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Opportunities for Integrating Service Learning into Engineering Capstone Projects

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ABSTRACT

BACKGROUND

Higher education has shifted in recent years toward experiential and student-centred learning, and capstone projects are essential for engineers to apply their knowledge and skills in real-world settings. Despite its acknowledged ability to foster community engagement, service learning has not yet gained widespread acceptance as a formal capstone project in the field of engineering.

PURPOSE

The study examines how community-based projects contribute to achieving learning objectives and compares them with results from regular capstone.

METHOD

The sample comprised 57 students who completed standard capstone projects and those who participated in service learning. Data were collected using standardised rubric-based grading exams. Statistical analysis was employed to identify differences in performance across five learning outcomes.

RESULTS

According to the results, students who participated in service learning projects performed better in several learning outcomes like communication, problem understanding, and root cause analysis. These findings demonstrate that service learning can meet the technical and reflective requirements of an engineering capstone when evaluated using a standardised rubric.

CONCLUSIONS

This study shows that service learning is an effective capstone format in engineering education. It emphasises the importance of real-world, community-based experiences in fostering students' technical proficiency and overall development.

KEYWORDS

Engineering education, industrial engineering, capstone project, service learning.

Introduction

Capstone projects are pivotal experiences for students to implement engineering design in addressing complex engineering challenges (Kamaruzaman et al., 2017). In recent years, engineering education has increasingly adopted experiential and student-centred learning approaches. This change aligns with accreditation criteria established by the Accreditation Board for Engineering and Technology (ABET), which strongly emphasises learning outcomes and assessment methodologies. The Capstone Project places a strong emphasis on problem definition, with the selected problem being required to meet the complexity standards defined by the Accreditation Board for Engineering and Technology (ABET 2024).

A growing area of interest involves integrating service learning into a capstone project. Service learning (SL) is a course-based, credit-bearing educational experience wherein students engage in a structured service activity addressing recognised community needs and reflect on the service activity to deepen their comprehension (Bielefeldt et al., 2010; Bringle et al., 2004). These programs foster civic engagement and present real-world engineering challenges within social contexts (Knox & Nairn, 2025). Adopting service learning as a capstone project offers an opportunity to improve student engagement and learning by addressing community needs, hence facilitating the development of transferable skills such as leadership, teamwork, communication, and ethical reasoning (Carvalho, 2016).

However, in terms of assessment, context-specific characteristics of service-learning could make it difficult to guarantee consistency across many student experiences (Queiruga-Dios et al., 2021). There is a need for a more systematic rubric-based assessment to evaluate student achievement and learning outcomes (Yusof et al., 2020). Comparative research on service learning frameworks found no generalised framework for service learning in higher education (Salam et al., 2019). Integrating service learning into an Industrial Engineering (IE) capstone course can enhance students' practical problem-solving skills (Onal et al., 2017). Based on the evaluation, service learning provided several benefits for the students, especially in developing practical skills and social awareness among IE students (Konrad et al., 2018).

Despite their potential, there is a lack of general agreement regarding the assessment for evaluating project success and social impact due to diverse stakeholder interests and unpredictable real-world constraints (Smith et al., 2022). The absence of standardised assessment could result in inconsistent recognition of student accomplishment (Armstrong et al., 2021; Othman & Abualsauod, 2021; Steiner et al., 2011). Furthermore, developing assessment rubrics tailored to community-engaged projects has facilitated more relevant and meaningful evaluations (Bonoff et al., 2024). Service learning projects tend to be underutilised as capstone experiences in Industrial Engineering programs, even though they align with the goals of design-based learning. This study investigates the opportunities to integrate service learning into capstone projects in Industrial Engineering curricula by comparing student performance using standardised assessment.

Literature Review

The capstone design is expected to integrate several elements of the student's learning outcomes in the engineering curriculum (Jaeger-Helton et al., 2019). The student's performance was evaluated through assessment rubrics. Capstone design project rubrics must align with accreditation standards (Howe & Goldberg, 2019). Standard capstone project rubric dimensions in IE include the ability to identify problems, conduct root cause analysis, design solutions, and stakeholder engagement (Othman & Abualsauod, 2021). Numerous studies emphasise the significance of educators incorporating technical and soft skills in rubrics to

assess student performance holistically (Higbee & Miller, 2020). Various academic and non-academic factors can influence student performance and project success. The factors affecting students' engagement and performance levels include academic performance, faculty mentorship availability, and the complexity of the assigned project (Kim et al., 2024; Steiner et al., 2011). Problem-solving efficacy also impacts perceived performance, emphasising the importance of motivational elements in capstone design courses (Joo et al., 2019).

The EPICS program at Purdue University incorporates service learning into capstone projects to assess students' teamwork, collaboration, moral responsibility, and communication effectiveness while encouraging diversity and student motivation (Coyle et al., 2005; Ellzey et al., 2019; Leidig et al., 2023). With an emphasis on problem definition, design development, and stakeholder interaction, service-learning capstone projects at Drexel University also demonstrate that these experiences enhance students' technical skills, as well as their social self-efficacy and employability (Wang et al., 2023).

A unique challenge in assessing student performance in capstone projects is the need for teamwork (Abu Salem et al., 2020; Rashwan et al., 2020). Modifying rubric-based assessments and using evaluation to accommodate specific criteria for team and individual accomplishments (Friess & Goupee, 2020). To ensure relevance and fairness, best practices involve incorporating multiple perspectives from industry stakeholders, faculty members, students, and accreditation boards' criteria into the assessment rubric (Kakkar et al., 2025; Othman & Abualsauod, 2021; Steiner et al., 2011). Additionally, evaluators continually revise and calibrate the assessments to guarantee inter-rater reliability and reduce subjectivity in grading (Chong & Romkey, 2017).

Capstone projects based on service learning can improve student learning experiences while addressing real societal issues (Kim et al., 2019; Mackenzie et al., 2019). Service learning can lead to an understanding of the societal impact of engineering knowledge while fostering systems thinking ability (Lasker, 2019; Nusaybah et al., 2022). Both quantifiable results for the community and educational outcomes for students must be evaluated in service-learning-based projects (Kegley, 2020). Improvements in processes, stakeholder satisfaction, the sustainability of proposed solutions, and the feasibility of innovations suggested by students are metrics that reflect the impact of the projects (Clua & Feldgen, 2020). Hence, dimensions such as the solution's feasibility, stakeholder involvement, ethical considerations, and long-term benefits must be considered when developing an assessment rubric.

Methods

This study used a comparative research design to assess the viability of recognising service learning as a senior capstone project. The sampling method employed was purposive sampling. A total of 57 students were chosen, all of whom were Industrial Engineering seventh-semester students enrolled in the capstone project course in the same academic year. The main instrument for collecting data was the grading assessment rubric utilised by faculty evaluators. Descriptive and inferential statistical methods were employed to compare the academic performance of the two groups.

The control group represents students who enrolled in regular capstone, while the experimental group represents students who continued their service learning as their capstone project. The Mann–Whitney U test was employed to compare student performance across two groups (Castedo et al., 2019; Munir et al., 2025). This non-parametric test is suitable for data without specific distribution assumptions (MacFarland & Yates, 2016). A key limitation of the

study is that it only involved students from a single cohort, which may limit the generalizability of the findings to other academic years or program structures.

Capstone projects are carried out in teams, with eligible students beginning by selecting an Industrial Engineering body of knowledge. The Capstone Project coordinator assigns students to teams, which then select a project topic and focus area. Currently, there are two pathways for undertaking the capstone project: the regular path, where topics are proposed independently, and the service learning pathway, where students continue projects initiated during their thematic service learning program. The selected topics may therefore originate from either path. This study focuses on comparing students' academic performance in Capstone Project 1 across these different topic sources.

Students in the service learning pathway typically work on engineering projects centred on local Micro, Small, and Medium-Sized Enterprises (MSMEs). Examples include developing tools to enhance shuttlecock MSMEs' manufacturing processes, such as automated adhesive application systems to improve production consistency and ergonomic and poka-yoke-based fixtures to reduce shuttlecock assembly defects. Other projects have addressed occupational safety in Cepogo's copper craft MSMEs, including creating safety signage and guidelines for personal protective equipment, redesigning facility layouts, and developing mechanical tools to reduce the risk of work accidents for high-risk operations, such as pouring molten metal. These projects integrate technical problem-solving with stakeholder engagement, in line with ABET's definition of complex engineering problems. Figure 1 illustrates the flow of the Capstone Project 1 course in the Industrial Engineering Department, Sebelas Maret University.

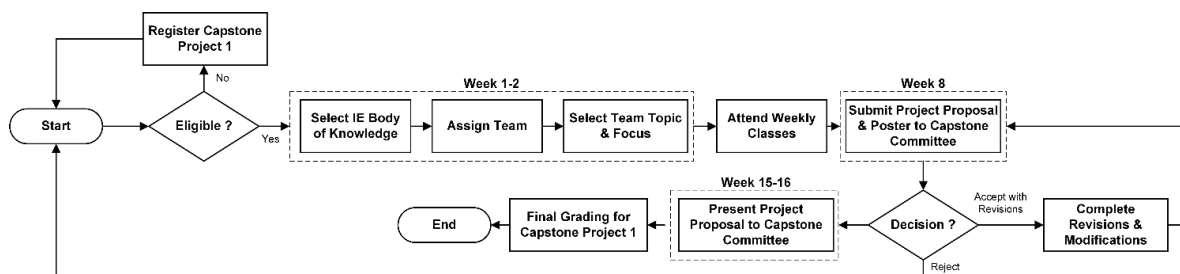


Figure 1: Capstone Project 1 Process Flow

Findings

ABET is responsible for the accreditation of the IE program and is recognised as the reference point for educational quality and program standards for Capstone Projects. ABET has identified seven Student Outcomes (SOs) that must be achieved throughout the curriculum. Table 1 illustrates the correlation between the Student Outcomes (SO) and the course assessment criteria for Capstone Project 1.

Table 1: ABET Student Outcomes and the Capstone Project Course Outcomes

ABET Student Outcomes	Assessment Criteria
• SO 4: An ability to identify, formulate, analyse, and solve complex engineering problems in an integrated system	Criteria 1: Students are able to identify and understand complex problems Criteria 2: Students are able to identify root causes and define realistic constraints

ABET Student Outcomes	Assessment Criteria
• SO 7: An ability to plan, accomplish, and evaluate tasks under given constraints • SO 8: An ability to work in a multidisciplinary and multicultural team	Criteria 3: Students are able to propose alternative solutions based on in-depth analysis of bodies of knowledge Criteria 4: Students are able to make rational decisions Criteria 5: Students are able to collaborate across multiple disciplines and multicultural environments

Table 2 presents the descriptive statistics and the results of the Mann-Whitney U-test.

Groups	N	Mean	Median	Std. Deviation	U-Statistic	P-Value
Service Learning	8	82.91	83.18	0.79	304	0.0133
Regular Capstone Project	49	81.09	81.01	2.00		

Figure 2 displays the box plots for each of the assessment criteria provided in Table 1 for the two groups.

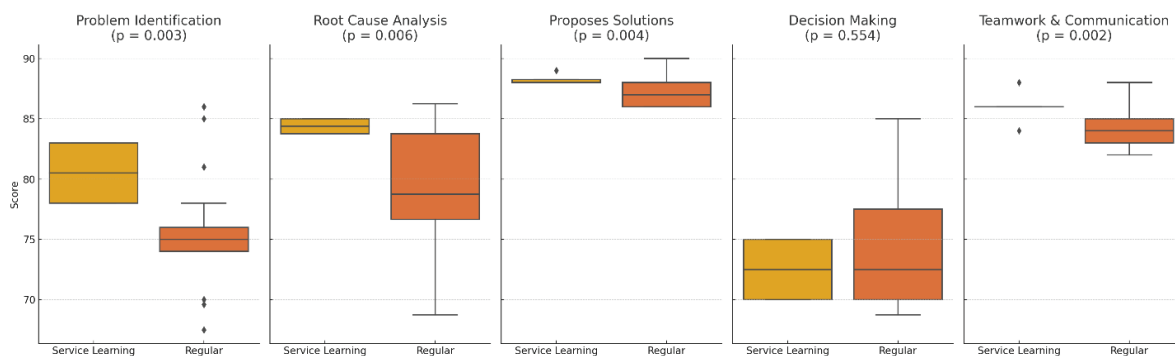


Figure 2: Comparison Between Service Learning and Regular Capstone

In sum, there is a statistically significant difference ($p\text{-value} < .05$) in the student performance between service learning (experimental group) and regular capstone (control group) across each assessment criteria except criteria 4 (decision making). This study provides empirical evidence for incorporating service learning as a valid and evaluable capstone model in Industrial Engineering curricula. The higher grades of the service learning group suggest that real-world, community-engaged activities may improve student outcomes in problem identification, proposing solutions, root cause analysis, communication, and teamwork.

Students in the service-learning pathway performed better on the majority of assessment criteria, which could be attributed to several factors. First, real-world, authentic problems that directly affect the community are integral to service learning projects, which can increase student engagement and motivation. Second, continuous communication with community stakeholders requires students to improve their problem definitions and increase the adaptability and feasibility of the project solutions. Third, service learning students enter the Capstone Project with prior knowledge of the problem domain, which allows them to adapt quickly. Additionally, the observable results of their solutions might strengthen their sense of accountability and ownership, promoting better teamwork.

The result is consistent with research by Kegley (2020), which showed that students working on capstone projects with a community improve their hard-skill knowledge and grow their capacity for civic engagement and critical thinking. Similarly, Mackenzie et al. (2019) argue that service learning promotes cognitive and affective learning outcomes, making it a high-impact pedagogical practice well-suited to capstone projects. While prior studies have highlighted the educational advantages of service learning, they often fail to demonstrate its integration into capstone projects. For instance, Othman & Abualsauod (2021) did not examine service learning as an approach but focused on standardising the internal processes of the capstone project. Similarly, Metcalf (2010) and Mackenzie et al. (2019) highlight the advantages of community-based projects in terms of community engagement and reflectiveness. Still, they also pointed out that there aren't many reliable evaluation instruments for these settings.

The methodological approach in this study, which utilises the Mann–Whitney U test, also presents certain limitations. The service learning group had a smaller sample size compared to the regular capstone group, which may reduce statistical power. As students self-selected into either the service learning continuation or the regular capstone pathway, the groups were not random, raising the possibility of selection bias due to pre-existing differences in motivation or experience. The study also assessed performance only at capstone project 1, which does not capture potential changes across the complete capstone sequence.

Despite these limitations, this study shows that service learning can produce comparable or even better student performance in several technical learning outcomes and can be rigorously evaluated using structured rubric-based frameworks. This study demonstrates that students engaged in service learning excel in fundamental technical competencies, including problem identification and root cause analysis, despite prior research having predominantly associated service learning with enhancing soft skills such as communication, teamwork, and empathy.

Conclusion

Achieving a capstone design project that is thoroughly integrated and encompasses all aspects of community service learning is best regarded as a temporal process. Through a comparative analysis using the Mann–Whitney U test, the results showed statistically significant differences in several assessment criteria—particularly in problem identification, root cause analysis, and teamwork—with higher scores achieved by students whose capstone topics were derived from their service-learning experiences. Furthermore, the model was implemented in the Industrial Engineering department of a public university. The implementation supported its adoption in curriculum design, demonstrating that using service learning as a foundation for capstone topics is both feasible and beneficial for students.

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