

Article

Capstone Projects as Preparation for Engineering Practice: A Graduate-Based Evaluation of Supervision and Industry Readiness

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Abstract

Capstone projects in undergraduate engineering education are widely regarded as a central bridge between academic learning and professional practice, enabling students to integrate disciplinary knowledge, design processes, teamwork, and problem-solving skills in a project-based learning experience. This study examines how 131 engineering graduates and practicing engineers retrospectively evaluate capstone supervision and its contribution to industry readiness. Correlation analysis and multiple regression were used to examine relationships between the supervisor's approach, perceived industry preparation, supervision satisfaction, and capstone project quality. Regression models including supervisor's approach and perceived industry preparation explained substantial variance in both supervision satisfaction ($R^2 = 0.75$) and project quality ($R^2 = 0.78$). Follow-up analyses identified connection to engineering work as the strongest retained predictor of supervision satisfaction ($\beta = 0.34$), and cognitive factors as the strongest retained dimension associated with project quality ($\beta = 0.52$). However, 60.3% of graduates perceived the capstone project as making little or no contribution to finding engineering employment, suggesting a gap between this intended bridging role and its perceived value after graduation. These findings highlight the need to strengthen the connection between supervision practices and professional engineering work and contribute a graduate-based perspective to capstone project evaluation in engineering education.

Keywords: capstone projects; engineering education; capstone supervision; project-based learning; industry readiness; graduate perceptions; professional practice



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1. Introduction

The capstone project occupies a distinctive and widely recognized position in undergraduate engineering education. It is commonly understood as the culminating academic experience of the degree: a site where students are expected to integrate knowledge and skills acquired throughout their studies, apply them to a substantial and open-ended engineering task, and develop professional competencies that will be required after graduation. Because it serves both as an integrative academic experience and as intended preparation for engineering practice, the capstone project is widely regarded as one of the most educationally significant components of the engineering curriculum (Dutson et al., 1997; Howe & Goldberg, 2019; Pembridge & Paretti, 2019; Shurin et al., 2020). In educational

terms, it represents a concentrated form of project-based and problem-based learning (PBL), drawing on principles of active inquiry, problem solving, teamwork, and applied knowledge construction that have been widely studied and advocated in engineering education research (Dutson et al., 1997; Hauhart & Grahe, 2015; Howe & Goldberg, 2019).

Engineering education research has devoted considerable attention to the design, assessment, and outcomes of capstone programs (Hotaling et al., 2012; Todd et al., 1993). However, a persistent gap remains in how the capstone experience is evaluated: many assessment practices are conducted during or immediately after the course, at a point when students may lack the professional experience needed to judge whether the project prepared them for engineering work. This temporal limitation is particularly significant for capstone education, because one of its central purposes is to support students' transition from academic study to professional practice. Evaluation conducted before graduates have encountered professional practice may therefore offer only a limited account of whether this purpose has been achieved.

Prior research has documented persistent challenges in capstone supervision, including mismatches between supervisors' expertise and project domains, unclear role definitions, limited preparation for the supervisory task, and inadequate institutional support structures (Shurin et al., 2023), and broader questions about the theory–practice gap in engineering education suggest that the transition from academic study to professional work is neither automatic nor uniformly supported (Shurin et al., 2020; Trevelyan, 2019). These findings collectively point to a need for evaluation frameworks that extend beyond the course period and incorporate the perspective of graduates who have already entered the workforce. Recent work on deep learning and employability in STEM contexts further reinforces this view, suggesting that the perceived contribution of a learning experience to professional readiness may be more fully assessed retrospectively, after graduates have entered professional practice (Kapania et al., 2025).

The present study addresses this gap by examining the retrospective perceptions of 131 engineering graduates and practicing engineers regarding the capstone supervision they received during their undergraduate studies and the extent to which the capstone experience contributed to their preparation for professional engineering practice. The study focuses on which dimensions of capstone supervision—including supervisor's approach, perceived industry preparation, and key characteristics of the supervision process—are most strongly associated with graduates' satisfaction with supervision and their assessment of capstone project quality. In doing so, it contributes a practice-informed perspective to capstone project evaluation and highlights the importance of examining supervision not only as an academic support mechanism, but also as a factor in the perceived professional value of the capstone experience after graduation. The findings further indicate that graduates' evaluation of the capstone experience is closely associated with both the supervisor's approach and the perceived connection between the project and professional engineering practice.

1.1. Literature Review

1.1.1. Capstone Projects in Engineering Education

The capstone project is widely recognized as a central component of undergraduate engineering education. It is commonly described as the point at which students are expected to integrate knowledge and skills acquired throughout the degree into a substantial engineering task. Unlike ordinary course assignments, capstone projects are typically extended, supervised, and open-ended, requiring students to define or interpret a problem, negotiate constraints, apply disciplinary knowledge, produce a technical deliverable, and communicate their outcomes.

In this role, capstone projects are intended not only to assess students' accumulated knowledge, but also to expose them to engineering processes that resemble professional work, including problem definition, iterative decision-making, teamwork, documentation, and engagement with practical constraints. For this reason, capstone projects are widely regarded as one of the most important learning experiences in engineering curricula and as a key mechanism for supporting the transition from academic study to engineering practice (Dutson et al., 1997; Hauhart & Grahe, 2015; Howe & Goldberg, 2019; Pembridge & Paretti, 2019; Shurin et al., 2020; Todd et al., 1993).

This dual role, academic integration on the one hand and preparation for professional practice on the other, creates a persistent challenge. Such a project may be academically demanding and still be perceived as weakly connected to actual engineering work. For this reason, examining capstone quality only during the academic period may provide an incomplete picture. If one of the declared functions of the capstone project is preparation for engineering practice, then the perspective of graduates who have already entered the workforce becomes especially important. This raises the question of how the project-based structure of the capstone supports, or fails to support, this intended professional preparation.

1.1.2. Capstone Projects as Project-Based and Problem-Based Learning

The capstone course is closely aligned with PBL traditions. It shifts learning from the passive reception of disciplinary content toward active engagement with complex tasks, independent inquiry, teamwork, and applied problem solving. In engineering education, this approach is particularly relevant because professional engineering work often requires engineers to apply theoretical knowledge under uncertain, interdisciplinary, and constraint-rich conditions.

The educational value of PBL lies in its ability to transform fragmented disciplinary knowledge into integrated learning processes. Through project work, students are required to identify what they do not yet know, seek resources, make decisions, test alternatives, and justify design or engineering choices. These features make PBL especially suitable for engineering education, where learning is expected to move beyond theoretical understanding toward practical judgment and professional action (Guo et al., 2020; Hotaling et al., 2012; Shurin et al., 2023).

Recent work in engineering education further supports this view, showing that PBL can contribute to students' problem-solving abilities, engagement, and application of engineering knowledge in practical contexts (Gutierrez-Berraondo et al., 2025). In the capstone context, however, the value of PBL depends not only on the existence of a project, but also on how project work is supervised. The supervisor therefore plays a central role in helping students translate project activity into meaningful learning and professional preparation.

1.1.3. The Supervisor as a Pedagogical and Professional Mediator

Because supervision shapes how students interpret and develop their project work, the role of the capstone supervisor differs from conventional lecturing. In a lecture-based course, the instructor often organizes and transmits disciplinary knowledge. In a capstone project, the supervisor is expected to guide students through an open-ended process, support independent learning, help them make decisions, and provide feedback at critical stages. This places capstone supervision closer to mentoring than to traditional content delivery (Pembridge & Paretti, 2019).

Research on teaching in higher education distinguishes between content-centered approaches, in which the teacher primarily transmits knowledge and expertise, and learning-centered approaches, in which the teacher supports inquiry, autonomy, reflection, and independent knowledge construction (Dunkin, 2002; Kember & Kwan, 2002; Ramsden,

2003). This distinction is particularly important in capstone supervision because students are expected to operate with increasing independence while still receiving structured guidance. A learning-oriented supervisor does not merely provide answers; rather, the supervisor helps students frame problems, evaluate alternatives, justify decisions, and develop confidence in their own engineering judgment. This view is consistent with broader calls in engineering education to move from traditional instruction toward mentoring and coaching roles that support students' independent professional development (Goldberg et al., 2014).

This supervisory role is also connected to the theory–practice gap. The supervisor is often the main academic figure who can help students understand whether the project is merely an academic assignment or a meaningful approximation of engineering practice. In this sense, the supervisor functions as a mediator between the academic requirements of the project and its professional relevance. Therefore, capstone supervision should not be understood only as technical assistance, but also as a pedagogical process through which students learn to interpret their work as engineering practice. This is consistent with arguments that capstone assessment should attend to the project process and supervisory guidance, not only to the final deliverable (Lawson et al., 2015).

1.1.4. Industry Readiness and the Theory–Practice Gap

This supervisory role is particularly important because engineering capstone projects are expected to support preparation for professional engineering practice. This expectation includes not only technical performance but also professional competencies such as communication, teamwork, self-management, problem definition, decision-making, and the ability to work under constraints (Passow & Passow, 2017; Winberg et al., 2020). This broader view of engineering preparation is also consistent with calls to prepare engineers for changing technological, social, and professional demands, rather than for narrowly defined technical roles alone (National Academy of Engineering, 2004). Earlier studies have noted that engineering education may be perceived as theory-heavy, producing graduates with strong theoretical foundations but limited practical readiness for real engineering work (Shurin et al., 2020; Trevelyan, 2019).

Capstone education may address this gap when project work requires students to integrate disciplinary knowledge with professional, interpersonal, and problem-solving skills in contexts that resemble engineering practice, consistent with practice-oriented engineering education frameworks (Crawley et al., 2014). However, industry readiness should not be assumed simply because a project is practical, technical, or applied. A project may involve an engineering topic and still fail to help students understand professional constraints, workplace processes, or the kinds of decisions engineers are required to make. This concern is especially relevant given evidence that engineering employers seek a combination of professional and technical skills, with problem-solving emerging as the most frequently requested professional skill in a large-scale analysis of engineering job advertisements (Fleming et al., 2024). Therefore, the question is not only whether students complete a project, but whether the project and its supervision help them interpret their work as preparation for engineering practice.

Research on employability and graduate readiness in higher education reinforces this point. Employability has been conceptualized as more than obtaining employment; it also involves the skills, understandings, and attributes that support graduates' success in their chosen occupations (Yorke, 2006). Learning experiences are increasingly evaluated not only through immediate academic performance but also through their perceived contribution to skills, readiness, and transitions into professional work. Recent work in STEM education suggests that deep learning, meaningful application, and student satisfaction are connected

to students' perceived employability and professional preparedness (Kapania et al., 2025; Winberg et al., 2020). In the context of capstone education, this supports the need to examine not only the project task itself, but also how supervision connects project work to later professional practice, as perceived by graduates after entering the workforce (Deters et al., 2024; Winberg et al., 2020).

1.1.5. Dimensions of Capstone Supervision

Graduates' evaluations of capstone supervision may reflect multiple dimensions of the supervision experience, including cognitive dimensions, such as clarity, organization, intellectual challenge, problem structuring, and feedback, as well as affective dimensions, such as support, availability, confidence, and the quality of the supervisor–student relationship. This distinction is consistent with broader research on teaching quality in higher education, where both cognitive and affective dimensions have been shown to shape students' evaluations of teaching and learning (Dunkin, 2002; Hativa & Goodyear, 2002).

In the capstone context, these dimensions become especially important because students must manage complex, open-ended work over an extended period. They are expected to identify gaps in knowledge, seek resources, divide tasks, manage time, and respond to uncertainty. These demands are closely connected to self-directed learning and professional skill development. Capstone students are not simply completing a predefined assignment; they are expected to take increasing responsibility for the direction, quality, and justification of their work, making supervision especially important for connecting project activity to professional preparation.

Many capstone projects are also collaborative, and therefore the social and affective conditions of teamwork matter. Research on PBL teams highlights the importance of psychological safety, team creativity, and academic well-being in collaborative learning environments (Clausen et al., 2025). This is relevant to capstone supervision because effective guidance may shape how graduates later evaluate not only technical progress, but also teamwork, confidence, communication, and the support conditions surrounding the project.

1.1.6. Graduate-Based Evaluation of Capstone Supervision

Most evaluations of teaching and supervision are conducted during or immediately after the academic experience. Such evaluations are useful, but they may not fully capture whether a capstone project later proves relevant to professional practice. Current students can evaluate workload, clarity, support, and satisfaction, but they may not yet know whether the project helped them enter the workforce or understand engineering work.

Graduate retrospective evaluation therefore offers a distinct perspective. Graduates can evaluate the capstone project after encountering real engineering tasks, workplace expectations, and professional norms, making their views especially relevant for examining perceived industry preparation. Their perceptions do not replace immediate student evaluations, but they add a practice-informed account of the professional relevance of the capstone experience after academic completion (Deters et al., 2024; Winberg et al., 2020).

Prior studies have examined capstone supervision and teaching practices from multiple perspectives, revealing challenges such as mismatches between supervisors' expertise and project domain, unclear role definitions, insufficient preparation for the supervisory task, and the complexity of the pedagogical roles performed by capstone faculty (Pembbridge & Paretti, 2019; Shurin et al., 2023). However, fewer studies examine capstone supervision from the perspective of graduates and practicing engineers after the transition to work. Related work by Deters et al. (2024), for example, analyzed written responses from new engineering graduates regarding how they described being prepared for engineering work,

underscoring the value of post-graduation perspectives on professional readiness. The present study addresses this gap by examining how engineering graduates and practicing engineers retrospectively evaluate capstone supervision, in relation to perceived industry preparation and capstone project quality.

Taken together, this literature suggests that graduate-based evaluation of capstone projects should consider how the pedagogical character of supervision is associated with graduates' perceptions of the project's professional relevance. While previous studies have examined capstone projects, project-based learning, supervision, and employability, less attention has been given to how engineering graduates and practicing engineers retrospectively evaluate capstone supervision in relation to perceived preparation for industry and overall project outcomes. The present study therefore examines how supervisor's approach and perceived industry preparation are associated with graduates' supervision satisfaction and retrospective assessment of capstone project quality.

1.2. Research Questions

This study addressed the following research questions, focusing exclusively on engineering graduates and practicing engineers ($N = 131$):

- (1) How do engineering graduates and practicing engineers retrospectively evaluate the capstone project and its supervision as preparation for professional engineering practice?
- (2) To what extent are supervisor's approach and perceived industry preparation associated with supervision satisfaction and capstone project quality?
- (3) Which sub-dimensions of graduates' retrospective evaluations are most strongly associated with supervision satisfaction and capstone project quality?
- (4) What graduate background, supervisor, and supervision-process characteristics are associated with supervision satisfaction and project quality?

2. Methods

2.1. Participants

The sample comprised 131 engineering graduates and practicing engineers. Participants were recruited using a non-probability convenience sampling method through academic and professional networks of engineering graduates. The inclusion criterion was prior completion of an undergraduate engineering capstone project. Responses were excluded if participants had not completed such a project or if the information provided was insufficient for analysis. Because the questionnaire was distributed through open invitations rather than through a predefined sampling frame, a response rate could not be calculated.

Participants were graduates of 13 academic institutions, including universities and academic colleges. Engineering disciplines included industrial engineering and management, mechanical engineering, civil/structural engineering, software engineering, electrical engineering, and other engineering fields. This multidisciplinary composition allowed the study to examine capstone supervision and perceived preparation for engineering practice as a broader feature of undergraduate engineering education, rather than as an experience limited to a single engineering discipline.

Given the retrospective nature of the study, participants were also characterized by the time elapsed since graduation, employment status, and whether they were currently working in the field of their undergraduate studies. These characteristics help contextualize the retrospective, practice-informed nature of the evaluation. Table 1 summarizes the main participant characteristics.

Table 1. Main participant characteristics.

Characteristic	Category	<i>n</i>	%
Engineering discipline	Mechanical engineering	45	34.4
	Industrial engineering and management	36	27.5
	Electrical engineering	18	13.7
	Civil/structural engineering	10	7.6
	Software engineering	8	6.1
	Other engineering fields	14	10.7
Institution type	University	60	45.8
	Academic college	70	53.4
	Not relevant/not classified	1	0.8
Years since graduation	Up to 4 years	55	42.0
	5–10 years	31	23.7
	11 years or more	45	34.4
Employment status	Employed in industry	106	80.9
	Other employment	20	15.3
	Not employed	5	3.8
Working in field of undergraduate study	Yes	100	76.3
	No	31	23.7
Current education level	Bachelor's degree	84	64.1
	Master's degree	39	29.8
	PhD	8	6.1

2.2. Instruments

The questionnaire used in the present study was designed for engineering graduates and practicing engineers who had previously completed an undergraduate capstone project. The questionnaire drew on established teaching-evaluation components, including cognitive, affective, learning-oriented, and content-oriented dimensions of teaching, together with engineering-education measures related to industry preparation, required skills, and the connection between academic project work and engineering practice. Items were adapted to the retrospective perspective of graduates and practicing engineers by referring to the completed capstone project and its supervision in past tense and by omitting items that were not applicable after graduation or to engineers working in industry. The grouping of items into indices was guided by the study's conceptual model, the source measures, and the theoretical literature reviewed above. Index scores were computed as the mean of their respective items. Internal consistency for multi-item indices is reported using Cronbach's alpha (α). The item composition and reliability values for all indices are summarized in Table A2. The primary research indices were:

Supervisor's Approach (3 items, $\alpha = 0.87$): assessing the extent to which the supervisor employed a learning-centered approach, including encouraging independent knowledge acquisition, providing guidance, and offering intellectual challenge.

Industry Preparation (11 items, $\alpha = 0.92$): assessing the extent to which the capstone experience supported preparation for engineering practice, including sub-indices for connection to engineering work (6 items, $\alpha = 0.88$) and required skills (5 items, $\alpha = 0.85$).

Secondary indices included Affective Factors (9 items, $\alpha = 0.89$), Cognitive Factors (5 items, $\alpha = 0.85$), and Learning Approach (2 items, $\alpha = 0.85$). In the graduate/practicing-engineer questionnaire, Content Approach was represented by a single item adapted from the original content-oriented teaching scale to the capstone supervision context;

therefore, no internal consistency coefficient is reported for this measure. Dependent variables were Supervision Satisfaction (5 items, $\alpha = 0.79$) and Capstone Project Quality Assessment (11 items, $\alpha = 0.89$), calculated as a multi-item index reflecting graduates' retrospective evaluation of the completed capstone project and related aspects of the project and supervision experience. All items were scored on a 5-point Likert scale (1 = not at all, 5 = to a very great extent).

The study constructs were operationalized as follows. Supervisor's approach referred to a learning-oriented mode of guidance, including intellectual challenge, guidance, and support for independent knowledge acquisition. Perceived industry preparation referred to graduates' evaluation of the capstone project as preparation for professional engineering practice. Supervision satisfaction referred to graduates' satisfaction with the supervision process and the supervisor's involvement. Capstone project quality referred to graduates' multi-item retrospective evaluation of the capstone project they completed, including a general project-quality rating and related affective and cognitive evaluation items. Connection to engineering work referred to the perceived link between the project and applied engineering processes and work practices. Learning approach referred to supervision that encouraged independent learning and knowledge construction. Cognitive factors referred to clarity, organization, intellectual challenge, and structured guidance. Affective factors referred to the supportive and interpersonal dimensions of supervision, including availability and positive attitude. Unmet support needs referred to graduates' perception that they needed more support from the supervisor during the capstone project.

The instrument's content validity was addressed by grounding the items in the literature reviewed above, adapting established teaching-evaluation components to the capstone supervision context and target population, and aligning the item grouping with the study's conceptual model and source measures. Appendix A presents the questionnaire items used in the quantitative analysis and their mapping to the study indices. Table A1 provides the item-to-index mapping, and Table A2 summarizes the item composition and internal consistency coefficients for the study indices.

2.3. Procedure

Questionnaires were distributed to graduates and engineers who had previously completed capstone projects. Participation was anonymous and voluntary; all participants provided informed consent. The study was approved by the Ethics Committee for Non-Clinical Human Research at Ariel University (approval no. AU-SOC-ND-20220529). Generative AI tools were used to assist with academic language editing and translation of text. No AI was used in study design, data collection, analysis, or interpretation.

2.4. Statistical Analysis

Data were analyzed using one-way ANOVA, independent-samples *t*-tests with post hoc comparisons, Pearson correlations, and multiple regression with backward elimination. All statistical analyses were conducted using IBM SPSS Statistics, Version 29 (IBM Corp., Armonk, NY, USA). The analyses were exploratory and explanatory in nature and were intended to identify patterns of association among graduates' retrospective evaluations rather than to test a causal model.

Group comparisons were used to examine whether selected background, supervisor, and supervision-process characteristics were associated with supervision satisfaction and perceived capstone project quality. These comparisons were treated as exploratory analyses and were interpreted cautiously given the number of comparisons conducted.

Pearson correlations were used to examine associations between the main study indices and the dependent variables. Multiple regression with backward elimination was

used to examine the relative contribution of theoretically relevant study variables and to identify the strongest retained predictors in the final models. Backward elimination was selected because the analysis aimed to identify which variables remained associated with each outcome when entered together, rather than to test a predefined hierarchical sequence of predictors. Standardized β coefficients are reported for the regression models. Effect sizes for selected group comparisons are discussed where relevant, and group-comparison results are interpreted cautiously as exploratory analyses.

Given the explanatory, cross-sectional, and retrospective design of the study, the follow-up sub-index analyses are interpreted cautiously and are not treated as evidence of causal effects. The analysis involving Capstone Project Quality Assessment is presented as an internal decomposition of a composite index, rather than as a regression model predicting a distinct outcome from independent predictors. Because this composite index shares several items with the Affective Factors and Cognitive Factors sub-indices, the high R^2 primarily reflects the internal structure and item overlap of the measure. It is therefore not interpreted as evidence of prediction among distinct constructs.

3. Results

3.1. Graduate Evaluation of the Capstone as Preparation for Practice

A key descriptive finding concerns graduates' evaluation of the capstone project as preparation for employment and professional engineering practice. As shown in Table 2, 43.5% of graduates rated the capstone project as not helping them at all in finding engineering employment, and 60.3% rated its contribution to finding engineering employment in the two lowest response categories. In contrast, only 11.5% rated the capstone project as helping them to a very great extent. Although employment entry is only one dimension of the broader Industry Preparation construct, this finding suggests that the employment-related contribution of the capstone experience cannot be assumed and should be examined explicitly alongside broader dimensions of professional preparation.

Table 2. Capstone contribution to finding engineering employment ($N = 131$).

Response	<i>n</i>	%
1 = Not at all	57	43.5
2	22	16.8
3	22	16.8
4	15	11.5
5 = To a very great extent	15	11.5
Total	131	100.0

3.2. Correlation Between Dependent Variables

A Pearson correlation confirmed that the two dependent variables were strongly and positively related: $r(129) = 0.86$, $p < 0.001$. This indicates that graduates' supervision satisfaction and project quality assessments are closely linked, though not identical, and both warrant separate analysis as distinct outcomes of graduates' retrospective evaluations.

3.3. Background and Graduate Characteristics

One-way ANOVA and *t*-tests examined whether graduate background characteristics were associated with the two dependent variables. Education level, working in the field of study, and project grade were associated with supervision satisfaction and capstone project quality. Post hoc comparisons indicated that graduates with advanced degrees

reported higher ratings than bachelor's-degree holders. Table 3 presents the significant group differences.

Table 3. Means and Standard Deviations of Dependent Variables by Selected Graduate Background Characteristics.

Variable	Project Quality					Supervision Satisfaction		
	Group	<i>n</i>	M	SD	F/t	M	SD	F/t
Education level	Bachelor's only	84	3.22	0.82	7.03 **	3.20	1.01	4.38 *
	Master's	39	3.66	0.76		3.66	0.92	
	Doctoral	8	4.07	0.78		3.98	0.92	
Working in field of study	Yes	100	3.49	0.73	t = 2.27 *	3.49	0.92	t = 2.24 *
	No	31	3.11	1.08		3.04	1.18	
Project grade	90–100	91	3.53	0.75	t = 3.69 **	3.51	0.92	t = 2.94 **
	70–89	30	2.92	0.87		2.93	1.00	

Note. * $p < 0.05$. ** $p < 0.01$.

3.4. Supervisor Characteristics

Table 4 presents the means and standard deviations of the dependent variables by supervisor-level characteristics. Domain expertise was associated with higher ratings of both project quality and supervision satisfaction. Industry experience was also associated with higher ratings, but this association should be interpreted cautiously, as it may reflect the domain-relevant knowledge associated with industry experience.

Table 4. Means and Standard Deviations of Dependent Variables by Supervisor Characteristics.

Variable	Project Quality					Supervision Satisfaction		
	Group	<i>n</i>	M	SD	F/t	M	SD	F/t
Domain expertise	Yes	84	3.66	0.72	12.92 **	3.66	0.94	10.35 **
	No	23	2.94	0.83		3.03	0.97	
Industry experience	Yes	73	3.55	0.85	t = 2.23 *	3.57	1.07	t = 2.39 *
	No/Unknown	58	3.22	0.79		3.16	0.87	
Number of supervisors	Single	91	3.36	0.88	t = −1.11	3.28	1.03	t = −2.02 *
	Pair	39	3.53	0.72		3.66	0.90	
Supervisor type	Academic only	95	3.44	0.77	2.01	3.42	0.96	1.86
	Industry only	18	3.05	1.17		2.99	1.22	
	Academic + Industry	18	3.54	0.71		3.59	0.94	

Note. *n* values reflect valid responses for each comparison; missing or not-reported responses were excluded unless combined within the reported category. * $p < 0.05$. ** $p < 0.01$.

3.5. Supervision Process and Project Characteristics

Table 5 presents the means and standard deviations of the dependent variables by supervision process and project characteristics. Overall, supervision process characteristics were associated with graduates' retrospective evaluations: lower meeting frequency and higher unmet support needs were associated with lower ratings of supervision satisfaction and capstone project quality. Post hoc comparisons for supervision format indicated that graduates who reported online-only supervision rated capstone project quality lower than those who reported face-to-face or hybrid supervision, although this comparison involved

a small online-only group. No significant difference was found between the face-to-face and hybrid groups.

Table 5. Means and Standard Deviations of Dependent Variables by Supervision Process Characteristics.

Variable	Project Quality					Supervision Satisfaction		
	Group	<i>n</i>	M	SD	F/t	M	SD	F/t
Meeting frequency	Low ($\leq$ monthly)	59	3.00	0.89	14.77 **	2.80	0.90	27.28 **
	Medium (every 2 weeks)	50	3.67	0.64		3.72	0.77	
	High (weekly+)	20	3.85	0.62		4.18	0.82	
Supervision format	Face-to-face only	28	3.34	0.71	6.35 **	3.11	0.87	2.11
	Hybrid	9	3.07	0.86		3.09	1.03	
	Online only	6	2.17	0.62		2.30	0.75	
Unmet support needs	Low need	54	3.89	0.51	40.99 **	3.84	0.88	17.91 **
	Medium need	28	3.63	0.59		3.54	0.79	
	High need	49	2.74	0.82		2.80	0.97	

Note. *n* values reflect valid responses for each comparison; missing, not-reported, or non-applicable responses were excluded. Small group sizes should be considered when interpreting these comparisons. ** $p < 0.01$.

3.6. Pearson Correlations: Main Indices and Dependent Variables

Pearson correlations indicated strong positive associations between supervisor approach and both supervision satisfaction ($r = 0.74$, $p < 0.001$) and project quality ($r = 0.84$, $p < 0.001$). Industry preparation was also positively associated with supervision satisfaction ($r = 0.68$, $p < 0.001$) and project quality ($r = 0.55$, $p < 0.001$). Table 6 presents the full correlation matrix.

Table 6. Pearson Correlation Matrix: Main Research Indices and Dependent Variables ($N = 131$).

	Supervision Satisfaction	Project Quality	Supervisor Approach
Supervision Satisfaction	-	0.86 ***	0.74 ***
Project Quality		-	0.84 ***
Supervisor Approach			-
Industry Preparation	0.68 ***	0.55 ***	0.33 ***

Note. *** $p < 0.001$ (2-tailed).

3.7. Multiple Regression: Main Indices Predicting Dependent Variables

To move beyond descriptive patterns and examine the explanatory contribution of the main study variables, multiple regression with backward elimination was performed with supervisor's approach and industry preparation as predictors. Both predictors were retained in the final models. For supervision satisfaction, the model explained 75% of the variance, $F(2,128) = 192.51$, $p < 0.001$, with supervisor's approach ($\beta = 0.57$) and industry preparation ($\beta = 0.48$) both emerging as significant predictors. For capstone project quality, the model explained 78% of the variance, $F(2,128) = 233.18$, $p < 0.001$, with supervisor's approach ($\beta = 0.73$) and industry preparation ($\beta = 0.30$) again retained as significant predictors. Taken together, these models indicate that both supervisor's approach and perceived industry preparation made independent explanatory contributions to graduates' supervision satisfaction and perceived capstone project quality. Supervisor's approach was the stronger predictor of project quality, whereas both predictors made substantial contributions to supervision satisfaction. Table 7 presents the full regression results.

Table 7. Multiple Regression: Main Indices Predicting Supervision Satisfaction and Project Quality.

Dependent Variable	Predictor	B	SE	β	t	p
Supervision Satisfaction	Supervisor Approach	0.47	0.03	0.57	12.28	<0.001
	Industry Preparation	0.51	0.05	0.48	10.30	<0.001
Project Quality	Supervisor Approach	0.50	0.03	0.73	16.89	<0.001
	Industry Preparation	0.27	0.04	0.30	7.02	<0.001

Note. Supervision satisfaction model: $R^2 = 0.75$, $F(2,128) = 192.51$, $p < 0.001$. Project quality model: $R^2 = 0.78$, $F(2,128) = 233.18$, $p < 0.001$.

3.8. Follow-Up Explanatory Sub-Index Analysis

As a follow-up explanatory analysis, multiple regression with backward elimination was performed using the measured sub-indices to examine which evaluative dimensions were most strongly associated with the two analyzed measures. For supervision satisfaction, the final model explained 82% of the variance, $F(4,126) = 147.19$, $p < 0.001$, with connection to engineering work emerging as the strongest retained sub-index ($\beta = 0.34$). For project quality, the follow-up analysis is presented as an internal decomposition of the composite Capstone Project Quality Assessment index. Because this index shares several items with the Affective Factors and Cognitive Factors sub-indices, the high R^2 primarily reflects the internal structure and item overlap of the measure, rather than evidence of prediction among distinct constructs. Cognitive Factors showed the strongest association with the composite project-quality score ($\beta = 0.52$). Connection to engineering work was included in the analysis but was not retained in the final backward-elimination model. Table 8 presents the final follow-up models.

Table 8. Follow-Up Sub-Index Analysis for Supervision Satisfaction and Project Quality.

Dependent Variable	Retained Sub-Index	β	t	p	Rank
Supervision Satisfaction	Connection to engineering work	0.34	6.63	<0.001	1st
	Learning approach	0.28	4.40	<0.001	2nd
	Cognitive factors	0.27	3.80	<0.001	3rd
	Affective factors	0.20	3.26	0.001	4th
Project Quality	Cognitive factors	0.52	27.67	<0.001	1st
	Affective factors	0.43	20.23	<0.001	2nd
	Learning approach	0.14	6.49	<0.001	3rd

Note. Supervision satisfaction analysis: $R^2 = 0.82$, $F(4,126) = 147.19$, $p < 0.001$. Capstone Project Quality Assessment analysis: $R^2 = 0.98$, $F(3,127) = 1942.77$, $p < 0.001$. Only sub-indices retained in the final backward-elimination analyses are shown.

4. Discussion

The discussion below interprets the findings in relation to the study's central objective: understanding how capstone projects and their supervision are perceived by graduates as preparation for professional engineering practice. Across the analyses, the findings suggest that graduates' perceived professional value of the capstone project is associated not only with the existence of a substantial final project, but also with the extent to which supervision, project content, and project processes are explicitly connected to authentic engineering work.

4.1. The Centrality of Supervisor's Approach

The most consistent finding of this study is that supervisor's approach, specifically a learning-oriented style, was a significant predictor retained in the regression models for both supervision satisfaction and project quality. Supervisor's approach was a major predictor retained across the regression models ($\beta = 0.57$ for satisfaction, $\beta = 0.73$ for

quality), indicating that graduates evaluate capstone supervision not only according to technical expertise but also according to the extent to which the supervisor supported independent learning, problem solving, and intellectual challenge within a process that resembles professional engineering practice. From the graduate perspective, capstone supervision appears to matter not only as technical support, but also as a learning-oriented process associated with perceived support for independence, problem solving, and a clearer connection between academic project work and professional engineering practice.

At the level of specific evaluative dimensions, the finding that connection to engineering work was the strongest predictor of supervision satisfaction ($\beta = 0.34$), while cognitive factors were most strongly associated with project quality ($\beta = 0.52$), reveals an important differentiation. Graduates' satisfaction with supervision was closely tied to concrete relevance to engineering practice, whereas their assessment of project quality was strongly associated with cognitive and organizational features of the supervision process, including clarity, intellectual challenge, and structured guidance.

4.2. Industry Preparation: Significant but Contested

Industry preparation was the second significant predictor retained in both regression models ($\beta = 0.48$ for satisfaction, $\beta = 0.30$ for quality). As reported in Section 3.1, 43.5% of graduates indicated that the project did not help them at all in finding engineering employment, and 60.3% rated this item in the two lowest response categories. This finding points to an important limitation in the employment-related contribution of the capstone experience. This does not mean that capstone projects lack educational value; rather, it suggests that academic success and perceived workforce preparation are not automatically the same outcome. A plausible explanation is that some projects functioned as meaningful academic experiences but were not sufficiently connected to graduates' first engineering positions or to the practical processes encountered in industry. In addition, graduates' current employment context, including whether they were working in the field of their undergraduate studies, may have shaped how they evaluated the project's employment-related contribution. This is consistent with the finding that connection to engineering work was the strongest retained predictor of supervision satisfaction, suggesting that graduates' perceived professional value of the capstone is closely associated with the extent to which project work and supervision are explicitly linked to authentic engineering practice.

Viewed in this way, the result extends earlier research on capstone projects in engineering education (Howe & Goldberg, 2019; Shurin et al., 2020) by showing that questions concerning industry preparation remain important when examined retrospectively among graduates and practicing engineers. Rather than assuming that capstone projects prepare students for practice simply because they are applied or project-based, these results suggest that programs should define more explicit mechanisms for linking project work, supervision processes, and engineering decision-making to professional practice.

4.3. Supervisor and Supervision Process Characteristics

Domain expertise showed the strongest supervisor-level association with graduates' evaluations in the group-comparison analyses ($F = 12.92^{**}$, quality; $F = 10.35^{**}$, satisfaction), with large effect sizes ($d = 0.72$, quality; $d = 0.63$, satisfaction). The pattern of findings suggests an important nuance: supervisor's industry experience may matter most when it provides knowledge directly relevant to the specific project domain. The practical implication is that institutions may need to consider domain match, not only general industry credentials, when assigning supervisors.

Supervision process characteristics were also associated with graduates' evaluations. Meeting frequency was associated with graduates' retrospective evaluations, while unmet

support needs showed particularly strong associations with both outcomes: graduates who strongly felt their support needs were unmet showed the largest outcome deficits ($d = -1.15$ for quality; $d = -1.04$ for satisfaction). Together, these findings suggest that regular meetings may be an important component of positively evaluated supervision, but they are not sufficient on their own unless graduates also perceive that they received enough guidance, feedback, and professional orientation. More broadly, these findings point to several practical implications for supporting students' preparation for professional engineering practice through the capstone project. Supervisors should be selected and supported not only for general academic expertise, but for their ability to connect project decisions to applied engineering practice. These findings support structuring supervision as an ongoing learning-oriented process rather than limiting it to technical problem solving or final deliverable assessment. Finally, capstone programs should make the professional purpose of the project explicit by linking milestones, feedback, and evaluation criteria to engineering tasks, constraints, and decision-making processes encountered in practice.

4.4. Limitations and Future Research

This study has several limitations. First, its retrospective, cross-sectional, and self-reported design means that the findings should be interpreted as graduates' perceptions and patterns of association rather than as evidence of causal effects. The retrospective design may have introduced recall bias, and the use of a single questionnaire completed by the same respondents may have contributed to common method variance. In addition, the regression analyses were reported using model fit statistics and standardized coefficients, but did not include full regression diagnostics, such as multicollinearity statistics, residual diagnostics, homoscedasticity checks, and influential-case analyses. This should be considered when interpreting the high R^2 values.

Second, the sample represented a broad range of engineering capstone experiences, including different disciplines, team structures, project types, project origins, and levels of industry involvement. Because the number of participants within each discipline was limited, the findings should not be interpreted as representative of any single engineering discipline or project configuration. Future research should examine these discipline- and project-level factors more directly.

Third, although the questionnaire included an optional open-ended comment field, only a small number of participants provided written comments; therefore, these responses were not analyzed as a separate qualitative dataset.

Finally, the very high R^2 in the follow-up analysis involving Capstone Project Quality Assessment should be interpreted in light of the measurement structure of the index. Because this composite index shares several items with the Affective Factors and Cognitive Factors sub-indices, the analysis is presented as an internal decomposition of the project-quality composite rather than as evidence of prediction among independent constructs. Future studies using longitudinal designs, additional data sources, and external indicators of professional readiness could further strengthen the interpretation of these findings.

5. Conclusions and Practical Implications

5.1. Conclusions

This study examined how engineering graduates and practicing engineers retrospectively evaluate capstone supervision and its contribution to industry readiness. By focusing on graduates who had already encountered professional engineering practice, the study provides a practice-informed perspective on the extent to which the capstone project is perceived as fulfilling one of its declared educational functions: preparation for engineering work.

The central finding is that supervisor's approach, particularly a learning-oriented style, as well as perceived industry preparation, were significant predictors retained in the regression models for both supervision satisfaction and capstone project quality. These two indices explained 75% of the variance in supervision satisfaction and 78% of the variance in project quality. This suggests that graduates' evaluations of the capstone experience are associated not only with the existence of a final project, but also with supervision that supports independent learning, problem solving, and the perceived connection between academic project work and professional engineering practice.

At the same time, the employment-related item showed that 60.3% of graduates rated the capstone project's contribution to finding engineering employment in the two lowest response categories, whereas only 11.5% rated it as helping them to a very great extent. This suggests that the employment-related contribution of capstone projects should not be assumed simply because they are applied, supervised, or positioned as culminating experiences, and that this dimension should be considered alongside broader indicators of professional preparation. Additional analyses further indicated that domain expertise, meeting frequency, and unmet support needs were associated with graduates' evaluations. Taken together, the findings suggest that capstone programs should treat supervision, industry relevance, and graduate feedback as central components in evaluating whether the capstone project is perceived by graduates as supporting the transition from academic study to engineering practice.

5.2. Practical Implications

Based on these observed associations in graduates' retrospective evaluations, institutions may consider prioritizing domain expertise when assigning supervisors. Supervisors may also benefit from structured training in learning-oriented, student-centered mentoring, particularly training that helps them connect project decisions to professional engineering practice. Programs should consider setting clearer expectations for regular supervision meetings, since lower meeting frequency was associated with lower graduate evaluations. Programs may also consider systematically collecting graduate feedback on capstone supervision, since graduates can evaluate the project through the lens of professional practice and provide practice-informed insights that are not available during the course itself. Graduate feedback may therefore be used not merely as alumni satisfaction data, but as a delayed evaluation of graduates' perceptions of whether the capstone project fulfills one of its declared educational functions: preparation for professional engineering practice. Programs may also seek to make the industry-oriented function of the capstone project explicit by linking project milestones, supervision discussions, and evaluation criteria to professional engineering practice.

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Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request, subject to ethical and privacy restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Questionnaire Items Used in the Quantitative Analysis

Closed-ended questionnaire items were rated on a 5-point Likert scale ranging from 1 = not at all to 5 = to a very great extent. Table A1 presents the questionnaire items used in the quantitative analysis and their mapping to the study indices in the graduate/practicing-engineer questionnaire. Table A2 summarizes the study indices, item composition, and internal consistency coefficients.

Table A1. Questionnaire item-to-index mapping.

Item No.	Questionnaire Item	Index/Construct
1	In my opinion, the project advanced me professionally.	Industry Preparation; Connection to engineering work
2	In my opinion, I learned new things during the capstone project.	Industry Preparation; Required skills
3	In my opinion, carrying out the project exposed me to skills that I had not previously encountered during my studies.	Industry Preparation; Required skills
4	In my opinion, my independent learning improved during the project.	Industry Preparation; Required skills
5	In my opinion, carrying out the project exposed me to processes required in the applied work of an engineer.	Industry Preparation; Connection to engineering work
6	In my opinion, the capstone project allowed me to cope with implementation challenges required of engineers in their routine work.	Industry Preparation; Connection to engineering work
7	In my opinion, the capstone project is important within the overall academic training of engineers.	Industry Preparation; Connection to engineering work
8	In my opinion, the project helped me find employment as an engineer.	Industry Preparation; Connection to engineering work
9	In my opinion, the project was difficult.	Affective Factors; Capstone Project Quality Assessment
10	In my opinion, the technological equipment in the laboratories helped me.	Cognitive Factors; Capstone Project Quality Assessment
11	In my opinion, I used the theoretical knowledge acquired during my engineering studies to carry out the project.	Industry Preparation; Required skills
12	In my opinion, there was a connection between the theoretical knowledge acquired during my studies and its practical application in the project.	Industry Preparation; Required skills
13	The project met my expectations.	Supervision Satisfaction
14	If the capstone project were defined as an elective course, I would recommend that students take it.	Supervision Satisfaction
15	I am satisfied with the institution where I completed my undergraduate capstone project.	Affective Factors
16	Overall evaluation of the completed capstone project.	Affective Factors; Capstone Project Quality Assessment
17	In my opinion, the supervision in the capstone project was interesting.	Cognitive Factors; Capstone Project Quality Assessment
18	In my opinion, the supervision created an intellectual challenge.	Cognitive Factors; Capstone Project Quality Assessment

Table A1. *Cont.*

Item No.	Questionnaire Item	Index/Construct
19	In my opinion, the supervision was clear.	Cognitive Factors; Capstone Project Quality Assessment
20	In my opinion, the supervision was organized.	Cognitive Factors; Capstone Project Quality Assessment
21	The supervision was based on regular meetings with the supervisor, rather than meetings only when needed.	Supervision Satisfaction
22	In my opinion, the supervision contributed to the project process.	Supervision Satisfaction
23	In my opinion, the supervision in the project advanced me professionally.	Industry Preparation; Connection to engineering work
24	During the project, I felt “lost” and did not know how to proceed.	Affective Factors
25	I felt pressure during the project.	Affective Factors
26	In my opinion, the supervisor’s attitude toward me was positive.	Affective Factors; Capstone Project Quality Assessment
27	In my opinion, the supervisor’s responses to questions and comments were positive.	Affective Factors; Capstone Project Quality Assessment
28	In my opinion, the supervisor’s availability was high.	Affective Factors; Capstone Project Quality Assessment
29	In my opinion, the supervisor enjoyed supervising my project.	Supervisor’s Approach; Learning Approach
30	In my opinion, the supervisor helped me with difficulties in the project.	Supervisor’s Approach; Learning Approach
31	In my opinion, the project development process was based on the supervisor’s knowledge.	Supervisor’s Approach; Content Approach
32	I wanted to receive more support from my supervisor during the project.	Unmet support needs
33	I am satisfied with the supervisor’s involvement in the supervision process.	Supervision Satisfaction
34	Overall evaluation of the supervisor who supervised the project.	Affective Factors; Capstone Project Quality Assessment

Note. Items 9, 24, and 25 were reverse-coded before index scores were calculated.

Table A2. Study indices, item composition, and internal consistency.

Study Index/Construct	Items Included	Number of Items	Internal Consistency
Supervisor’s Approach	29, 30, 31	3	$\alpha = 0.87$
Learning Approach	29, 30	2	$\alpha = 0.85$
Content Approach	31	1	Not applicable
Industry Preparation	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 23	11	$\alpha = 0.92$
Connection to engineering work	1, 5, 6, 7, 8, 23	6	$\alpha = 0.88$
Required skills	2, 3, 4, 11, 12	5	$\alpha = 0.85$
Affective Factors	9, 15, 16, 24, 25, 26, 27, 28, 34	9	$\alpha = 0.89$
Cognitive Factors	10, 17, 18, 19, 20	5	$\alpha = 0.85$
Supervision Satisfaction	13, 14, 21, 22, 33	5	$\alpha = 0.79$
Capstone Project Quality Assessment	9, 10, 16, 17, 18, 19, 20, 26, 27, 28, 34	11	$\alpha = 0.89$
Unmet support needs	32	1	Not applicable

Note. Cronbach’s alpha is reported for multi-item indices only and was not applicable for single-item measures.

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