quality of life. In 2012, UNO published its *UNO Campus Priorities: Charting a Clear Vision for 20/20* [1]. One of the campus priorities outlined "STEM As a Priority" [1]. STEM (Science, Technology, Engineering, and Mathematics) was deemed critical to UNO's metropolitan university mission. UNO stated it "must come together with area K12 school districts, community colleges, informal educational organizations and businesses to help make STEM concepts come alive, and to help students to see the relevance and excitement in what they learn" [1, p. 29]. The university proposed various external and internal funding endeavors, creating methods of review and recognition, establishing a STEM learning center, and developing new STEM workshops and courses [1].

Two years later, Project HALON (High Altitude Learning Over Nebraska) was conceptualized and started. Project HALON was inspired by the work of Christopher Koehler at the University of Colorado at Boulder with freshman engineering students [2]. Project HALON focused on middle and high school students' design, build, test, and launch of experiments conceived for upper atmosphere conditions [3]. Project HALON high altitude experiments were achieved using large weather balloons filled with helium or hydrogen. Middle and high school student teams for the project were solicited from local secondary schools. Teams were generally composed of afterschool Science club students and their respective faculty sponsor [3]. Project HALON conducted three successful yearly launches and recoveries over four years with public and parochial schools from throughout the metropolitan area.

Project HALON was funded by the NASA Nebraska Space Grant (NSG). To build on the effectiveness of Project HALON to engage youth in STEM concepts and practices at the postsecondary level, NASA NSG arranged for UNO faculty and the Project HALON facilitator to visit the University of Colorado at Boulder and Christopher Koehler in 2016. The visit was foundational to addressing one of UNO's campus STEM priorities to develop a new STEM course. The visiting group met with Koehler during his freshman engineering course and observed students near-space experiments' proposal presentations, toured teaching and learning spaces, workshops, and laboratories. The group also interviewed students who worked in Koehler's small satellite laboratory and learned about their responsibilities, motivations, and goals. At the end of visit, the group and Koehler discussed the expectations and necessities of establishing and implementing a similar course at UNO.

Over the next year and a half, partnerships and funding were secured along with curriculum development to establish a course for STEM education both on campus through the Teacher Education Department (TED) and in the community, and to demonstrate to effectiveness of engineering education in traditional curricula. In 2018, TED 2800 Science Methods and Design was approved by UNO as a 4-hour Natural & Physical Science general education course with laboratory. The course was also cross listed with a STEM prefix (i.e., STEM 2800) to ensure non-education majors and advisors outside of the College of Education would have access to enroll in the course.

Since 2018, TED/STEM 2800 has had nine attempts at launches with eight successful attempts and eight successful recoveries for: 243 students, 94% freshman/sophomores, and 55% underrepresented ethnic groups. In 2021, TED/STEM 2800 was retitled to present the course content more explicitly in its title: Science Experimentation and Engineering Design (SEED). One section was offered in the Fall of 2018 and beginning Fall 2024, there will be two sections offered each fall and spring. The cross-listing of TED/STEM 2800 SEED has been supported across campus through the Thompson Learning Community (a First-Generation student scholarship program) reserving a "sheltered" section each fall for a cohort class, the Aviation Institute directing its advisors to promote the course with 1st and 2nd year aviation majors, and the course being accepted as an approved technical science course for the University of Nebraska-Lincoln College of Engineering's Civil & Environmental Engineering Department.

SEED provides a unique undergraduate, innovative STEM experience for first- and second-year students. The Thompson Learning Community's (TLC) Buffett Scholars sheltered course and other sections primarily consists of pre-Education majors. The diversity of majors in the TLC section or those that enroll in STEM 2800, along with the mix of Early Childhood, Elementary, and Secondary Education content areas requires a thoughtful, practical means to effectively engage all students regardless of their backgrounds in STEM. Therefore, the course framework for SEED is a key element to its success.

1.1. Course Description

TED/STEM 2800 Science Experimentation and Engineering Design (SEED) addresses emerging trends in STEM (Science, Technology, Engineering, and Mathematics) Education and uses Science and Engineering Practices (SEPs) [4] as a platform for the teaching and learning of science content and fulfills four hours of the general education Natural & Physical Sciences requirement for the University of Nebraska at Omaha. SEED fosters 21st Century Learning [5] through study and work in active, team-based experiential learning environments through all phases of near-space experiments (NSEs) using high-altitude ballooning. NSEs require research question development, experiment hardware fabrication, experiment software integration, payload launch and recovery, data analysis, and formal experiments' results reporting. SEPs are central to students' experiences and work in the course, as the course models the interdisciplinary connectedness of academic fields, industry, and the community to encourage collaboration and discovery to effectively implement STEM concepts, practices, and innovation. Teaching and learning in SEED is comprised of teaming, weekly written reflections, various laboratories, engineering design reviews, numerous informal and formal presentations, and performing a high-altitude balloon launch and recovery.

1.2. Course Framework

TED/STEM 2800 SEED is based on the theoretical frameworks of Constructivist Learning Theory (CLT) and Inquiry-Guided Learning (IGL). CLT posits that learners construct knowledge and meaning from personal experiences of doing and creating, thus learners piece together new information with their prior knowledge, therefore creating their own learning experiences [6]. CLT can contribute to learner self-initiative and autonomy, foster the use of varied resources (such as laboratory-provided and/or self-sourced), encourage dialogue between learner/teacher and learner/peers, promotes learner inquiry through open-ended questions between the learner/teacher and learner/peers; and assess learner's knowledge and skills through application and performance of open (or ill)-structured tasks [6]. CLT is further supported using Inquiry-Guided Learning (IGL) in that IGL suggests learners should be provided opportunities to construct their knowledge identifying and analyzing data and/or scenarios during problem-solving exercises such as laboratories [7].

IGL provides a framework for new knowledge acquisition along with skills and dispositions in learners through increasingly independent investigations of questions, problems, and cases for which there may not be a single objective solution [8]. Learning in SEED is scaffolded according to the first three of the four inquiry levels of IGL: (1) Limited; (2) Structured; (3) Guided; (4) Open [9]. These inquiry levels were implemented in an inquiry-guided engineering laboratory and outlined as follows [10]:

1. Limited inquiry was used as the basis for traditional in-person laboratories where the task objective(s), resource(s), and outcome(s) were prescribed;

2. Structured inquiry provided the task objective(s) and resource(s), and the learner(s) were challenged to research and provide an outcome(s);
3. Guided inquiry provided only the task objective(s) and the learner researched the necessary resource(s) to provide an outcome(s); and
4. Open inquiry provided a case (usually real-world or industry-related) which required the learner to research and propose the task objective(s), necessary resource(s), and outcome(s).

1.3. Coursework

TED/STEM 2800 SEED provides experiential learning opportunities that improves engaged interactions amongst student "science team" members and their effective use and development of Science and Engineering Practices over the semester (Fig. 1). Students build content/subject knowledge through weekly reflections of in-class topics, discussions, and science exploration [11].

	Topics (Activity)	**Assignments**
Week 1	Introduction to Course The Sciences	Syllabus and Objectives
Week 2	The Scientific Method Team Science Lab #1	Science Reflection #1 Evaluation #1
Week 3	Research Question Team Science Lab #2	Team Science Report #1 Science Reflection #2
Week 4	Single-Board Microprocessors Single-Board Microprocessors Lab	Team Science Report #2 Science Reflection #3 Evaluation #2
Week 5	Module Infrastructures Module Infrastructure Lab	Team Research Question Science Reflection #4
Week 6	Module Infstr Presentation Design Reviews	Module Infrastructure Evaluation #3
Week 7	Preliminary Design Lab Preliminary Design Presentation	Preliminary Design Review Science Reflection #5
Week 8	Critical Design Lab Critical Design Presentation	Critical Design Review Evaluation #4

	Topics (Activity)	**Assignments**
Week 9	Fall Break – No Class Flight Readiness Lab	Science Reflection #6
Week 10	Flight Readiness Presentation Launch Readiness Lab	Flight Readiness Review Evaluation #5
Week 11	Launch Readiness Presentation **Team Science Lab #3 (NSEs)**	Launch Readiness Review Near Space Experiments
Week 12	Data Analysis Data Analysis Lab	Science Reflection #7 Evaluation #6
Week 13	Presentation Development Team Presentations	Team Science Report #3 Team Presentation
Week 14	Team Presentations Holiday Break - No Class	Team Presentation Evaluation #7
Week 15	Optimization Optimization Presentation	Optimization Presentation Science Reflection #8
Week 16	Study Week	Evaluation #8
Week 17	Final	Formal Poster Presentation

Fig. 1. TED/STEM 2800 Science Experimentation and Engineering Design Semester Schedule

Within "science teams", student scientists conduct scaffolded team experiments that gradually develop their science experimentation and engineering design knowledge and skills. Laboratory experiments include water quality tests of potable water sources across the university's campus, mold (air quality) tests throughout all floors of the course's building, and various atmospheric properties tests using commercially-off-the-shelf equipment like the PocketLab Air and Raspberry Pi and various atmospheric sensors. The work on these laboratories help to form the teamwork attributes necessary to work effectively toward their laboratory goals. Open communication and timely feedback are essential to completing the laboratories and the required science laboratory report. To support the development of constructive teamwork attributes, students complete bi-weekly self and team evaluations. The evaluations 1.) consist of a written reflection of the individual's contributions and impediments to the team's work and a statement to how they can increase their contributions and reduce their impediments and 2.) an online anonymous teammate evaluation [12].

Science teams research and determine the necessary hardware and software such as with Raspberry Pi, Arduino, sensors, and peripherals are required, alongside novel means, to conduct experiments. Science teams then utilize engineering practices to design and built their respective team's near-space experiments through the NASA Student Launch: Handbook and Request for Proposal Design Review [13]. The Design Review consists of the Preliminary Design Review, Critical Design Review, Flight Readiness Review, and Launch Readiness Review. Each review provides a structured analysis of detailed stages necessary to ensure a successful launch of the near-space experiments (NSEs) via a high-altitude balloon. In addition, science teams are trained and participate in the tracking and reporting of their NSE payloads in flight. Upon recovery and analysis of their NSEs, science teams compose detailed science laboratory reports and research poster of their experiments. Formal poster presentations are conducted before invited faculty and staff from the university's STEM leadership, Teacher Education Department faculty, and students' invited guests.

2. Discussion

Since 2018, TED/STEM 2800 Science Experimentation and Engineering Design (SEED) has become a recognized success at UNO and in the community. SEED engages students in STEM concepts and their applications and is one of the first UNO STEM cross listed courses. The course fosters 21st Century Learning through study and work in active, experiential learning environments through all phases of near-space experiments on high-altitude balloon platforms. Over 200 students have developed and presented supervised research and formal poster presentations. SEED students have been the most diverse at UNO with classes of more than half underrepresented minorities, nearly 2-to-1 female-to-male, and more than half first-generation. The course has been successful in helping students meet UNO Natural & Physical Sciences Student Learning Outcomes [14] (Fig. 2).

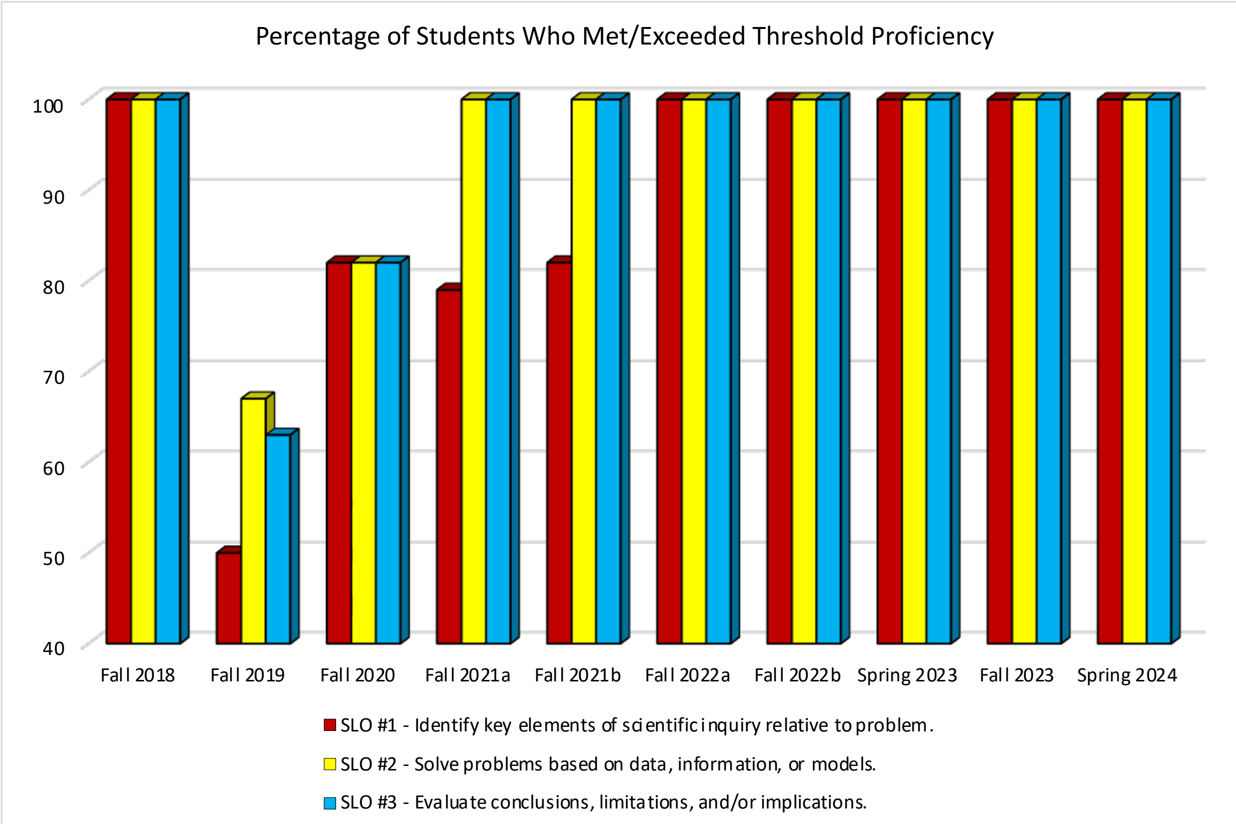


Fig. 2. Natural & Physical Sciences Student Learning Outcomes (SLOs) for TED/STEM 2800 Science Experimentation and Engineering Design

2.1. Impact on Self-Efficacy

SEED Student Learning Outcomes have been consistently met and thus prompted a study of specific intrinsic values students shared after taking the course such as a gained confidence in their interest in science or in doing an engineering-related task. The Engineering Skills Self-Efficacy Scale (ESSES) [15] was first administered Fall 2022 as a pre-test/post-test qualitative study to determine self-efficacy gain in science and engineering. Over four semesters (Fall 2022 – Spring 2024), students reported an increased self-efficacy in both science and engineering, as measured by the ESSES subscales Experimental Self-Efficacy and Design Self-Efficacy (Table I).

TABLE I
ENGINEERING SKILLS SELF-EFFICACY SUBSCALES PRE-TEST/POST-TEST GAINS

Subscale	Fall 2022	Spring 2023	Fall 2023	Spring 2024
Experimental				
I can perform experiments independently.	39%	14%	34%	9%
I can analyze data resulting from experiments.	9%	4%	30%	10%
I can orally communicate results of experiments.	9%	4%	22%	5%
I can communicate results of experiments in written form.	22%	14%	30%	20%

I can solve problems using a computer.	0%	19%	-5%	4%
Design				
I can design new things.	22%	33%	43%	25%
I can identify a design need.	31%	52%	47%	47%
I can develop design solutions.	29%	41%	38%	35%
I can evaluate a design.	30%	42%	34%	36%
I can recognize changes needed for a design solution to work.	14%	42%	25%	30%

Science self-efficacy (Experimental subscale) reported modest gains across its five items in each of the semesters (Figures 3-6). Students generally reported a *certainty* confidence in science at the start of the course thus resulting in modest gains by the end of the course. The largest consistent gain over the four semesters in science self-efficacy centered on the item "I can communicate results of experiments in written form.". SEED requires students and science teams to compose various written science products such as Science Reflections, Design Reviews, and Science Laboratory Reports (Fig. 1) throughout the course. Despite the level of confidence (*certainty*) students report at the start of the course, the post-tests report that students do gain science self-efficacy.

Engineering self-efficacy (Design subscale) reported large gains across its five items in each of the semesters (Figures 3-6). Students consistently reported a similar amount of *uncertainty* and *certainty* confidence in engineering at the start of the course. Unlike science self-efficacy at the start of the course, students' engineering self-efficacy is lower likely because they do not have prior exposure to engineering concepts and practices as engineering is not a core K-12 subject like science. As a result, engineering self-efficacy is reported as the largest consistent gain subscale over the four semesters. SEED requires science teams to employ the NASA Design Reviews [13] to conceptualize, design, build, test, and launch near-space experiments. The levels of engineering self-efficacy (*uncertainty*) students report at the start of the course for the five Design subscale items (Figures 3-6) are improved to near consensus *certainty* on the post-tests' reports.

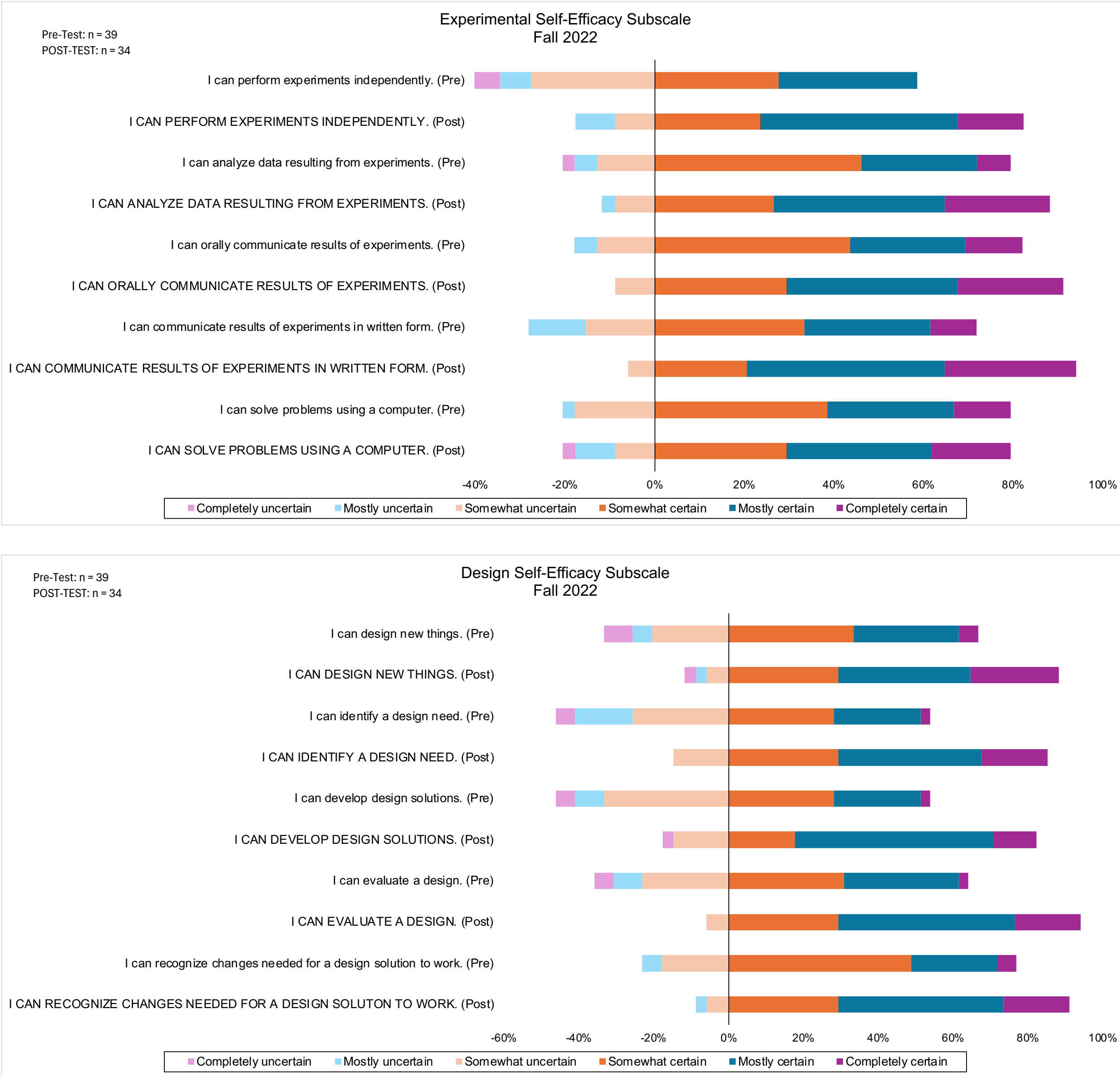


Fig. 3. Students' Responses on the Engineering Skills Self-Efficacy Scale in Science (Experimental) and Engineering (Design), Pre-Test and Post-Test, Fall 2022

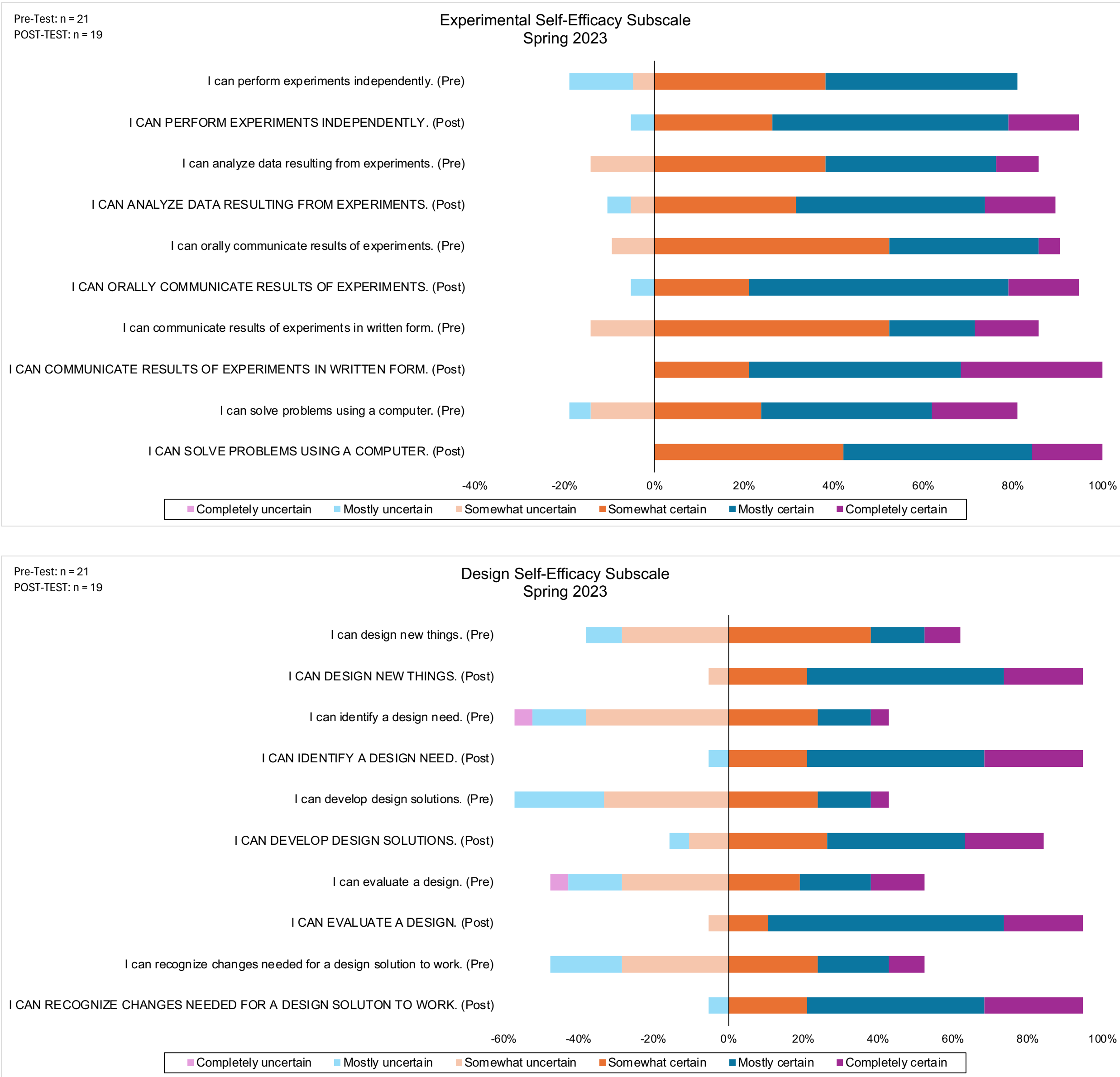
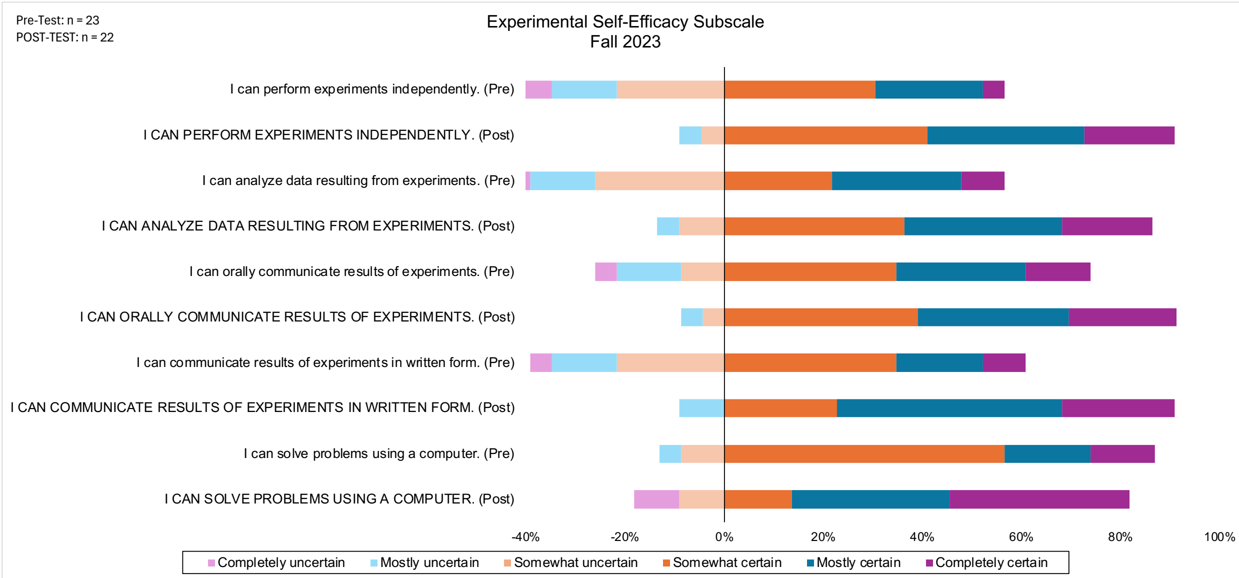


Fig. 4. Students' Responses on the Engineering Skills Self-Efficacy Scale in Science (Experimental) and Engineering (Design), Pre-Test and Post-Test, Spring 2023



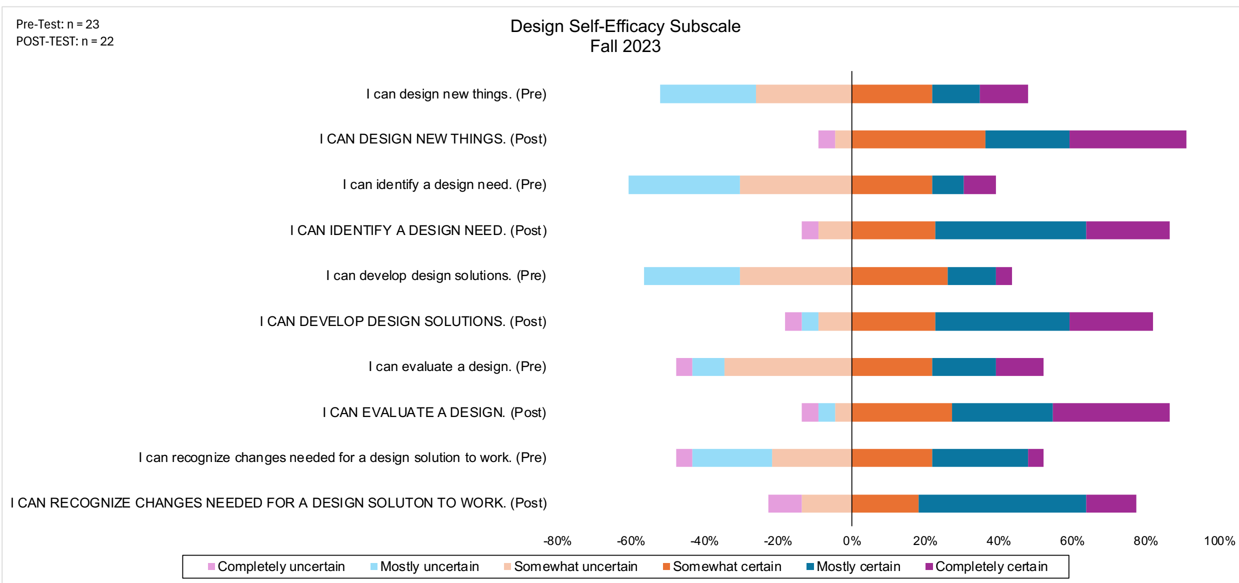
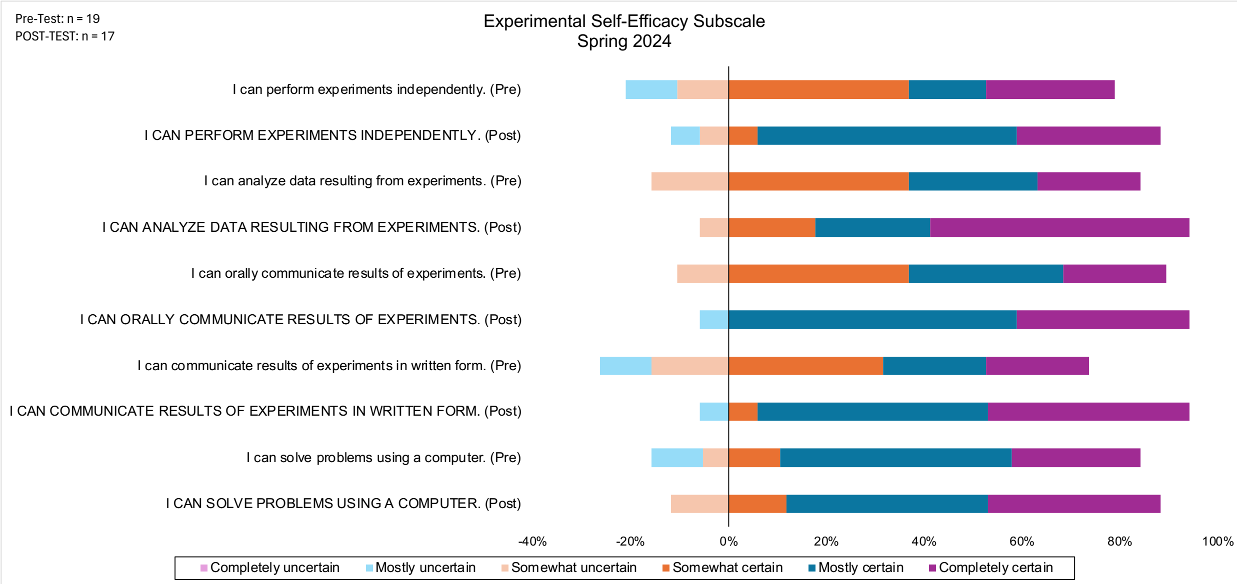


Fig. 5. Students' Responses on the Engineering Skills Self-Efficacy Scale in Science (Experimental) and Engineering (Design), Pre-Test and Post-Test, Fall 2023



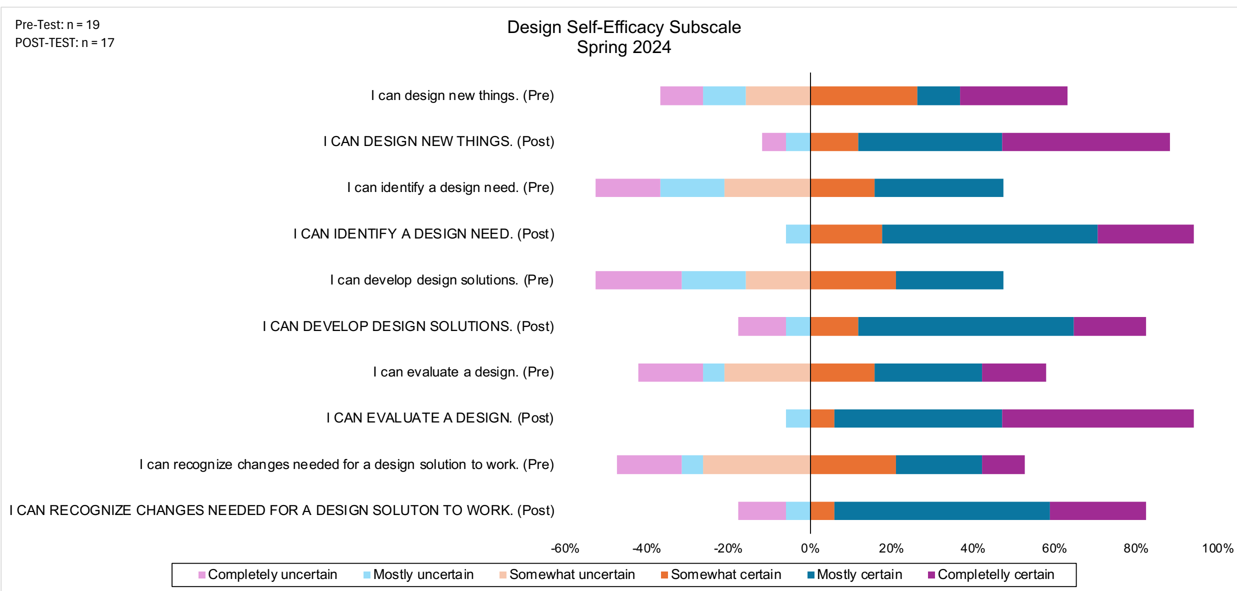


Fig. 6. Students' Responses on the Engineering Skills Self-Efficacy Scale in Science (Experimental) and Engineering (Design), Pre-Test and Post-Test, Spring 2024

3. Future Direction

The effectiveness of TED/STEM 2800 SEED has led to the concept of a course that would follow SEED that involves applied engineering hardware and software components to meet its course objectives. The conceptual course, Advanced Near Space Experimental Research (ANSER), will also be a general education science course that reinforces integrative STEM concepts within an operations-focused near-space research program. The course will require students to work in a team-based experiential learning environment and apply the science and engineering concepts and practices to plan, design, and conduct advanced near-space experiments from a high-altitude balloon platform to meet solicited research goals. ANSER will be in collaboration with the

Nebraska Defense Research Corporation (NDRC) and NASA Nebraska Space Grant. Therefore, ANSER will focus on the fourth inquiry level of Inquiry-Guided Learning: Open [9]. Open inquiry will address a case provided by the NDRC, or other stakeholder(s), which will require science teams to research and propose the task objective(s), necessary resource(s), and outcome(s) for a successful near-space experiment [10].

Underpinning the established research elements of SEED are the experiment hardware fabrication, software development, testing, and operational processes used to build and safely control the experiment and collect real-time data for analysis by the science teams. ANSER will model the interdisciplinary connectedness of academic fields, industry, government, and the community to encourage collaboration and discovery to effectively implement STEM concepts, practices, and innovation.

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