(Full Paper) Enhancing Sense of Belonging in First-Year Engineering Students through Integrated Project-Based Learning and Communication Skills Development

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Introduction

The transition to college can be challenging for first-year students, particularly for disciplines like engineering that often require a steep learning curve and rigorous academic demands [1-3]. Those challenges can impact their self-efficacy beliefs and sense of belonging to the school community, as there is a noted decrease in motivation to study engineering after the first year of undergraduate coursework [4-6]. Fostering a strong sense of belonging among first-year students has been identified as a critical factor for student engagement, academic success, and retention rates [7-9].

Educational institutions can implement various programs and workshops to assist first-year engineering students in overcoming challenges during the transition and enhance their sense of belonging. Numerous studies show that project-based learning (PBL) is proven to enhance student's motivation, promote their participation and engagement, and enrich a better and deeper understanding of engineering concepts and practices through realistic projects [10, 11]. Writing experience also promotes students' academic engagement, and providing students with formative feedback on their writing can improve their mindset, belonging, and perseverance in college [12, 13]. Effective oral communication can build student's self-confidence and enhance their connections and inclusions with peers and faculties. Creating a supportive learning environment through practices like engagement and providing opportunities for positive interactions among diverse peers can further promote students' sense of belonging [14].

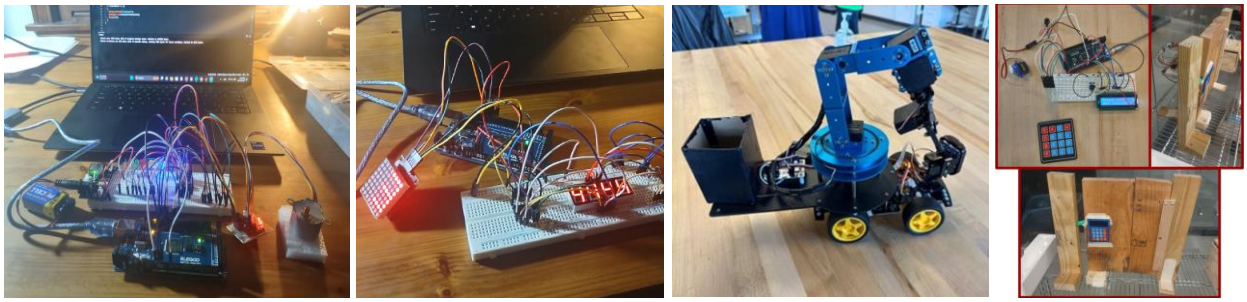
Research Significance

While industry increasingly values engineers with strong technical skills and effective communication abilities [15], limited institutions have integrated substantial communication training into first-year engineering courses. Northwestern University has developed an interdisciplinary first-year course that integrates project-based engineering design with freshman communication and collaboratively taught by a team of engineering and writing faculties [16]. It is shown that this interdisciplinary teaching approach improves both engineering design and communication skills, providing students with an exceptionally solid foundation for their future engineering courses and careers. However, the course did not investigate the effect of the approach on fostering first-year students' sense of belonging.

This study presents a series of project-based learning and communication skill development activities for 20 first-year engineering students enrolled in the ES143 Engineering and Design class at the University of Hartford (UHart) in Fall 2023 semester. Throughout the semester, students conducted hands-on projects to explore diverse engineering disciplines, while engaged in weekly assignments involving technical reports, presentation slides, posters, and in-class oral presentations. Peer evaluation and a revise-resubmit process were implemented for most assignments. Two surveys assessing students' sense of belonging and perception of technical writing were also conducted at the beginning and end of the semester.

Course Description and Project-Based Learning Structure

In Fall 2023, the course adopted the Arduino-based Elegoo Mega 2560 The Most Complete Starter Kit as the project-based teaching tool. The kit provides an open-source electronics prototyping platform including MEGA controller board with over 60 kinds of components and sensors [17]. The curriculum was meticulously designed to empower students to delve into eight different engineering programs offered in the college, including acoustical, aerospace, biomedical, civil, computer, electrical, mechanical, and robotics engineering. Students learned basic Arduino programming, mechanism of each sensor and component, and basic circuit diagram. Through weekly hands-on individual and group projects using the kit, this project-based teaching and learning approach enriches students' deep understanding of each discipline's principles and real-world applications. Fig. 1a shown below demonstrates a mechanical project integrating photocell, stepper motor, and LED lights to simulate a solar panel application, and Fig. 1b shows an electrical project integrating 4-digit 7-segment display and LED dot matrix display to simulate a digital display function.



(a) (b) (c) (d)

Figure 1. ES143 course projects: (a) mechanical project; (b) electrical project; (c) autonomous garbage truck; and (d) secure door lock

After completing all the individual disciplinary projects, students applied their learning to create multidisciplinary design expo projects over the last four weeks of the semester. These projects incorporate a minimum of three sensors or features to address real-world challenges. Example projects are depicted in Fig. 1c and 1d.

Communication Skills Assessment

A comprehensive series of technical writing and oral presentation learning activities were incorporated into the course to assess students' comprehension of each project, as well as to develop students' communication skills. For the first four engineering disciplines, students were assigned to write individual and group technical reports. After their initial submission, all the reports were randomly and anonymously distributed to the class for peer review while the instructor demonstrated and explained both effective and ineffective examples in front of the class. Students then revised and resubmitted their work based on the received feedback. This initial submission – peer review – revision and resubmission process efficiently enhanced students' learning journey by providing the opportunities for them to review and revise their mistakes, as well as to learn from their peers, as evidenced by the subsequent discussion section in this paper. Students worked on presentation slides for the next two disciplines and posters for the last two. Both group slides and posters were presented in the class after the initial

submission, with peers and the instructor reviewing and providing live feedback. Similarly, students could revise and resubmit their work based on the received feedback. Both the instructor and students used the same grading rubric for technical writing and oral presentations. All preceding training activities laid a robust foundation to develop students' communication skills, preparing them for showcasing in the final design expo.

Sense of Belonging and Technical Writing Surveys

In order to assess students' development of belonging and writing capabilities throughout the semester, two anonymous surveys were conducted at the beginning and end of the semester. Sense of belonging survey (Table 1), adapted from the questionnaire in [12], includes social belonging (items 1-10) and academic self-efficacy (items 11-18) questions. Technical writing survey (Table 2) addresses technical report components (item 1, 2, 6) and technical languages (item 3-5) with instructor-provided correct answers highlighted in the table. Students were given the informed consent before the pre-survey and had the option to opt out. Students under 18 years old at the start of the semester were also ineligible to participate. In total, 13 out of 20 students (65%) participated in the pre-survey and post-survey. Note that due to the survey's anonymity, there is no guarantee that the same 13 students participated in both surveys.

Table 1. Sense of belonging survey form with statistical analysis on response results.

Questions and Scales	**Pre-Survey (n_1=13)**		**Post-Survey (n_2=13)**		*SD=standard deviation		
strongly agree=5; agree=4; neither agree nor disagree=3; disagree=2; strongly disagree=1	mean (x_1)	SD* (s_1)	mean (x_2)	SD* (s_2)	pooled SD* (s_p)	|t|	Cohen's |d|
1. I feel comfortable at UHart.	4.15	0.55	3.92	0.76	0.67	0.88	0.35
2. I belong at UHart.	3.85	0.90	3.46	1.05	0.98	1.00	0.39
3. Other students at UHart accept me.	3.77	0.73	3.62	0.65	0.69	0.57	0.22
4. Other students understand more than I do about what's going on at UHart.	3.23	1.01	3.00	1.29	1.16	0.51	0.20
5. I think in the same way as do students who do well at UHart.	3.46	0.66	3.15	1.21	0.98	0.80	0.31
6. It is a mystery to me how UHart works.	2.23	0.60	2.69	1.03	0.84	1.39	0.55
7. I feel alienated from UHart.	2.15	0.90	2.00	0.82	0.86	0.46	0.18
8. Students at UHart are a lot like me.	3.15	0.69	3.46	0.78	0.73	1.07	0.42
9. I fit in well at UHart.	3.69	0.48	3.85	0.69	0.59	0.66	0.26
10. Compared with most other students, I know how to do well at UHart.	3.77	0.83	3.69	0.85	0.84	0.23	0.09
11. I feel confident that I have the ability to do well at UHart.	4.15	0.90	4.31	0.95	0.92	0.42	0.17
12. I feel that I have less ability than others at UHart.	2.31	0.95	2.46	1.05	1.00	0.39	0.15
13. Being successful at UHart is important to me.	4.92	0.28	4.77	0.83	0.62	0.63	0.25
14. Classes at UHart are very interesting for me.	3.85	0.55	4.00	0.91	0.76	0.52	0.20
15. I enjoy academic work at UHart.	3.46	0.88	3.38	1.04	0.96	0.20	0.08

16. In the future I could see myself doing well academically at UHart.	4.38	0.51	4.23	0.83	0.69	0.57	0.22
17. In the future, I could see myself impressing a UHart professor.	4.38	0.77	3.92	1.12	0.96	1.23	0.48
18. In the future, I could see myself working closely with a professor on an independent project (such as research, honors, or capstone thesis).	4.08	1.04	4.00	1.00	1.02	0.19	0.08

Table 2. Technical writing survey form with response analysis.

Question	Options		Correct Percentage	
			Pre-Survey	Post-Survey
1. In a technical report, a short paragraph that summarizes the study purpose, what was done, results and conclusions is called _____.	a) Abstract	b) Introduction	54%	92%
2. An abstract should be written first.	TRUE	FALSE	23%	69%
3. Which of the two sentences below is the appropriate writing style for a technical report?	a) We determined that the digital power supply voltage should be adjusted to 10 volts.	b) It was determined that the digital power supply voltage should be adjusted to 10 volts.	38%	23%
4. Which of the two sentences below is the appropriate writing style for a technical report?	a) I assemble the passive components on to the protoboard.	b) The passive components were assembled on the protoboard.	69%	100%
5. Which of the two sentences below is the appropriate writing style for a technical report?	a) You can see from the figure of the circuit diagram that ……	b) It can be seen from the figure of the circuit diagram that ……	62%	100%
6. The discussion section analyzes an experiment's results but does not include any errors that occur during the experiment. Also, it does not draw any logical conclusions.	TRUE	FALSE	54%	31%

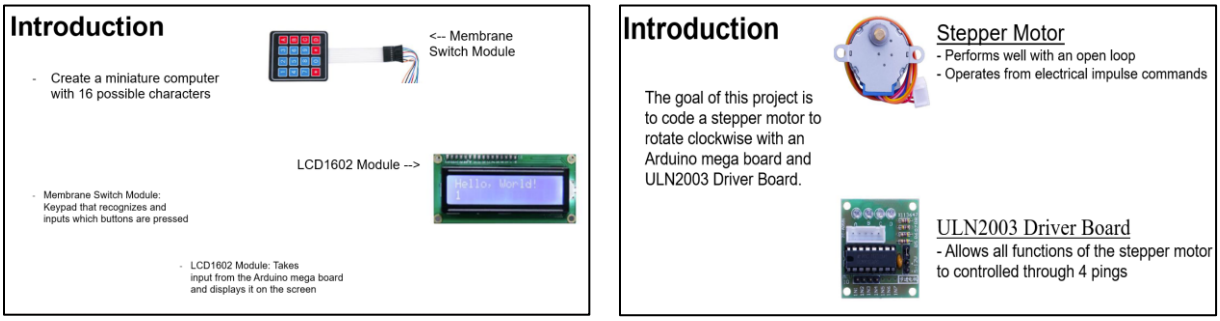
Results and Discussion

The technical reports from students who participated in the survey were analyzed. The writing samples and overall comments from the third author of this paper for some students are outlined in Table 3 below. The "before" scenario refers to the student's first report on acoustical engineering, while the "after" scenario refers to the student's fourth report on civil engineering. The table shows that the content of students' reports was more fully developed and better integrated with graphics in the "after" reports compared to the "before" reports, indicating significant progress in students' understanding of the subject. In terms of technical writing, the format, language, and grammar were better organized and more consistent in the "after" reports, reflecting the effectiveness of the peer evaluation and refinement of the work in enhancing students' learning and writing skills. In addition, the sample presentation slides in Fig. 2 illustrate paired pictures with text descriptions in the "after" scenarios, contrasting with

randomly arranged pictures and texts in the "before" scenarios. This demonstrates students' improvement in organizing slides contents throughout the practices.

Table 3. Analysis results of students' technical reports.

Student	Item	Before (Acoustical)	After (Civil)
#1	Sample	*"In order to complete this task, I downloaded the code from lesson 7 and the passive buzzer. I then used the notepad app to…"*	*"The goal of this is to design a system that can detect a change of inclination and activate a set of 4 LED bulbs."*
	Comment	Minimal completion and formatting. Some graphics, no context or integration.	Sections N/A clearly noted, format more professional. More graphics use; not integrated or contextualized
#2	Sample	*"… Then, working together in a group, combine this with the sound sensor module to record the sound. We were successful in generating…"*	*"The code was successful in defining the pins that were being used and identifying when to turn on and off. The project was able to help practice…"*
	Comment	Uses template, notes N/A sections. Fuller completion of some components; some key sections missing; most boilerplate left in	Uses template, notes N/A info, sections fully completed, no boilerplate, most sections completed fully
#3	Sample	*"The goal of this project is to produce sound with both the active and passive buzzer. This is achieved by using 2 female to male…"*	*"This project is about getting a ball switch to detect when it is tilting and to light up four of the eight LED lights…"*
	Comment	Uses template, most sections completed (some cut and paste). Provides graphics and some interpretation/integration	Uses template, notes N/A sections, complete and full completion of components, uses more graphics.
#4	Sample	*"In this lesson, you will learn how to generate a sound withan active buzzer."*	*"This project uses a shift register to indicate the inclination on a ball…"*
	Comment	Uses template, some boilerplate left in, irregular formatting, some section content has detail/development	Fuller completion of report components, more refined formatting, more extensive use of graphics, some graphics interpretation and integration



(a) **(b)**

Figure 2. Sample presentation slides for (a) "before" scenario; and (b) "after" scenario

Two statistical tests were conducted on sense of belonging survey responses to evaluate the impact of the learning activities on students' sense of belonging (Table 1). An independent samples t-test was used for each survey question, as the survey was anonymous and individual responses could not be matched. The significance level was set at 0.05 for a two-tailed t-test to determine whether the observed mean differences between pre-survey and post-survey were statistically significant. The critical t value obtained from the t-distribution table is 2.064 with the degree of freedom being 24. Additionally, Cohen's d values are interpreted as approximately 0.2

for a small effect, 0.5 for a medium effect, and 0.8 or higher for a large effect. As seen in Table 1, the calculated t values for all questions are smaller than the critical t value of 2.064, indicating the observed changes between pre and post responses could be due to random variation. This suggests that the implemented learning activities had minimal statistically significant impact students' sense of belonging. However, the calculated Cohen's d values for questions 6 (d=0.55), 8 (d=0.42), and17 (d=0.48), suggest moderate practical significance. Question 6 (It is a mystery to me how UHart works) shows an increase in average ratings from 2.23 in the pre-survey to 2.69 in the post-survey, indicating students had been discovering more mysterious parts of the university since starting their first semester. The average rating for question 8 (Students at UHart are a lot like me) increases from 3.15 in pre-survey to 3.46 in post-survey, reflecting students had been making friends and finding their cohort with whom they share similarities. Question 17 (In the future, I could see myself impressing a UHart professor) sees a decrease from an average of 4.38 in the pre-survey to 3.92 in the post-survey. This change reflects that students had developed increased self-awareness and clearer understanding of the quality requirements of their work in college compared to those in high school. Overall, results highlight that, despite the limited statistical power potentially due to the small sample size, the teaching interventions could still have a meaningful impact on certain aspects of students' sense of belonging. It should also be acknowledged that first-year engineering students face various unknowns and challenges, especially during their first semester, which might not be easily addressed by a single course or program.

For the technical writing survey (Table 2), correct response rates moderately decrease from the pre-survey to post-survey for questions 3 and 6, but substantially increase for all the other questions. This indicates an overall enhancement in students' understanding of technical report structures and language requirements. However, it also suggests that writing training in a single course may not sufficiently establish a solid foundation for first-year students.

Conclusion

This study introduced the first-year ES143 Engineering and Design class offered by the College of Engineering, Technology, and Architecture at the University of Hartford, which integrated project-based learning and comprehensive communication training activities in Fall 2023 semester. Surveys on the sense of belonging and technical writing were conducted at the semester's start and end. The assessments of technical writing, including reports, presentation slides, posters, and technical writing survey, demonstrate effective enhancement in students' mastery of technical language requirements and professional organization of content in various formats. The sense of belonging survey results, although not showing statistically significant changes, still reflect a practically meaningful impact on certain aspects of student's social belonging and self-awareness. Overall, the study highlights the complex situation faced by first-year engineering students and the need for multiple meticulously tailored courses and programs from universities. Future work involves collaborating with more first-year engineering course instructors to expand technical writing training and sense of belonging surveys, ensuring a sufficient sample size for statistical analysis.

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