Self-Evaluation of the Introduction to Scientific Research Course Design Based on the Affinity Research Groups (ARG) Model

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Abstract:
Our paper reports the self-evaluation of a research-based course taught in the School of Engineering at the University of Bridgeport. The University of Bridgeport received funding from the National Science Foundation Hispanic Serving Institution program in 2022. The project, called Project Achieve, aimed to foster, engage, and retain underserved and underrepresented undergraduate men and women, with particular emphasis on Hispanic students in engineering and computer science majors. As a part of the project, a multi-disciplinary effort among faculty in mechanical, electrical, computer engineering, and computer science designed an undergraduate course, Introduction to Scientific Research, based on the evidence-based Affinity Research Group model, one of the signature models in the Computing Alliance of Hispanic-Serving Institutions (CAHSI) Network. This 2-credit yearlong course offered undergraduate engineering and computer science students an opportunity to participate in authentic research experiences with faculty and graduate students. It had two components: lecture and research activities. Students spent two to four hours per week working on research projects as a team. The course, Introduction to Scientific Research, is cross-listed among Computer, Electrical, Mechanical, and Computer Science programs. The course objectives are (1) To identify real-world problems and survey their broader impacts, (2) To brainstorm possible solutions to real-world research problems, (3) To apply the scientific method while solving a real-world research problem, (4) To develop basic laboratory skills and safety procedures relevant to the project, (5) To communicate scientific information in oral formats effectively, (6) To collaborate effectively with a team to solve a scientific problem. The paper presents the faculty, graduate students, and undergraduate students' feedback and experiences following participation in the project as the outcome while providing the details of the course design and its implementation in the engineering curricula.

Keywords: Undergraduate research, the Affinity Research Groups (ARG) model, retention, self-efficacy

1. Introduction

First-generation and underrepresented minorities face significant barriers to completing their degrees in science and engineering. They are present from K-12 education to university and broader institutional levels [1]. For instance, historically underrepresented in science, technology, engineering, and mathematics (STEM), Hispanic adults continue to be an underutilized talent pool. Although lower Hispanic enrollments in higher education have been cited as a primary barrier to

STEM careers, more Hispanic high school students are enrolling in higher education. They represent the second largest ethno-racial group among undergraduates (25%). Despite the relatively high representation in undergraduate education, they represent only 8% of the total STEM workforce. Women and Hispanic women remain severely underrepresented in STEM fields. Currently, women comprise 25% of the STEM workforce, and Hispanic women comprise less than 2% of the STEM workforce [1]. Addressing the equity gaps in male-dominated fields is essential to move forward. Studies reported that the organizational structures of computer science and engineering programs could reinforce biases towards first-generation women, create hostile classroom environments and harmful stereotypes upholding institutional racism and sexism, offer significantly fewer interactions with instructors than men and continuing-generation women, and unsupportive and discouraging environments. Most undergraduate engineering and Computer Science (CS) students only start working on research-based engineering projects through the Senior Design Project in their senior year. Although the students may take elective research-based courses - usually graduate-level - in their senior year, the classroom environments do not create a friendly and encouraging environment for female undergraduate students. Some of the reasons are:
(1) Female students are not invited to join a team of male students.
(2) Female students feel shy or discouraged from joining a team.
(3) Female students are assigned note-taking or report-writing tasks, while male students work in teams on computing and project development.
(4) The team members may not consider Female students' ideas or suggestions.
(5) Teams schedule their meetings on days/times at a location that female students do not prefer.
(6) Course instructors do not observe the team dynamics, so they are unaware of female students' struggles and challenges in teams and fitting into the profession.
(7) The course instructor/male students are biased toward female students.

While Hispanic students have demonstrated interest in STEM disciplines, including engineering and computer science, comparable to their White peers, Hispanic students are less likely to graduate with a STEM degree [2]. The STEM sector continues to grow, and workforce shortages stymie progress while the underrepresentation of hispanic and black/african americans in STEM disciplines persists. Several factors contribute to hispanic underrepresentation in computer science and engineering majors and the STEM workforce. These contributors include:

1. Less access to STEM classes at the high school level.
2. Hispanic students have lower GPAs than overrepresented students. These gaps are primarily attributed to structural inequalities, lower social and economic capital, and financial obstacles to higher education.
3. Lower confidence in their STEM knowledge and capacity.
4. Hispanic students' schooling paths differ from overrepresented students, including beginning baccalaureate education at community colleges [3].

Hispanic-Serving Institutions like the University of Bridgeport have provided greater access to higher education for Hispanic students, a growing population in the US. The Hispanic Association of Colleges and Universities reports that Hispanic Serving Institutions (HSIs) comprise 17% of US higher education institutions and enroll 67% of all Hispanic undergraduates [4]. HSIs provide innovative recruitment, educational approaches, academic support, and financial aid to overcome barriers to graduation and entry into the STEM workforce.

Our project, called Project ACHIEVE, implemented the Affinity Research Group Model from the Computing Alliance for Hispanic-Serving Institutions (CAHSI) through an engaging undergraduate research-based course, Introduction to Scientific Research. This course offered an opportunity to participate in research experiences with faculty and graduate students in Computer Science, Computer, Electrical, and Mechanical Engineering programs. The overarching goal of this project was to implement, evaluate, and produce preliminary knowledge on evidence-based methods to overcome significant barriers to entry and persistence among undergraduate engineering and computer science degree programs. The project adapted the Affinity Research Group Model, a set of practices built on a cooperative team framework to support creating and maintaining dynamic and inclusive research groups. It piloted an intervention to mitigate known barriers to maintaining engagement in and completing STEM majors, focusing on students' acquisition of career-related skills, connectedness to professionals, and building their confidence to complete an intellectually demanding course of study. It helped to answer the following research questions. (1) How does the Affinity Research Group Model play a role in increasing students' persistence in engineering and computer science majors during their first two years of study? (2) How does the model increase students' engineering self-efficacy during their first two years of study? (3) What approaches are used by the faculty when implementing the model that leads to developing students' research skills (laboratory research skills followed by publication) – a community of practice, engagement with students outside the classroom, etc.? It will also develop a community of practice for faculty to apply the model to other underrepresented STEM undergraduates.

The project adapted the Affinity Research Group (ARG) Model, developed at the University of Texas, El Paso, a Hispanic Serving Institution, which adapted the model to benefit those traditionally underrepresented students in higher education with differing abilities in undergraduate computing programs. The model has also been developed, refined, and disseminated through multiple NSF grants, along with the US Department of Energy and the Institute
of Electrical and Electronics Engineers (IEEE)[6]. The approach is promising for Hispanic and underrepresented students in STEM because it is structured to help students to acquire the skills for successful research participation and professional development rather than assuming that professional skills have already been developed by graduation[5, 6, 7]. Research on ARG for Hispanic students has shown positive results and is endorsed as a best practice by the CAHSI, a National INCLUDES Alliance [8]. Studies have found that successful participation in the ARG model is associated with student growth and development in science-related fields and a transformation of identity from student to professional [9, 10]. ARG participation promotes self-efficacy. ARG has been designed as a situated learning approach involving an apprentice-style research experience [6, 10]. The focus is on inviting students with potential but who lack confidence, low self-efficacy, or a sense of belonging [11]. Research on the model has demonstrated several positive outcomes for traditionally underrepresented students, including:
a) Increased retention and participation in undergraduate computing majors [12].
b) Increased likelihood of participants going to graduate school [13].
c) Increased GPA for engineering students with moderate academic performance [14].
d) Higher student participation rate in publishing compared with NSF REU students [10].
Students learn and apply the knowledge and skills required for research and cooperative work in an ARG.

Members share a core purpose, and the research group is designed to emphasize the conscious and explicit development of students' disciplinary knowledge, research abilities, and team skills. An ARG deliberately organizes activities to develop students' disciplinary knowledge, research abilities, and team skills. The ARG framework offers a purpose to faculty as well as students.
The following sections present the undergraduate-level research course design process and the first semester evaluations.

2. Introduction to Scientific Research: An undergraduate-level research course design

We adopted an undergraduate research course, NSCI 120: Introductory Scientific Research Challenges, from Wiess
School of Natural Sciences at Rice University. We designed ours as an elective 1+1 course, arranged into two components: lecture and research activities. This course allowed first-year students to participate in authentic research experiences with faculty and graduate students. Students spend two to four hours per week engaged in open-ended research projects. Introduction to Scientific Research course cross-listed between electrical, mechanical, and computer engineering and computer science programs. Four professors taught the course as co-instructors who guided and mentored student work on four research projects in electrical, mechanical, computer engineering, and computer science disciplines.

2.1 Student recruitment

Each research team, composed of five undergraduates, one graduate student, and one faculty member, used the ARG model in team meetings. Targeted students were the ones entering their second year or third year in their program.
We used several approaches to recruit students for the course:
1) faculty members invited first-generation minority, or underrepresented students as potential participants based on their interest in STEM,
2) Upper-level students were encouraged to invite first-year students and establish a buddy (ally) system and
3) The existing core engineering courses are used to advertise and encourage students to register.

The course was structured such that the whole class met once a month, with the remainder of the time spent in the ARG research teams in weekly meetings for research and reporting. Four graduate students provide research support for the ARG research team faculty mentors and were peer mentors to the students enrolled in the course. The course modules included conducting hands-on experiments, developing solutions for real-life problems, writing algorithms, presenting their results in a group, classroom, and school, reporting experimental results, developing teamwork skills, communication skills, networking, etc.

2.2. Course objectives and salient features

The Introduction to Scientific Research course focused on utilizing the scientific method to investigate open-ended research challenges. Course objectives were defined as follows: Students will learn:

1. To apply the scientific method while solving a real-world research problem.
2. To develop basic laboratory skills and safety procedures relevant to the project.
3. To effectively communicate scientific information in written and oral formats.
4. To collaborate effectively with a team to solve a scientific problem.
5. To recognize the importance of unexpected results and troubleshoot an experiment.

Salient features of the course:

1. An annual orientation for students registered in the course was conducted at the beginning of the two-semester course sequence. The orientation explained the ARG group organization and its goals. It provided opportunities for students to start connections with each other and be introduced to the intentional structure and functions of the ARG model.
2. Course enrollment was limited to 20 students, with five students per research group. Targeted students were entering their second or third year, with ethno-racial minority students receiving priority. As space permitted, another underrepresented minority group of ENG/CS majors were permitted to enroll. Ultimately, this course was offered to all ENG/CS majors.
3. The course was structured such that the whole class meets once a month, with the remainder of the time spent in the ARG research teams in weekly meetings for research and reporting.
4. Four graduate students provided research support for the teams. Course completers, who are undergraduate students, were hired to serve as mentors for the following year. This near-peer relationship fostered continuity and community integration into the ARG team and the discipline.
5. Each ARG research team worked towards a deliverable of a research poster they presented at an annual conference such as the American Society of Engineering Education (ASEE). In addition, some students led authorship for a student research publication or be invited to be an author with an ENG/CS faculty member.

2.3. Grading Policy

Students submitted their assigned work to Canvas each week. Late assignments received a 5% deduction per day. If a student had difficulty completing tasks on time, the graduate student and instructor discussed a plan to help the student. We used the following points for the learning objectives mentioned above.

Table 1. Introduction to Scientific Research course assignments and grading policy

Learning objective	**Assignment**	**Points/Total points**
Scientific method	Hypothesis & Aims Experimental design plans	20 points & 40 points
Laboratory safety	Safety quiz, Safety tour	15 points total
Reading scientific literature	Reading literature quizzes (4) Article discussions (2) Background literature summaries (2)	25 points total 10 points total 50 points total
Laboratory skills	Technique worksheets Instructor evaluation	25 points total 100 points total
Written communication	Report section drafts (3) Lab report sections Final lab report Lab notebook checks Weekly reflections	30 points total 35 points total 120 points 100 points total 150 points total
Oral communication	Hypothesis & update presentations	50 points total
Poster presentation	Poster draft presentation Final poster presentation	30 points 100 points total
TOTAL (subject to change)		900 points total

2.4. Learning objectives

Scientific Method: This course focused on the Scientific Method, and students experienced every step of this process. Students submitted a draft of their hypothesis as a Canvas discussion post to get feedback from their peers before submitting the final draft. The student's assigned team submitted experimental plans via a shared Google Document to the instructor and graduate assistant. These plans were graded for completion, and the student received feedback before moving on with each project step.

Reading scientific literature: During the scientific literature unit, the team learned how to read each section of a scientific article. Students shared a couple of research articles with their peers via

Canvas discussions, and they summarized the articles in short assignments. These articles helped students' experimental planning and scientific writing.

Laboratory skills: Students learned various lab skills throughout the semester, and at the beginning of the semester, they had a few small assignments related to their projects, such as basic coding skills in Python, MATLAB, EEG acquisition, etc. The instructor evaluations also included points for lab skills and safety procedures.

Written communication: Part of the Scientific Method is communicating findings, so students kept a detailed notebook each week. These notebooks were checked periodically and graded according to the rubric on Canvas. Students learned how to write the different research sections by submitting small chunks of a report throughout the course. First, students submitted drafts via Canvas discussions to get feedback from their peers and graduate students, and then they submitted second drafts to Canvas assignments. At the end of the semester, students submitted a final report that included all the sections they previously wrote and any new material they had.

Weekly reflections: Students were expected to complete a weekly review via Google Forms each week, sharing what they did. These were completion grades each week, and the course instructor used these to ensure everyone is progressing as needed.

Oral presentations: Teams presented twice to the class. These presentations were about 10 minutes long, and all information was posted in the Canvas assignment and rubric. All team members were expected to participate equally in the presentations.

Poster presentation: Each semester culminated in a poster session outside our classroom. Each team presented its results at the poster session. All team members were expected to participate equally in the presentations.

Team Member Roles: We defined six roles for the team members. Each member chose one of the following roles, rotating among the members every week.

1. The coordinator runs the team meeting.
2. The reporter writes and submits the outcomes as meeting minutes.
3. The recorder takes the meeting attendance and writes down the brainstorming ideas.
4. The monitor ensures the members do not interrupt each other during the discussions and design development process.
5. The out-of-the-box thinker discards traditional solutions and thinks from an unconventional perspective.
6. The fifth person shows the flaws of the other four members' conclusions.

3. Four Teams- Four Research Projects

3.1 Team of Electrical Engineering

Initially, the Fall semester started with a team of four undergraduate Electrical Engineering students, one mentor student from the Department of Computer Science, and a faculty member. The team’s main research project was designing and implementing a small-scale prototype autonomous vehicle in a smart environment setting. The project has a fully autonomous small robot, called the “AotUBot.” The team decided to utilize this unique name because it is an autonomous robot that continues to be tested and improved on at the University of Bridgeport (UB). The autonomous robot uses artificial intelligence to process the data received through a camera mounted to the front to navigate through a small town-like course.

The research tasks were distributed between the graduate student and undergraduate team members according to the complexity and difficulty of the tasks. The research was divided into phases with a team of undergraduate students, a graduate student, and a faculty member completing each phase. The phases were literature review, problem statement, vehicle building, smart environment challenges analysis, developing algorithms, implementation of proposed solutions, analysis, testing, and data collection.

The first half of the Fall semester was devoted to reviewing the literature, defining the design challenges, and understanding the vehicle’s kinematics and motion. In the second half of the Fall semester, students used the collected information to work as a team in building the vehicle’s hardware. Students devoted three-fourths of their Fall’s time to implementing the vehicle with all required sensors, motors, cameras, and software. For the Spring semester, the team included only three of the undergraduate students, the mentor-student, a new member who is a graduate student with a Computer Science background, and the faculty member. The first half of the Spring was utilized in the software building and the configuration of the Robotic Operating System (ROS) libraries, and settings. The results and reflections are analyzed in the second half of the Spring semester. The research team interconnected the corresponding systems (traffic lights, traffic signs, human minifigures, small-scale smart city, LIDAR system), collected the project's outcomes and results, documented them, and built a research poster titled “AotUBot : Beyond the steering wheel” that has been presented in two events. The first event is the UBRISE, which is an internal event inside the University of Bridgeport community. The second event is the ASEE NE conference, which is a regional conference that includes undergraduate and graduate research posters from several universities in the Northeastern region of the USA.

3.2. Team of Computer Engineering

Students learned to record and analyze biosignals such as ECG, EEG, EMG, respiration rate, temperature, oxygen saturation, and blood pressure using an IX-TA-220 recorder with integrated sensors. In the second semester, students studied technical papers related to EEG/ECG measurement and analysis. The role of biosignal analysis in detecting abnormal physiological conditions cannot be understated. Although students use many publicly available databases, the team records the signals so that students understand the rigors and procedures involved in measuring these signals.

Students also learned the fundamental mathematical principles involved in data analysis. A short refresher course in signal processing will be introduced to familiarize the students with concepts such as Fourier analysis and filter design. MATLAB will be used to analyze these signals. All undergraduate engineering students take a CS101 course in their first year, so they should be familiar with this software.

3.3. Team of Mechanical Engineering

The UAV team consisted of five undergraduate mechanical engineering students and a graduate assistant in the class. The class utilized the Affinity Research Group model to conduct group meetings. Students developed professional and advanced design and research skills by creating a light, strong quadcopter 3D printed frame. The mechanical engineering design process was introduced and then used to guide the project development. Students were advised to develop design statements and specifications by reading and discussing papers, studying the existing drones in the market, and reverse engineering a racing drone kit. Mathematical modeling and finite element methods were introduced to help students understand how the fundamental principles of mechanics and engineering analysis tools are used in a drone arm design. Students gain experience designing 3D-printed arms through computer-aided design modeling, structural simulation, and optimization.

3.4. Team of Computer Science

With the increasing role of AI across all spectrums of digital technology, face recognition is becoming an important aspect of biometric security. The CS project aimed to engage students in this field by creating a laboratory course where students learned the applications of AI and got to play and experiment with concepts that they can right away see being applied through concepts of simple Calculus and Python programming.

Deep Convolution-based networks with the Triplet loss were quite successful (e.g., FaceNet) in face recognition, resulting in greater than 99% accuracy on benchmarks such as LFW. With the recent success of transformer-based Natural Language Processing architectures (e.g., ChatGPT), transformers have been attempted in Computer Vision applications. They have shown considerable success with better computational efficiency than CNN-based architectures. In this project, we compared the FaceNet and transformer-based architecture for face recognition. We also provided an insightful understanding of the face recognition process, its limitations, and future directions.

The project involves understanding the deep learning architectures for face recognition and their programming in Python using Pytorch libraries. Recent research papers in face recognition are studied to understand this field's state of the art.

4. Self-Evaluation of the Course

The project evaluation comprised formative and summative assessments, including student enrollment and retention data, classroom observations, the engineering design self-efficacy (EDSE) instrument, and student focus groups, focusing on several course-related aspects. Classroom observations were conducted each semester to determine the approaches used by the faculty when implementing the ARG model. The engineering design self-efficacy (EDSE) instrument was used as a pre-/post-participation assessment to evaluate students' engineering self-efficacy, and to monitor changes as a result of program participation. Finally, student focus groups and faculty interviews were conducted at the end of each spring semester to evaluate the program's effectiveness and to garner recommendations for future program implementation.

4.1 Student Enrollment and Retention

Out of 20 students who enrolled in Fall 2022, seven decided not to continue the second part of the course in Spring 2023, and three students transferred out or dropped out of the engineering program. This retention rate of 85% was an improvement over the 78.8% retention rate from 2016-2021. The retention rate in 2021 was only 66.1%, perhaps due to Covid related issues. In the 2023-24 cohort, 17 students enrolled in Fall 2023, out of which 3 dropped out. The retention rate of 82.3% was an improvement over the 2022-23 cohort.

4.2 Classroom Observation

Classroom observations have been conducted each semester and were focused on student and faculty engagement in research as part of the course. The focus was on students' interaction with their faculty mentors and graduate students and their active engagement in research activities. Faculty members were observed assigning student roles in alignment with the ARG model, facilitating team discussions, providing necessary background information, and supporting students in conducting research. Students were observed fulfilling the roles of coordinator, reporter, and recorder, discussing specific questions and aspects of the engineering design process, brainstorming ideas, and actively engaging in research as a team. Observations have revealed strong student engagement in course activities and evidence of faculty following the ARG model.

4.3 EDSE Instrument

The EDSE instrument is a 36-item questionnaire designed to measure students' self-concepts toward engineering design tasks. It assesses four areas related to engineering identity development using a scale of 0 to 100 (0 = low level; 50 = moderate level; 100 = high level). The areas assessed include: self-efficacy, motivation, expectancy, and anxiety. In each area the following engineering design tasks were assessed: conducting engineering design, identifying a design need, researching a design need, developing design solutions, selecting the best possible design, constructing a prototype, evaluating and testing a design, communicating a design, and redesigning.

In the fall 2022 semester, 8 students completed the EDSE survey, and, in the spring 2023 semester, 13 students completed the EDSE survey. The reason for the difference in number of surveys completed may be due to student attrition from the project. In the fall 2023 semester, 14 students completed the EDSE survey, and, in the spring 2024 semester, only 13 students completed the EDSE survey due to one student leaving the university.

In the fall 2022 semester, the mean score for self-reported self-efficacy among engineering students enrolled in Project Achieve was 67.5. Students reported the highest average self-efficacy (75.00) in communicating a design need and the lowest reported average self-efficacy (58.74) in conducting engineering design. In the area of motivation, the mean score was 86.75 with the highest reported average motivation (91.25) in constructing a prototype and the lowest reported average (82.50) in identifying a design need. For outcome expectancy, the mean score was 73.38. Students believed they would be most effective in communicating a design (average score of

76.25) and least effective in redesigning (average score of 68.75). Finally, for engineering design anxiety, a lower score means lower levels of anxiety on a specific engineering design task. In the fall 2022 semester, the mean for engineering design anxiety was 44.63. Students reported greater anxiety in the tasks of researching a design need and selecting the best possible design (average score of 51.43), they also reported lower levels of anxiety in developing design solutions (average score of 42.86).

In the spring 2023 semester, the mean score for self-efficacy was 79.15 with the highest average self-efficacy reported in communicating a design (90.00) and the lowest average self-efficacy in conducting engineering design (74.62). In the area of motivation for engineering design, the mean score was 85.92 with the highest average motivation (89.23) in selecting the best possible design and communicating a design, and the lowest average motivation (81.54) in identifying a design need. The mean for outcome expectancy, in the spring 2023 semester, was 78.00. Students believed they were most effective in communicating an engineering design (average score of 84.62) and least effective (average score of 72.31) in conducting an engineering design and constructing a prototype. Finally, in engineering design anxiety, the mean score was 48.00. Students reported less anxiety in communicating a design (average score of 36.92) and greater anxiety (average score of 53.85) in conducting an engineering design.

Table 2. Comparison of Fall 2022 and Spring 2023 EDSE Survey Data

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Fall '22 Self-efficacy	67.5000	8	22.85357	8.07996
	Spring '23 Self-efficacy	84.7500	8	3.77018	1.33296
Pair 2	Fall '22 Motivation	86.7500	8	6.43095	2.27368
	Spring '23 Motivation	89.3750	8	4.53360	1.60287
Pair 3	Fall '22 Outcome Expectancy	72.3750	8	22.63965	8.00432
	Spring '23 Outcome Expectancy	82.8750	8	3.39905	1.20175
Pair 4	Fall '22 Anxiety	41.6250	8	33.58119	11.87274
	Spring '23 Anxiety	49.5000	8	21.16601	7.48331

When comparing the mean scores from the fall 2022 and spring 2023 semesters, students reported increased self-efficacy, motivation, outcome expectancy, and anxiety for engineering design. Students' self-reported self-efficacy increased by 25% from the fall 2022 to the spring 2023 semester. Their motivation for engineering design increased by 3% and their outcome expectancy, or belief in the success of their efforts, increased by 15%, and their anxiety increased by 19%.

Table 3. Paired sample t-test, Fall 2022 - Spring 2023

Paired Samples Correlations

		N	Correlation	Significance One-Sided p	Significance Two-Sided p
Pair 1	Fall '22 Self-efficacy & Spring '23 Self-efficacy	8	-.388	.171	.342
Pair 2	Fall '22 Motivation & Spring '23 Motivation	8	.386	.173	.345
Pair 3	Fall '22 Outcome Expectancy & Spring '23 Outcome Expectancy	8	-.382	.175	.351
Pair 4	Fall '22 Anxiety & Spring '23 Anxiety	8	-.032	.470	.940

Based on results from the paired sample t-test, there were no statistically significant impacts on students' self-efficacy (p = .342), motivation (p = .345), outcome expectancy (p = .351), or anxiety (p = .940) because of participation in the Project Achieve engineering design courses, using the ARG model. Based on these results, there is no relationship between students' self-efficacy, motivation, outcome expectancy, or anxiety for engineering design following participation in Project Achieve coursework in the fall 2022 and spring 2023 semesters.

In the fall 2023 semester, the mean score for self-reported self-efficacy among engineering students enrolled in Project Achieve was 57.26. Students reported the highest average self-efficacy (69.23) in researching a design need and the lowest reported average self-efficacy (47.69) in the areas of selecting the best possible design. In the area of motivation, the mean score was 79.83 with the highest reported average motivation (86.15) was in constructing a prototype and the lowest reported average (73.08) was in selecting the best possible design. For outcome expectancy, the mean score was 57.52. Students believed that they would be most effective in communicating a design (with an average score of 64.62) and least effective in developing a design solution (average score of 47.69). Finally, for engineering design anxiety, the mean for engineering design anxiety was 44.88. Students reported greater anxiety in the tasks of conducting engineering design and selecting the best possible design (average score of 49.23), they also reported less anxiety on the tasks of researching a design need and developing design solutions (average score of 38.46).

In the spring 2024 semester, the mean score for self-efficacy was 82.82 with the highest average self-efficacy reported on the task of researching a design need (91.54) and the lowest average self-efficacy reported on the tasks of selecting the best possible design and redesign (78.46). In the area of motivation for engineering design, the mean score was 84.7 with the highest average motivation (90.77) in constructing a prototype and the lowest average motivation (76.15) in researching a design need. The mean for outcome expectancy, in the spring 2024 semester, was 85.04. Students believed they were most effective in communicating an engineering design (average score of 93.08) and least effective (average score of 81.54) in selecting the best possible design. Finally, in engineering design anxiety, the mean score was 40.25. Students reported less anxiety on the task of researching a design need (average score of 28.46), and greater anxiety (45.38) on the task of evaluating and testing an engineering design.

Table 4. Comparison of Fall 2023 and Spring 2024 EDSE Survey Data

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Fall '23 Self-efficacy	57.2646	13	24.30012	6.73964
	Spring '24 Self-efficacy	82.8208	13	11.77280	3.26519
Pair 2	Fall '23 Motivation	79.8300	13	17.73067	4.91760
	Spring '24 Motivation	84.7000	13	10.80346	2.99634
Pair 3	Fall '23 Outcome Expectancy	57.5215	13	24.07513	6.67724
	Spring '24 Outcome Expectancy	85.0431	13	8.34709	2.31507
Pair 4	Fall '23 Anxiety	44.8823	13	19.31505	5.35703
	Spring '24 Anxiety	40.2554	13	28.48726	7.90095

When comparing the mean scores from the fall 2023 and spring 2024 semesters, students reported increased self-efficacy, motivation, and outcome expectancy for engineering design, and decreased anxiety in engineering design. Students' self-reported, self-efficacy increased by 44% from the fall 2023 to the spring 2024 semester. Their motivation for engineering design increased by 6% and their outcome expectancy, or belief in the success of their efforts, increased by 48%, while their anxiety decreased by 10%.

Table 5. Paired sample t-test, Fall 2023 - Spring 2024

Paired Samples Correlations

				Significance	
		N	Correlation	One-Sided p	Two-Sided p
Pair 1	Fall '23 Self-efficacy & Spring '24 Self-efficacy	13	.146	.317	.634
Pair 2	Fall '23 Motivation & Spring '24 Motivation	13	.616	.012	.025
Pair 3	Fall '23 Outcome Expectancy & Spring '24 Outcome Expectancy	13	.236	.219	.437
Pair 4	Fall '23 Anxiety & Spring '24 Anxiety	13	.430	.071	.142

Based on results from the paired sample t-test, there were no statistically significant impacts on students' self-efficacy ($p = .634$), outcome expectancy ($p = .437$), or anxiety ($p = .142$) because of participation in the Project Achieve engineering design courses, using the ARG model. However, participation in Project Achieve had a statistically significant impact on students' motivation for engineering design ($p = .025$). Based on these results, there is a relationship between students' motivation for engineering design following participation in Project Achieve coursework in the fall 2023 and spring 2024 semesters.

4.3 Student Focus Groups

Student focus groups were conducted each year and student interviews were conducted at the conclusion of the two-year project. Focus group and interview participation was optional and provided insight into the experiences of the students.

During the focus group, when asked about the components of the program they most enjoyed, students expressed their enjoyment of the group process and working with different people to discuss their varied ideas. One student stated, “To me, it was about confidence, because in the beginning when I was taking the class, I was a little shy to speak, expressing my thoughts. But then, over time, I was getting more confident.” Another student expressed that participation in the course “gives us a different perspective of engineering.” They went on to state, “we actually apply what we’re doing, we get to travel, we get to meet people, and develop actual problem-solving skills.” Another student shared, “we’re allowed to research an issue that we see… to solve the problem to the best of our ability.” Students also expressed their interest in the research they were conducting and the ability to “make something from nothing.”

Students also enjoyed learning from their peers, having the flexibility to do different things each class, and being able to use their skill set in cooperative work that mirrors the cooperative work they anticipate in their future careers. One student stated, “what I liked the most was being given tasks that were big enough, but small enough to be broken down.” They went on to describe how each team member had a role to fill and how their collaborative efforts made accomplishing tasks easier. Having the experience of following a research project from start to finish was cited as another benefit of participation. Learning about the engineering design process was viewed as a valuable experience that will help students in their future careers, and numerous students shared the joy of attending professional conferences, seeing other university campuses and laboratories, as well as collaborating with colleagues in the STEM field. A student shared, “our tiny world of University of Bridgeport, just got a lot bigger in scope of, you know, we’re all in STEM.”

In sharing what they would like to change about the course, students expressed time constraints as being one of their biggest concerns. The overall perception was that the courses needed additional, scheduled class time in order to facilitate teamwork and to accomplish their goals. They shared the struggle of finding time, outside of class, to meet as a team. Some students questioned the recruitment efforts, expressing the need for more students in the courses and changes to the approach to recruiting those students. Finally, students expressed their interest in working on interdisciplinary projects, having the opportunity to collaborate with their peers in other STEM fields, and the desire to have a choice in the project.

5. Reflections and Conclusion

Numerous studies have linked undergraduate students' academic performance and retention in engineering fields to self-efficacy [15, 16]. Bandura has defined four sources from which efficacy beliefs are developed: mastery experiences, vicarious experiences, social persuasions, and physiological states. Self-efficacy beliefs are shaped by mastery experiences (e.g., active engagement in research in engineering) through one's interpretation of their performance on a particular task. Theory and research predict mastery experiences as the most influential source of student self-efficacy beliefs. Vicarious experiences are slightly less effective. However, when individuals are unsure of their abilities in a specific area or have no experience, their views will be influenced by how they perceive the outcomes experienced by others who have performed similar tasks. The results of vicarious experiences on individuals' self-efficacy beliefs depend mainly on the extent to which they see similarities between themselves and those they observe. For instance, participation in a team-based approach to research can lead to increased self-efficacy, as team members can serve as models to one another when completing group tasks. The verbal judgments of others, called social persuasions by Bandura, can also influence self-efficacy beliefs. For example, in traditionally male-dominated fields, such as engineering, vicarious experiences and social influences may play a more dominant role in forming women's self-efficacy beliefs. These findings can be extrapolated from women to other members of under-represented groups in engineering fields. Finally, physiological states associated with an action, whether anxiety, stress, fatigue, or any other emotion, can also somewhat influence individuals' self-efficacy beliefs [15, 16].

An element of this course that impacted students' mastery experiences was their active participation in research. Students' self-efficacy increased by 25% during the first year of the program and by 44% in the second year. Students' outcome expectancy, or their belief in the success of their efforts, increased by 15% during the first year and by 48% in the second year. While the results were not statistically significant, they still point to changes in students' perceptions regarding their self-efficacy for engineering design as a result of active participation in research. Additionally, students' motivation for participating in engineering design increased by 3% in year one and by 6% in year two. The changes in motivation, during year two, were statistically significant and highlight the relationship between participation in research and students' motivation for engineering design.

Students' vicarious experiences and physiological states (anxiety) can impact their self-efficacy for engineering design. This is evident in student responses to the focus group questions and on the EDSE survey. During the focus groups, students shared the positive impact of working on research as a team. They shared that collaborating and learning from one another, as well as attending professional conferences and meeting other students and professors in the field, had a positive impact on their course participation. Additionally, during year two, students reported a 10% decrease in their anxiety surrounding participation in research and engineering design. Previous research studies have found that students' successful participation in the ARG model is associated with their academic growth and development in science-related fields and a transformation of identity from student to professional, thereby promoting field-specific self-efficacy [9,10].

The presented research course for undergraduate engineering and computer science students will contribute to efforts at HSIs and other universities to improve first-generation, underrepresented, and underserved students, particularly Hispanic students, professional self-efficacy, and their retention in computer science and engineering careers. This project focused not on students' access to these majors, as students are already enrolled in engineering programs when the ARG model is applied. The project aimed at piloting an intervention to mitigate known barriers to maintaining engagement in and completing STEM majors, focusing on students' acquisition of career-related skills, connectedness to professionals, and building their confidence to complete an intellectually demanding course of study. This project will also provide helpful information on an ARG implementation that includes added elements to especially engage first-year freshman and sophomore students.

Acknowledgment: This work is supported by the National Science Foundation, Hispanic Serving Institutions (HSI) Program, under grant agreement 2150048. A part of this work was presented at the American Society of Engineering Education, Zone 1 Conference at Penn State College of Engineering on March 30-April 1, 2023.

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