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Augmenting Introductory Engineering Courses to Include a Collaborative Learning by Design Project: Assessment of Outcomes

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Introduction

This Complete Research paper examines the efficacy of a new introductory level course added to degree programs in the College of Engineering at Texas A&M University-Kingsville, a Hispanic Serving Institution (HSI). The new course, GEEN 1201, provides general and department specific engineering content and also includes a discipline appropriate project-based collaborative design experience. The GEEN 1201 course is intended to aid freshmen and sophomore students as they transition to upper-level study within their degree programs. The efficacy of the course is evaluated based on pre- and post-course surveys completed by participating students. The impact of the course on student performance, as measured by grade distribution, is also examined as is student retention. This paper extends the understanding of project-based learning in Engineering courses by focusing on its use in multiple sections of an introductory course at an HSI across a period of three years, similar to [19] but without a learning community emphasis, providing a consideration within a specific but expanding context (Engineering instruction at HSIs), at a critical point in Engineering education (an introductory course), with greater scope than other studies, including a large number of students from Hispanic/Latinx backgrounds, and having been completed in a context about which there is a growing but still limited volume of literature, Hispanic-Serving Institutions.

The creation of the new course is one element of a larger NSF funded project in the College of Engineering at Texas A&M University-Kingsville that is focused on assisting historically underserved students to successfully negotiate critical transition points in their educational journey. During the first year of the NSF project (2020) the new GEEN 1201 course was added to the curriculum for freshmen students in three departments: Electrical Engineering and Computer Science (EECS), Mechanical and Industrial Engineering (MIEN), and Chemical and Natural Gas Engineering (CHNG). The new course replaced an existing one that was previously required for those students, UNIV 1201. While the UNIV 1201 course consisted of mainly generic student success material applicable to students of all majors, the new GEEN 1201 course added engineering and discipline specific content relevant to a student's intended major field of study to that curriculum.

Each of the three departments (EECS, MIEN, and CHNG) designed their own version of the GEEN 1201 course to emphasize topics appropriate for their majors. In addition, each department also developed a collaborative, hands-on design project to include in the course that would be appropriate and engaging for their students [16]. The topics of the design projects implemented were a robotics design task for EECS students, a reverse engineering and 3D printing task for MIEN students, and a water filtration project for CHNG students. Encouraged by the promising results observed from the 2020 and 2021 offering of the course for students in the EECS, MIEN, and CHNG departments, an additional version of the course was developed and integrated into the curriculum for students in the Civil and Architectural Engineering Department (CAEN) in 2022. Additionally, GEEN 1201 courses have since been developed for the remaining departments of the college and since the fall of 2023 are now offered to all freshmen engineering students. Each of the newer GEEN 1201 courses includes a discipline appropriate hands-on design project.

The following section describes the design of the GEEN 1201 course, the design rationale, and also provides a brief look at related research that influenced the design. This is followed by a description of the methods used to assess the efficacy of the course and its impact on learning, retention, and student performance. The limitations of the study are examined next, followed by a description of the informants of the study. The findings of the study are then presented including an examination and analysis of survey results, grade distributions, and retention rates. The paper then concludes with a brief summary of results, a statement on the generalization of the approach, and recommendations.

GEEN 1201 Course Design and Rationale

Prior to the development of the GEEN 1201 course, first-year engineering students at Texas A&M University-Kingsville were required to take a more general course called UNIV 1201 that was designed to orient new students to the university environment and promote the success of first-year students. The course was taught to all new students and its content was not department or college specific. The development of the GEEN 1201 course provided an opportunity for engineering departments at Texas A&M University-Kingsville to enhance their early curricular student experience by customizing entry level courses to combine the most relevant student success material from the generic UNIV 1201 course with introductory technical content appropriate for their majors.

The implementation of the GEEN 1201 course in the college of engineering at Texas A&M University-Kingsville has occurred incrementally. It began on an experimental basis and was originally limited to three departments (EECS, MIEN, and CHNG). This resulted in each department creating its own version of the GEEN 1201 course with content appropriate for their majors, rather than the creation of a single college-wide introductory engineering course. However, important common elements in each of the versions of the course were retention of student success elements from UNIV 1201 and the inclusion of a collaborative design experience.

The primary goals of developing the GEEN 1201 course was to support freshmen and sophomore students in their transition to upper-level studies through development of knowledge and skills. The desired impacts for the course were to: (1) provide a general introduction to key skills so students have a platform on which to build as they enter discipline specific courses, (2) provide a guided experience related to design projects that are often part of upper level courses, (3) initiate patterns relevant to teamwork as engineering practice commonly involves collaborative processes, and (4) reinforce commitment among engineering students early in their studies to aid in retention. In support of those outcomes, a learning by design experience approach was chosen in which each GEEN 1201 course would contain department specific introductory engineering content and also include a discipline appropriate entry-level collaborative engineering design experience. An important additional goal for the course was to serve as a vehicle to study the efficacy of this approach for a primarily Hispanic student population.

The remainder of this section provides a brief review of various results and discussion that have been reported in the literature from research projects that influenced the design of the GEEN 1201 courses. The focus is especially on literature related to projects that have utilized an approach including one or more of the key characteristics of the GEEN 1201 course: being department specific, integration of a design experience, use of team-based projects, and integrating project-based learning.

Department Specific Introductory Courses

Various studies have examined and evaluated strategies for the design and implementation of an introductory level engineering course [2, 7]. An important consideration is whether an introductory level course should be generalized and intended for all engineering majors within a college or instead be program specific for each academic department within the college [4, 8, 10, 29]. An advantage of college-wide introductory courses is the ability to expose new students to a wide range of engineering disciplines, something especially helpful for those that have not yet settled on an engineering major. This type of course also readily accommodates the inclusion of interdisciplinary projects, providing students with exposure to realistic engineering scenarios [7]. Discipline specific introductory engineering courses enable departmental level control over and customization of the format of those courses. While for some engineering programs a substantial lab component might be needed for others a traditional lecture format is more appropriate. The discipline specific approach also affords departments finer-grained control over the content taught to entry level students. The discipline specific approach has also been observed to promote increased contact between early program students and professors from their major, helping to foster a sense of student ownership and belonging in the department, which can be beneficial for student retention [7]. The discipline specific approach was chosen to allow content and projects to directly align with each area of specialization, to facilitate as much consideration of this material as possible including the project-based element, and to initiate relationships between faculty from each specialization and the incoming students.

Integrating Design Experiences

A project-based design experience was added to the course for the following reasons. Design experiences are already an important part of engineering curricula at many universities. In many degree programs senior engineering students are required to complete a one- or two-semester long capstone course sequence that emphasizes integration of concepts and material from previous classes in the completion of a substantial design project. Education researchers have also recognized the potential benefits design experiences can offer at earlier stages of an engineering curriculum, including introductory level courses [24, 35]. An important benefit is helping to make clear to students at an early stage the importance of and linkage between the supporting math and science courses they are required to take and the engineering field which they have chosen to study [10, 25, 32]. Design experiences completed early in the engineering curriculum can also make technical course content more relevant and interesting for students [9]. End of semester design projects in introductory level courses have been observed to increase student engagement, improve perceived competence, and provide a useful mechanism to relate and synthesize topics covered earlier in the course [12, 21, 22]. Including a design experience has also been observed to help increase motivation in early program students, help develop their engineering identity, and foster a sense of belongingness to the field [25, 32, 34].

Team-based Problem Solving

Team-based projects are often the format used to integrate a design experience into an engineering course. Team-based project work often comprises most if not all of a senior level capstone design course. In introductory level courses team project work typically makes up a smaller component of the overall course and is usually combined with material covered in a traditional lecture format [14]. The inclusion of a team project in an undergraduate introductory computer science course was observed to improve attendance, engagement, and presentation skills [6]. Another investigation explored the motivation levels of underrepresented minority students when team-based learning was integrated into an introductory level course and found it to be higher than that of their non-minority counterparts, underscoring the importance of these projects in creating an inclusive environment capable of reaching all students [11]. Student to student interaction such as that typical of team-based project work has also been found to be a have a significant positive influence on retention [5]. An integrative team-based learning project utilized in another entry level undergraduate computer science course was observed to help students forge connections between the topics covered in the separate modules of the course and demonstrate how that content could be integrated and synthesized to solve a problem [6]. Improvements were noted in both student attendance and engagement. Including reflection focused team meetings as part of a team-based project was observed to improve the development of reflective skills important for addressing difficult engineering problems [15].

Project-based Learning

Project-based learning is a popular and engaging student-focused pedagogical strategy often used in engineering education programs [30]. This inquiry-based learning approach offers a variety of potential student benefits including improved academic outcomes among diverse populations [28]. Social interaction among students is an important element of project-based learning as it facilitates knowledge acquisition and sharing [23]. This makes it an attractive model for structuring team-based problem-solving projects. Incorporating project-based learning into engineering courses has been observed to be a particularly effective strategy as it promotes student engagement with realistic material in scenarios that reflect actual engineering practice [13]. Project-based learning has also been observed to hold potential for improving learning outcomes for diverse students by helping them connect theoretical concepts with practical engineering applications [28]. When utilized in introductory level engineering courses, project-based learning has been shown to be beneficial for student performance in subsequent engineering courses [28]. The social component of project-based learning has also been observed to be an effective tool in helping students develop and refine soft skills such as communication, collaboration, creativity, and critical thinking that will be very important to their future success in a career [3].

Assessment Methods

Pre- and Post-Participation Surveys

Pre- and post-participation surveys were developed by the project's evaluator based on instructional goals and intended outcomes identified by the faculty during course development. These questions included a set of core queries to address the broad educational goals common to all course sections and discipline-specific questions related to the hands-on project enacted by faculty in each Engineering discipline. The questions employed were created for the project rather than drawn from other sources. This approach was taken as a means of closely aligning the queries with the instructional objectives and involved assessment of face and construct validity by experts in assessment and the academic disciplines involved.

The surveys were deployed via Qualtrics "in the three [discipline-specific] sections of GEEN 1201 in 2021" [16], in six course sections in 2022 (one each in Civil and Architectural and Chemical and Natural Gas Engineering and two each in Electrical Engineering and Computer Science and Mechanical and Industrial Engineering), and in six discipline-specific courses in 2023 for a total of 11 sections that year (Table A1). The six Engineering disciplines enacting courses in 2023 were Civil and Architectural Engineering (CAEN), Chemical and Natural Gas Engineering (CHNG), Electrical Engineering and Computer Science (EECS), Environmental Engineering (EVEN), Industrial Management and Technology (IMTE), and Mechanical and Industrial Engineering (MIEN). The disciplines offering multiple sections of the course in 2023 were Civil and Architectural Engineering (two sections with two different instructors), Electrical Engineering and Computer Science (three sections with different instructors for each) and Mechanical and Industrial Engineering (three sections with the same instructor).

Participating students received individualized access links to the applicable survey via email. The distribution lists were created from course rosters. Survey queries requesting ratings had informants use a ten-point scale to submit responses and they were instructed to use zero (0) for 100% disagreement with the statement and ten (10) for 100% agreement. Follow-on requests to complete the survey were sent as applicable but no more than two additional requests were made per class section.

The surveys were closed approximately a month after students were granted initial access. The survey responses were downloaded as Excel spreadsheets. Submissions from students who completed the informed consent questions but no other questions or who progressed no farther than submitting demographic information were excluded from analysis as being incomplete. Excel functions were employed to disaggregate and analyze the resulting response sets. Analysis was completed as non-paired t tests.

Grade Distribution Analysis

As has been noted in prior discussions of this undertaking [1, 17], the GEEN 1201 courses were an adaptation of a general introduction to university studies class. The GEEN 1201 material was customized to combine the most relevant student success material from the generic UNIV 1201 course with introductory technical content appropriate for their majors. The intention was to increase preparation of students for study of Engineering. One means of measuring this, beyond student perspectives of learning achieved, was comparison of grade distributions for the two courses. A request was submitted to the Office of Institutional Research of the University where the courses were enacted for records of grades in the two courses. These records extend back five years prior to the start of the project for the original general introduction course and through the entirety of the grant funding period for the GEEN 1201 class. These data were analyzed using descriptive statistics.

Retention of Participants in Engineering Degree Tracks
As the project was intended to prepare students for study of Engineering disciplines, a third means of assessing success was retention of students. The data for this assessment was obtained from the University's Institutional Research office and includes retention of students committed to the Engineering degree programs in which the GEEN 1201 course was enacted. The data was gathered for the five years prior to the grant for students that took the general introductory course (UNIV 1201) and for the three years of GEEN 1201 implementation for the students enrolled in that course. These data were analyzed using descriptive statistics.

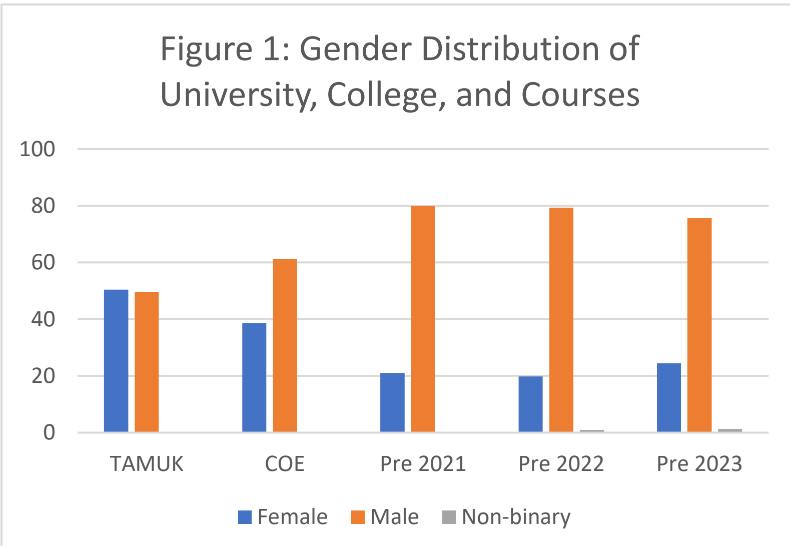
Limitations

The actions taken were completed at one university and will require verification at other institutions to be fully generalizable. Several other limitations exist in respect to the investigation. All activity occurred in courses taught by faculty from the College of Engineering at one mid-sized state university (total enrollment of 6,375 in fall of 2021). Some faculty developed and taught discipline-specific courses for one semester limiting the size of several discipline-specific samples. A number of these and other course sections had low enrollment, two with nine and one with 11 students (Table A1). The response rates on the surveys were moderate to low (Table A1). Only five of 16 pre-participation surveys had more than 45% of enrollees respond with three sections returning responses from less than 20% of enrollees. Post-participation rates were lower with six of 16 having response rates ≤20%, eight with >20% but ≤40% participation, and only two with response rates above 40%. This occurred despite repeated emailed reminders to complete the survey and several additional requests made by the faculty teaching the course. Thus, some of the samples achieved were too small for meaningful disaggregation and statistical analysis so some impacts, positive or negative, may have gone unnoted and the demographics of the respondents and the survey response rates prevented meaningful disaggregation by gender or ethnicity for most course sections (i.e., sections with low numbers of females and non-Hispanics). These are important considerations due to underrepresentation of females and some racial/ethnic groups in the Engineering workforce [27] and other studies having found differences in outcomes related to gender and racial/ethnic identity [26].

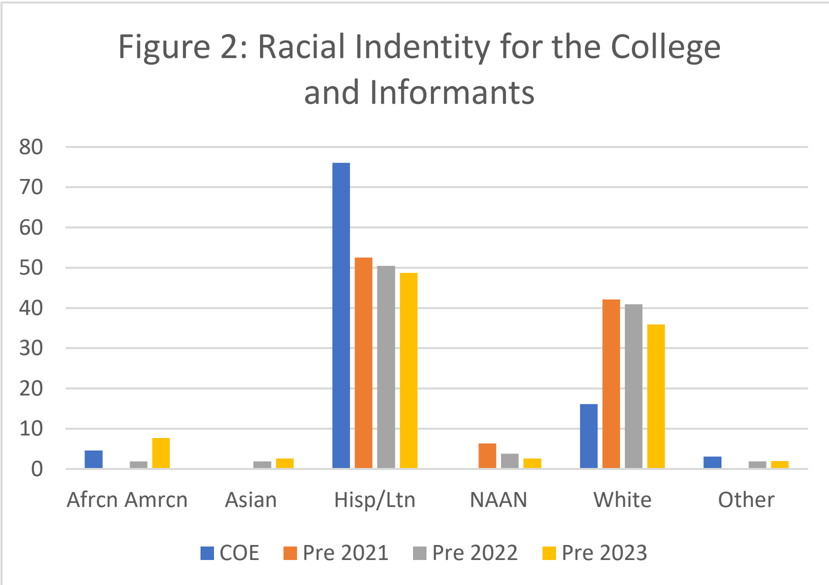
The College of Engineering (CoE) faculty defined the curriculum in the various discipline-specific course sections around a general set of principles rather than there being one uniform and closed curriculum. Faculty from each discipline developed their own courses around the general set of key concepts. Resulting variation in content and emphasis may have been large enough to introduce intervening variables. There was also content variation within one course, the Civil and Architectural Engineering section, as the experiential learning project in 2023 was different than that employed in 2022. In 2023, several of the faculty new to the process failed to share information with the evaluator that would have allowed the development of discipline-specific queries so there is no data in these areas. Finally, institutional policy regarding the course changed during the period of investigation. Initial success resulted in a decision to have all Engineering majors complete the course in 2023 when it had been an optional route for students in 2021 and 2022.

Description of the Informants

Demographic information was requested of students on the pre-participation survey. Participating students were asked to categorize their gender (i.e., female, male, non-binary, I do not care to respond), ethnicity (i.e., Hispanic/Latinx, non-Hispanic), and race. These items can be compared to the same measures for the College of Engineering at the University as the GEEN 1201 course is for the Engineering student population.



"The College of Engineering (CoE) student population has a higher concentration of males than the university's total enrollment" [16] (Figure 1). "But comparison of the pre-instruction data to the CoE enrollment indicates the sample skewed male" [16] in each year. There was variance from course to course and section to section, for example the "gender shift was most pronounced in the EECS and MIEN sections [in 2022] with 96.8% and 82.7% of informants, respectively, identifying as male" [16]. The other courses in 2022 "had gender distributions that included more females than the CoE enrollment, with the CAEN section at 47.1%, or slightly less and the CHNG section at 31.3%" [16]. For the three years, the overall ratio in the sample remained as reported in 2023 "approximately 2 females for every 8 males" [16] with two additional person identifying as non-binary. Even though the percentage of females in the respondent pool appears low, there were sufficient numbers of students identifying as female for gender-based analysis of responses to be completed.



In each year, "racial identity among the informants also differed from the distribution for the College of Engineering" [16] (Figure 2). "The apparently lower percentage of Hispanic/Latino individuals and higher percentage of parties who identify as White must, though, be viewed in light of ethnic identity for a clear understanding to be formed. Many of the parties who considered their racial identity to be White also classified themselves as Hispanic/ Latinx in respect to ethnicity…which is not uncommon" [16]. This figure exceeded 60% for parties identifying as White in each year. This placed "the percentage of informants who identify as Hispanic/Latinx above the institutional and college average" [16] but the difference was less than five percent of the total (79.87% in the sample, 76.1% for the CoE, 68.4% university). "Thus, the sample could be considered as skewing slightly Hispanic/Latinx even though the disaggregation by race clouds that fact" [16]. Like for gender, there were though sufficient counts of informants "identifying as Hispanic/Latinx and non-Hispanic…for analysis by ethnicity to be completed" [16].

Findings

Pre- and Post-Participation Surveys

As stated above in the Limitations section, response rates on surveys were low to moderate. Students were offered no incentive to complete the survey to avoid coercion impacting responses. Several emailed reminders were sent via Qualtrics and verbal reminders were provided by the instructors. Yet as is increasingly the case due to the high volume of surveys adults encounter in their day-to-day interaction with companies and service providers and that students receive from various groups at their universities, the response rates did not reach desired levels.

As was reported in 2023 and is illustrated in Table A1, low enrollment in some sections, as few as nine students, the moderate to low response rates of surveys, and informant demographics prevented comparison of responses by gender, ethnicity, and race by course sections taught as even dividing the responses into two groups often resulted in cells with fewer than four or five respondents. Had there also been annual variation in the faculty responsible for the courses, it would have been a substantial intervening variable as faculty behavior and traits have been shown by multiple researchers considering a variety of disciplines, including Engineering, and over several decades to have a significant impact on student outcomes [18, 20, 31, 33, 36].

Having the same faculty teach the course year-to-year and repeated offerings by departments did, though, make it possible to combine course section response sets to compile discipline-specific groupings. These were assessed to determine whether there were statistically significant differences between gender, ethnicity, and racial categories for each of the six discipline-specific course sections.

The pre- and post-participation data was disaggregated by gender and ethnicity to check for significant differences in submissions. As noted above, this was an important step due to underrepresentation of some groups in Engineering [27] and differences found by race/ethnicity and gender in other studies [26]. As had been the case in the past, there were no significant differences "found by gender in either the pre- or post-participation response sets" [16]. The one significant difference found when considering ethnicity in prior years persisted. "Students identifying as Hispanic/Latinx expressed stronger interest in becoming engineers than their non-Hispanic peers on the pre-participation survey" [16] in each year and, as a result, in the cumulative data set. Also like in each prior year, Hispanic/Latinx informants submitted, on average, higher ratings of their interest in becoming an engineer post-participation but the "difference was not statistically significant" [16]. There were also limited numbers of African Americans (n = 7), Asians (n = 4), and Native Americans/Alaska Natives (n = 6) in the group of 189 pre-participation informants. The remainder where Hispanic/Latinx (n = 100), White (n = 70), or Other (n = 2). No significant differences were found by racial category although several of the groups were too small for meaningful statistical analysis. The absence of differences by gender, ethnicity, and race are substantial findings as it indicates that the students entering and exiting the courses had a uniform perspective of their level of learning/skill. This demonstrates that the programming was uniformly efficacious, in contrast to [26], and made the compilation and use of discipline-specific response sets possible as any differences pre- to -post-participation would not be impacted by or a manifestation of differences between subsets of the compiled groups.

Questions about Activities Common to Engineering Disciplines

All informants were asked seven general engineering questions. They addressed: (1) confidence in ability to work as a team member on an engineering undertaking, (2) knowledge of the basics of engineering design, (3) understanding of how to conduct engineering experimentation, (4) knowing how to analyze engineering data, (5) knowledge of how engineers problem-solve, and (6) interest in becoming an engineer (two questions). Statistical analysis was completed comparing responses pre- to post-instruction for each of the six discipline-specific courses and for the combined responses from all informants for all courses. The second analysis was undertaken due to small sample sizes for some of the courses which limited statistical power in analyses for those courses. The details of analysis by course type appear in Table A2. Table 1 below presents a summary of the findings. Changes occurred in the direction intended for all but one question and all the statistically significant changes, even though some samples were small, represent increases in knowledge or confidence.

Table 1

Summary of Analysis of Responses to the Seven General Engineering Questions

Prompt	**Course-Specific Findings**	
	General Patterns	***Statistical Significance***
I am confident in my ability to work as a team member on an engineering project.	Post-participation means higher in 5 of 6 courses (exception IMTE which only had 3 informants)	CHNG: Increase in confidence at $p < .001$ level.
I know the basics of the engineering design process.		CHNG and MIEN sections: Increase at the $p < .001$ level.
I know how to do engineering experimentation.		CHNG, EECS, MIEN: Increase at the $p < .001$ level.
I am NOT familiar with ways to analyze engineering data.	Post-participation means decreased in 4 of 5 courses (IMTE had no post-participation responses for these questions)	CHNG: Decrease at $p < .05$ level. EECS: Decrease at $p < .01$ level.
I do NOT know how engineers do problem solving.		CAEN, EECS: Decrease at the $p < .05$ level.
I am very interested in becoming an engineer.	Post-participation means slightly lower in 6 of 6 courses	N/A
I am NOT certain that engineering is for me.	Post-participation means lower in 6 of 6 courses	N/A

The combined data set, which decreases the impact of unique cases, has strongly significant findings for six of the seven queries (Table 2). This analysis was completed since all the courses, even though tailored to meet the needs and interests of different departments, share the common goals encapsulated in the general questions about engineering and there were no known significant differences in the responses by subsets of respondents in the pre-participation data.

Table 2

Cohort Level Responses to General Engineering Questions

Prompt	**Period**	***n***	**Mean**	**Mode**	**SD**
I am confident in my ability to work as a team member on an engineering project.	Pre	188	7.89	10	2.10
	Post	100	8.59**	10	1.66
I know the basics of the engineering design process.	Pre	183	6.19	5	2.57
	Post	100	7.81***	10	2.07
I know how to do engineering experimentation.	Pre	182	5.36	5	2.78
	Post	100	7.63***	10	2.23
I am NOT familiar with ways to analyze engineering data.	Pre	177	4.13	3	2.78
	Post	85	2.88***	0	2.80
I do NOT know how engineers do problem solving.	Pre	163	3.43	1	2.57
	Post	80	2.28***	0	2.57
I am very interested in becoming an engineer.	Pre	184	9.20	10	1.37
	Post	100	8.62**	10	2.25
I am NOT certain that engineering is for me.	Pre	141	1.74	0	2.30
	Post	80	2.22	0	2.74

Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

The significant findings for the first six questions were two at the $p < .01$ level and four at the $p < .001$ level. These show student confidence in their ability to work as project team members increased as did their perceived knowledge of engineering design, experimentation, data analysis, and problem solving. These were accompanied by a decrease in the interest in becoming an engineer. While unexpected, this result represents a winnowing of interested parties based on having greater experience which is a positive outcome likely to increase persistence in engineering degree programs.

The other questions included in the pre- and post-participation surveys were about learning achieved and levels of confidence plus queries about interest in engineering post-instruction and queries about discipline-specific learning crafted around the team-based projects incorporated into each of the courses.

Post-Participation Levels of Learning, Interest, and Confidence
Table 3 lists the learning, interest, and confidence questions presented to each informant regardless of the course section they took. These queries were constructed to derive feedback regarding several key goals of the undertaking and as a secondary data set to elucidate the responses received pre- and post-participation about these topics. The first five questions address topics about which pre- and post-instruction data was gathered. The sixth and seventh address

Table 3

Responses to Learning, Interest, and Confidence Queries for All Sections

Prompt	*n*	Mean	Mode	SD
I learned about designing a system, component, or process to fill a recognized need.	97	8.36	10	2.09
I learned how to conduct experimentation in engineering.	99	8.20	10	2.19
I learned NOTHING about analyzing data and interpreting the results.	67	1.45	0	2.36
I learned an engineering design process.	100	8.32	10	2.39
I learned problem solving patterns applicable to engineering.	98	8.30	10	2.09
I learned NOTHING about writing for engineering during the process of creating the project report.	70	2.74	0	3.27
I learned what is relevant for an engineering presentation while preparing my team's project presentation.	98	7.60	10	2.69
The hands-on project increased my interest in engineering.	100	8.58	10	1.91
The hands-on project increased my confidence that I can be an engineer.	99	8.39	10	2.00

writing and presentation skills. The final two questions address interest in and confidence regarding becoming an engineer. Like all preceding questions, informants used a ten-point scale to submit responses and were instructed to use zero (0) for 100% disagreement with the statement and ten (10) for 100% agreement.

Responses indicate the instruction goals were achieved and these results align well with the pre- and post-instruction ratings as five of the seven prompts have mean responses between 8.20 and

8.58. These are strongly positive outcomes as students in an introductory course rated their learning, confidence, and interest well within the upper quintile of the scale. The two items that were not in this group, learning about writing for engineering and what is relevant for an engineering presentation, were both rated just outside the upper quartile which are also strong ratings following a single introductory course.

Discipline-Specific Questions

The prompts employed and descriptive and inferential statistics for pre- to post-instruction comparison of the discipline-specific queries appear in Table A3. There are large variations in sample size due to the progressive expansion of the course from the three initial departments, CHNG, EECS and MIEN, to include CAEN, EVEN and IMTE across a period of three years. The cumulative totals for MIEN informants, the course for which the most sections were offered, are as high as 73 pre-instruction and 30 post-instruction while the CAEN set is, at its highest levels, 15 pre-instruction and 5 post-instruction submissions. The CAEN responses were from one semester in which a trebuchet project was enacted. There are also no counts for EVEN and IMTE as they were only included in 2023 and the process of developing a set of discipline-specific queries was not completed for these sections.

Statistically significant results were found for three of the five CHNG pre-/post-instruction prompts (Table A3) along with positive responses to the two post-instruction only questions (i.e., interest in the hands-on project and seeing real-world applications for learning achieved through the project) which had ratings in the upper quintile. CAEN responses showed increases in perceived understanding pre- to post-instruction but none of the differences were statistically significant due to small sample size, 15 informants pre-instruction and five post-instruction. The query about seeing real-world applications for learning from the project had a mean of 8.2 on a ten-point scale, although this is a positive occurrence rather than outcome that can bear interpretive weight as there were only five informants. All four of the learning queries for the EECS returned statistically significant results and the informants, 43 pre-instruction and 27 after, rated interest in the project and seeing real-world applications in the upper quintile of the scale. Analysis of MIEN responses from 73 pre- and 30 post-instruction informants returned statistically significant findings for five of six learning objective prompts and ratings well within the upper quintile for interest in the hands-on project and recognizing real-world applications of learning achieved through it. Thus, as was the case with the cumulative analysis of responses to questions about activities common to the Engineering disciplines, there were strong and consistent indications of learning being achieved and they occurred at statistically significant levels in every discipline when that form of analysis was possible.

Grade Distribution Analysis

Comparison of grade distributions for UNIV 1201 and GEEN 1201 during the three years in which GEEN 1201 existed was completed to determine whether there was a difference in academic performance. There were adequate cumulative counts of students to ensure that the impact of variance would be minimized and to arrive at general patterns as grades for nearly 450 GEEN 1201 students and 4000 UNIV 1201 students were considered, counts sufficient to decrease the impact of variability and random fluctuations. A summary of the results appears in Table 4.

Table 4

Comparison of Grade Distributions: UNIV 1201 to GEEN 1201

Course	n	A	B	C	D	F	W
GEEN 1201 courses	442	58.1%	14.9%	11.3%	7.0%	7.0%	1.6%
UNIV 1201 courses	3912	46.4%	15.2%	10.9%	7.6%	16.8%	3.2%

While a broad comparison, looking at introductory classes designed for Engineering disciplines and another for all other majors at the University, both of which had a consistent set of shared student success modules, can, at a minimum, demonstrate whether there was a different pattern of outcomes. The size of the samples would dampen the impact of the variety of potential intervening variables on the outcomes, especially for UNIV 1201 with 3,912 students, and the calculations include all enrolled students, the largest counts possible. The result was GEEN 1201 students appear to achieve better academic performance than their peers in the introductory course for other majors. The most notable differences occur at the top and bottom of the scale. GEEN 1201 students are approximately 25% more likely to receive an A, more than 50% less likely to receive an F, and 50% less likely to withdraw. While this is not conclusive as faculty have differing approaches to instruction, differences in grading patterns, might alter which topics receive more emphasis or introduce topics their peers do not cover or do not cover to the same depth, it was a positive outcome for which the sample sizes were large enough to mitigate, to a substantial degree, variance with each group.

Retention of Participants in Engineering Degree Tracks

A final form of success possible for the course would be increasing retention of Engineering majors. Comparison of retention rates for students in the disciplines engaged in the project since its inception were calculated for prior to and the period during the project's intervention. Retention calculations were for fall-to-fall persistence in the College of Engineering and within the same Engineering major for all students, full- and part-time attendees, and for all first-time-in-college students. The percentage of active students who graduated during the designated periods was also calculated.

- Fall-to-fall retention within the College of Engineering for all students was higher in the five years preceding the intervention (64.5%) than during the intervention (59.6%).
- Fall-to-fall retention within the same Engineering majors for all students was higher in the five years preceding the intervention (61.6%) than during the intervention (58.1%).
- First-time-in-college students were also retained in the College of Engineering at higher rates prior to the intervention than during it, 77.2% to 67.8%.
- Graduation rates of active students were higher during the intervention (27.2%) than prior to it (20.0%).

Thus, decreases in retention but increases in graduation rates occurred when the programming intervention was taking place. While a causal link cannot be established, when viewed with the statistically significant decrease in being "very interested" in Engineering and associated but not statistically significant decrease in certainty that "Engineering is for me" (Table 2) there appears to be a connection between the introductory course implementation and these results. Further investigation gathering additional data would be required to establish a clear association especially since the project occurred during the COVID-19 pandemic, a period in which all instruction was moved online at the University. It is possible that the pandemic impacted the retention patterns to a significant extent.

Summary: Impacts Found and Comparison to Literature

There were several clear and important outcomes from the GEEN 1201 programming initiative. First, no significant differences were found by gender or ethnicity in the results, even though other studies had this outcome [26]. This indicates that the programming is effective in supporting all students and moving them toward the desired outcomes [also noted in 11]. If replicated, this pattern would contribute to preparing and maintaining parties currently underrepresented in Engineering study and careers in Engineering. This outcome should, though, be viewed in light of a caveat. The measured interest in Engineering decreased at a significant level although the initial levels of interest were very high and the post-instruction levels remained high, 9.20 and 8.62 on a ten-point scale (Table 2). Thus, the programming may also help parties refine personal goals based on practical experience which could also ultimately contribute to completion of degree programs.

There were significant findings for general engineering questions, activities common to all the Engineering disciplines engaged in the programming. This occurred at high levels of significance for five prompts which addressed: (1) confidence working as a team member on an engineering project, (2) knowledge of engineering design, (3) the process of experimentation in engineering, (4) data analysis in engineering, and (5) understanding of how engineers solve problems. Post-participation ratings of learning, interest, and confidence support these findings as informants submitted ratings between 8.20 and 8.55 on a ten-point scale for statements regarding learning: (1) "about designing a system, component, or process to fill a recognized need," (2) "how to conduct experimentation in engineering," (3) to analyze "data and interpreting the results," (4) an "engineering design process," and (5) "problem solving patterns applicable to engineering." They also noted the "hands-on project increased [their] interest in engineering," with an average rating of 8.58, and "increased [their] confidence that [they] can be an engineer" with an average rating of 8.39 (Table 3). Combined, these make a strong case for the programming being an effective instructional tool in the topic areas queried. They also parallel findings published by other parties, discussed above and that motivated the GEEN course development, particularly increases in understanding [3, 6, 9, 23] and competence [12, 15, 21, 22].

There were also three to four highly significant increases in understanding for each discipline-specific course that had 18 or more post-instruction informants (Table A3). These also align with outcomes reported in [6, 12, 15, 21, 22, 23, 28]. They occurred in Chemical and Natural Gas Engineering for use of different materials to remove offensive chemicals from water, ability to design a basic water filtration system, and knowing how to complete refractive index readings with water samples. They occurred in Electrical Engineering and Computer Science for building a simple chassis for a mobile robot, mounting electric motors and wiring on a mobile robot, working with a computer board that controls a robot, and writing a Python program that would control a robot. They also occurred in Mechanical and Industrial Engineering for understanding reverse engineering, using 3D software to complete motion study analysis, designing a product to fit predefined specifications, and using 3D software to complete assembly interference detection. That such a variety of processes would return highly significant findings speaks to the efficacy of the basic process, introduction of content relevant to the discipline and a team-based, extended experimental project in that discipline. This conclusion is supported by the post-instruction ratings of the "hands-on" project as increasing participant interest in becoming an engineer, as in [9], and confidence that they could achieve that end as noted above and in [10, 25, 32].

Finally, for every course, informants indicated at high levels that they perceived real-world applications for the learning they had achieved. The range of ratings on a ten-point scale was 8.20 to 8.72 (Table A3). Thus, the learning accomplished expanded the student conceptions and facilitated connections to processes and patterns they were aware of in their field of interest. This represents connection of relevance and interest [9] and theory to practice as reported by others [28].

Conclusions

The programming enacted was able to achieve all but one of the impacts desired, many of which had been identified by review of the literature. A key component of this was its ability to support learning and advancement for all students regardless of gender or ethnicity, something other studies had not found. Learning and skill advancement was achieved in both the topic areas common to engineering disciplines and in the discipline specific topic areas in ways that should prepare students for further study of engineering and that increased their interest in and confidence regarding the pursuit of engineering degrees. This included connection of theoretical content to real-world settings, a highly desirable pattern. The apparent winnowing of interested parties and decreases rather than increases in retention, the one desired impact not achieved, must be viewed in light of the concurrent potential impact of the COVID-19 pandemic, the extent of which is unknown.

Ability to Generalize from the Findings

The institution at which the courses were developed and enacted is an Hispanic-Serving Institution with approximately 70% of its student population identifying as Hispanic/Latinx. Outcomes described in this paper are directly generalizable to all HSIs in the southwest United States that have similar demographics and, due to the absence of differences in impact by gender, ethnicity, and race, to HSIs in the region with lower percentages of their student population that identify as Hispanic/Latinx (>300 universities). The absence of gender, ethnicity, and racial differences in outcomes also makes the results potentially generalizable to any college or university that would enact similar patterns, although curricular content and quality of instruction will influence results.

There is also a more limited potential to generalize from the findings to disciplines other than Engineering but with less certainty of similar outcomes. The similarities in practices across STEM fields have the potential to support similar results. Application outside those fields likely would also yield positive outcomes but with less certainty of paralleling those described in this paper.

Recommendations

The outcomes were encouraging, aligned with positive patterns described in the literature, and included universal efficacy even though other studies did not, but similar results in different institutional settings are not certain. The processes enacted would need to be replicated at other institutions to be certain impacts do generalize. The authors believe undertakings of this type are worth pursuing as there were substantial learning impacts with no variation by gender or ethnicity. This is a potential boon as a support mechanism for groups currently underrepresented in Engineering programs and professions. While there was lower retention in the Engineering disciplines during the project, that outcome appears to align with the decrease in certainty that "Engineering is for me" found on the surveys and a higher graduation rate for active Engineering students. Thus, it appears the programming may offer sufficient engagement with Engineering disciplines and research within those disciplines to help students recognize whether their initial career plans are viable and make adjustments, placing them and the College of Engineering in a better position for success with their active enrollees as they advance to upper-level courses. The need to move instruction entirely online during part of the project period due to the COVID-19 pandemic and the resulting impacts on students may, though, have also contributed to the decreased retention.

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Appendix 1. Results Tables

Table A1

GEEN 1201 Survey Response Rates by Discipline, Year, and Instructor

Engineering Discipline	Year	Instrctr	Survey	Enrolled	Rspndd	%
Civil and Architectural	2022	CAEN1	Pre	30	16	53.3%
			Post		6	20.0%
	2023	CAEN1	Pre	29	7	24.1%
			Post		6	20.7%
		CAEN2	Pre	25	5	20.0%
			Post		7	28.0%
Chemical and Natural Gas	2021	CHNG1	Pre	11	5	45.5%
			Post		4	36.4%
	2022	CHNG1	Pre	27	11	40.7%
			Post		6	22.2%
	2023	CHNG1	Pre	24	7	29.2%
			Post		9	37.5%
Electrical Engineering and Computer Science	2021	EECS1	Pre	9	4	44.4%
			Post		4	44.4%
	2022	EECS1	Pre	49*	28	57.1%
			Post		5	10.2%
	2023	EECS1	Pre	29	4	13.8%
			Post		7	24.1%
		EECS2	Pre	29	3	10.3%
			Post		3	10.3%
		EECS3	Pre	29	12	41.4%
			Post		9	31.0%
Environmental Engineering	2023	EVEN1	Pre	14	4	28.6%
			Post		1	7.1%
Industrial Management and Technology	2023	IMTE1	Pre	11	1	9.1%
			Post		3	27.3%
Mechanical and Industrial Engineering	2021	MIEN1	Pre	15	10	66.7%
			Post		14	93.3%
	2022	MIEN1	Pre	63*	40	63.5%
			Post		4	6.3%
	2023	MIEN1	Pre	91**	32	35.2%
			Post		12	13.2%

Note: * 2 sections ** 3 sections

Table A2

Responses to General Engineering Questions by Engineering Discipline

Prompt	Dscpln	Period	*n*	Mean	Mode	SD
I am confident in my ability to work as a team member on an engineering project.	CAEN	Pre	27	8.04	10	2.48
		Post	19	8.47	10	1.63
	CHNG	Pre	23	7.83	8	1.76
		Post	19	9.53***	10	0.60
	EECS	Pre	49	7.65	8	1.99
		Post	28	8.11	10	2.14
	EVEN	Pre	4	9.50	10	0.87
		Post	1	10.0	10	N/A
	IMTE	Pre	4	10.0	10	0.00
		Post	3	9.33	9	0.47
	MIEN	Pre	80	7.81	10	2.12
		Post	30	8.40	10	1.40
I know the basics of the engineering design process.	CAEN	Pre	27	5.70	5	2.59
		Post	19	7.05	7	1.90
	CHNG	Pre	23	6.74	8	2.11
		Post	19	9.05***	10	1.47
	EECS	Pre	46	5.85	10	2.64
		Post	28	6.96	8	2.26
	EVEN	Pre	4	9.25	9	0.43
		Post	1	10.0	10	N/A
	IMTE	Pre	4	9.50	10	0.87
		Post	3	8.33	7,8,10	1.25
	MIEN	Pre	79	6.08	5	2.52
		Post	30	8.17***	10	1.83
I know how to do engineering experimentation.	CAEN	Pre	27	5.65	7	2.99
		Post	19	6.21	7	1.99
	CHNG	Pre	23	5.17	5	2.71
		Post	19	8.68***	10	1.45
	EECS	Pre	45	4.76	4	2.55
		Post	28	7.04***	8	2.69
	EVEN	Pre	4	7.75	8	0.43
		Post	1	10.0	10	N/A
	IMTE	Pre	4	9.50	10	0.87
		Post	3	8.33	7,8,10	1.25
	MIEN	Pre	80	5.33	5	2.74
		Post	30	8.27***	10	1.67
I am NOT familiar with ways to analyze engineering data.	CAEN	Pre	27	3.46	2	2.40
		Post	19	3.05	0	2.72
	CHNG	Pre	22	4.86	7	2.77
		Post	14	2.50*	0	3.44
	EECS	Pre	46	4.57	5	2.70
		Post	26	2.65**	0	2.09
	EVEN	Pre	4	4.00	1,4,5,6	1.87
		Post	1	2.00	2	N/A
	IMTE	Pre	4	3.50	0	4.09
		Post	0	-	-	-

	MIEN	Pre	76	3.91	3	2.82
		Post	24	3.38	1	3.08
I do NOT know how engineers do problem solving.	CAEN	Pre	23	3.57	0	2.86
		Post	18	1.94*	0	1.78
	CHNG	Pre	21	3.81	1	2.75
		Post	12	2.25	0	2.77
	EECS	Pre	44	3.40	2	2.16
		Post	23	1.96*	0	2.29
	EVEN	Pre	4	1.25	1	1.09
		Post	1	2.00	2	N/A
	IMTE	Pre	3	3.33	0	4.71
		Post	0	-	-	-
	MIEN	Pre	70	3.42	5	2.52
		Post	24	2.96	1	3.10
I am very interested in becoming an engineer.	CAEN	Pre	27	9.19	10	1.74
		Post	19	8.26	10	2.49
	CHNG	Pre	23	8.65	10	1.78
		Post	19	8.58	10	1.79
	EECS	Pre	49	9.09	10	1.16
		Post	28	8.50	10	2.57
	EVEN	Pre	4	9.50	10	0.50
		Post	1	10.0	10	N/A
	IMTE	Pre	4	10.0	10	0.00
		Post	3	6.00	3,8,10	4.32
	MIEN	Pre	79	9.38	10	1.18
		Post	30	9.20	10	1.30
I am NOT certain that engineering is for me.	CAEN	Pre	21	2.43	0	3.55
		Post	18	2.28	0	2.76
	CHNG	Pre	18	2.06	1	1.75
		Post	17	2.12	0	2.56
	EECS	Pre	36	1.64	0	1.47
		Post	21	1.76	0	2.47
	EVEN	Pre	4	5.00	0	0.87
		Post	1	1.00	1	N/A
	IMTE	Pre	3	6.33	3,9,10	4.50
		Post	1	1.00	1	N/A
	MIEN	Pre	60	1.29	0	1.79
		Post	21	2.81	0	3.08
Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$						

Table A3

Prompts and Responses to Discipline-Specific Questions

Prompt	Period	*n*	Mean	Median	SD
CHNG Sections					
I understand how different materials can be used to remove offensive chemicals in water treatment systems.	Pre	22	4.77	4	2.79
	Post	17	8.41***	10	1.50
I can design a basic water treatment system.	Pre	21	3.90	3	3.22
	Post	17	7.47***	9	1.94
I DO NOT know how to use a peristaltic pump.	Pre	22	7.36	10	3.54
	Post	12	5.21	7	3.44
I know how to complete refractive index readings with water samples.	Pre	19	1.63	0	2.68
	Post	16	5.75***	10	3.38
I can explain the need for a prototype-test-repeat approach in engineering design.	Pre	23	6.09	5	3.09
	Post	18	7.78	10	2.66
I was NOT interested in the water treatment project.	Post	14	2.0	0	2.23
I see real-world applications for things I learned in the water treatment project.	Post	16	8.56	10	2.12
CAEN Section					
I can explain the way the positioning of a fulcrum impacts the effectiveness of a lever.	Pre	15	4.80	5	2.48
	Post	5	6.20	Mult.	2.56
I can explain stressors placed on the support structure of a trebuchet when it is operated.	Pre	14	5.50	8	2.77
	Post	5	6.60	7	2.24
I can list two or more things that effect the throwing distance of a trebuchet.	Pre	15	7.0	8	2.97
	Post	5	8.0	10	1.90
I can explain how kinetic energy is transferred to the projectile of a trebuchet.	Pre	15	5.80	8	2.95
	Post	5	8.20	10	1.60
I can list two or more forces that act on the arm of a trebuchet.	Pre	15	5.93	7	2.67
	Post	5	7.80	6	1.83
I can explain the significance of the relationship between the weight of the projectile and counterweight of a trebuchet.	Pre	15	6.53	10	3.03
	Post	5	7.60	10	2.06
I can document the distance traveled by a projectile thrown by a trebuchet through experimentation and calculate the expected average.	Pre	15	6.47	10	3.48
	Post	5	7.40	10	2.33
I see real-world applications for things I learned about forces, levers, and projectiles.	Post	5	8.20	10	2.23
EECS Sections					
I can build a simple chassis for a mobile robot.	Pre	43	4.63	0	3.92
	Post	27	8.21***	10	2.26
I can mount electric motors and associated wiring to a robot chassis.	Pre	42	4.74	10	3.79
	Post	26	8.48***	10	2.11
I have worked with a computer board for a small robot.	Pre	39	3.87	0	3.91
	Post	26	8.15***	10	2.72
I can write a program in Python to process data for guiding a robot.	Pre	38	3.74	0	3.23
	Post	26	7.00***	10	3.02
I find it motivating to compete with classmates to see whose design project works best.	Pre	48	6.79	10	3.09
	Post	26	7.56	10	2.56

I was NOT interested in the robot building project.	Post	18	1.65	0	1.94
I see real-world applications for things I learned in the robot building project.	Post	27	8.64	10	1.86
MIEN Sections					
I understand the reverse engineering process.	Pre	73	6.21	10	3.20
	Post	30	8.73***	10	4.19
I CANNOT use 3D modeling software to design a mechanism.	Pre	64	3.52	1	2.82
	Post	21	2.79	1	3.80
I know how to use 3D modeling software to do motion study analysis.	Pre	73	3.33	0	2.98
	Post	30	8.06***	10	2.27
I have designed a product that fit a predefined set of specifications.	Pre	67	4.27	0	3.71
	Post	17	7.88***	10	2.19
I have used 3D modeling software to complete a design project.	Pre	68	3.79	0	3.88
	Post	18	9.17***	10	1.17
I have used 3D modeling software to complete assembly interference detection.	Pre	59	2.91	0	3.00
	Post	18	8.11***	10	2.42
I do NOT find design of mechanisms interesting.	Pre	51	1.47	0	2.58
	Post	13	2.46	0	2.95
I see real-world applications for things I learned about reverse engineering.	Post	18	8.72	10	1.28
I do NOT see real world applications for things I learned about 3D modeling.	Post	15	1.79	0	2.91

Note: * $p < .05$, ** $p < .01$, *** $p < .001$; $^{+}$ = possible confusion regarding the rating scale for one student which significantly increased the standard deviation.