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Integrating Enterprise Resource Planning Systems (SAP S4HANA, Oracle, Maximo) in Undergraduate Engineering Education: Addressing the Industry Readiness Gap Through Systems-Based Learning

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Integrating Enterprise Resource Planning Systems in Undergraduate Engineering Education:
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Abstract

Contemporary engineering graduates face a persistent industry readiness gap, particularly in understanding integrated business processes and cross-functional organizational systems. Traditional undergraduate engineering curricula emphasize technical depth within specialized domains but often lack comprehensive exposure to enterprise-wide operational frameworks. This study examines the strategic integration of Enterprise Resource Planning (ERP) systems for example (SAP S/4 HANA, Oracle Cloud EPR, Microsoft Dynamics 365, NetSuite ERP) training within undergraduate engineering education as a pedagogical intervention to address this competency gap. ERP systems—integrated software platforms that manage core business processes including supply chain operations, production planning, quality management, financial controlling, and human capital management—serve as the operational backbone of modern industrial organizations. The research employed a mixed-methods quasi-experimental design comparing two cohorts of undergraduate engineering students (N=150 students per group) over four academic semesters. The experimental group received enhanced curriculum incorporating hands-on ERP training modules, while the control group followed the standard engineering management curriculum. Quantitative analysis utilized pre/post knowledge assessments, employer feedback surveys, and longitudinal career outcome tracking. Results demonstrate statistically significant improvements in the experimental group across multiple dimensions: systems thinking capability (+26 percentage points), time-to-employment (-40 days), starting compensation (+17.4%), and management track placement rates (+32 percentage points). The pedagogical framework emphasizes experiential learning through business process simulations, cross-functional scenario analysis, and real-time data-driven decision-making exercises. These activities demonstrably enhance ABET Student Outcome achievement, particularly in communication across disciplinary boundaries (Outcome 3), interdisciplinary teamwork (Outcome 5), and adaptive learning capacity (Outcome 7). Furthermore, the curriculum addresses emerging competencies essential for Industry 4.0 readiness, including cloud-based system architectures, artificial intelligence integration in business operations, advanced data analytics, and digital transformation management. This research provides empirical evidence that systematic ERP systems education enhances undergraduate engineering students' transition from technical specialists to systems-oriented professionals capable of bridging engineering and business domains, thereby improving immediate employability and enabling sustained career advancement in increasingly digitalized industrial environments.

1. Introduction

1.1 Goal and Motivation

The contemporary industrial ecosystem demands engineering professionals who possess not only deep technical expertise but also comprehensive understanding of integrated business operations and cross-functional organizational systems. However, a persistent competency gap exists between the capabilities developed through traditional engineering education and the holistic systems perspective required for effective organizational leadership [1], [2]. This gap manifests in multiple dimensions: limited exposure to enterprise-wide process integration, insufficient understanding of cross-functional business workflows, inadequate preparation for data-driven managerial decision-making, and minimal experience with real-world enterprise information systems that coordinate organizational operations [3].

The primary goal of this research is to investigate whether systematic integration of Enterprise Resource Planning (ERP) systems training within undergraduate engineering curricula can effectively bridge this industry readiness gap. ERP systems represent the operational infrastructure of modern industrial organizations, integrating core business processes across supply chain management, production operations, quality assurance, financial controlling, and human capital management into unified information platforms. By providing engineering students with hands-on experience in ERP-mediated business processes, this pedagogical intervention aims to develop systems thinking capabilities, cross-functional communication skills, and data-driven decision-making competencies that complement traditional engineering technical training.

This research is motivated by three critical factors. First, industry employer surveys consistently identify systems thinking and cross-functional collaboration as high-priority competency gaps in engineering graduates [4]. Second, digital transformation initiatives across manufacturing, technology, and service sectors have elevated ERP systems from back-office tools to strategic platforms central to organizational competitiveness [5]. Third, ABET accreditation criteria increasingly emphasize professional skills including interdisciplinary teamwork, stakeholder communication, and lifelong learning capacity—competencies that ERP-based pedagogical activities can demonstrably develop [6].

1.2 Related Work and Literature Review

Prior research on enterprise systems in higher education has primarily focused on business and information systems curricula rather than engineering programs. Seethamraju [7] demonstrated that ERP-based case studies in business education improve students' understanding of integrated organizational processes and cross-functional dependencies. Similarly, Léger et al. [8] found that simulation-based ERP learning environments enhance collaborative problem-solving and real-time decision-making skills in business students. However, these studies examine business students who already possess foundational understanding of organizational functions, whereas engineering students typically lack this business process context.

Within engineering education, several studies have explored industrial software tools. Magal and Word [9] provided comprehensive frameworks for teaching ERP concepts using simulation games, demonstrating improved student engagement and learning outcomes. Davis and Comeau [10] investigated the integration of ERP modules in industrial engineering curricula, finding enhanced student understanding of supply chain coordination. However, these studies focused on individual ERP modules or specific engineering subdisciplines rather than comprehensive ERP systems integration across undergraduate engineering education broadly.

Recent work on engineering education reform has emphasized the importance of systems thinking and interdisciplinary perspectives. Borrego and Newswander [11] argue that traditional engineering curricula inadequately prepare students for complex, cross-functional challenges characteristic of modern industrial practice. Frank et al. [12] demonstrated that project-based learning with real-world business scenarios improves engineering students' professional competency development. These studies provide pedagogical foundations but do not specifically examine ERP systems as educational tools.

The current study advances beyond existing work in three fundamental ways. First, it examines comprehensive ERP systems integration across undergraduate engineering curricula rather than isolated modules or business-specific applications. Second, it employs rigorous quasi-experimental methodology with substantial sample sizes (N=150 per group) and longitudinal outcome tracking, providing empirical evidence of educational effectiveness that prior studies have lacked. Third, it explicitly connects ERP-based learning activities to ABET Student Outcome achievement, establishing pedagogical legitimacy within engineering education accreditation frameworks. This research therefore represents the first systematic investigation of enterprise systems integration as a comprehensive pedagogical intervention for undergraduate engineering education.

1.3 Problem Statement

We formally define the engineering education competency gap as the measurable difference between the capabilities developed through traditional undergraduate engineering curricula (C_traditional) and the comprehensive skill sets required for effective performance in contemporary industrial organizations (C_industry). Mathematically, this gap G can be expressed as:

$$G = C\_industry - C\_traditional$$

Where C_traditional emphasizes technical competencies T (domain-specific engineering knowledge, analytical methods, design skills) while C_industry requires both technical competencies T and systems competencies S (cross-functional process understanding, integrated business operations, data-driven decision frameworks, enterprise information systems proficiency). The gap G is therefore primarily attributable to insufficient development of systems competencies S in traditional curricula.

The research problem addressed in this study is: Can systematic integration of ERP systems training within undergraduate engineering curricula (denoted as C_enhanced) effectively reduce the competency gap G by developing systems competencies S without compromising technical competencies T? Formally, we investigate whether $C\_enhanced \approx C\_industry$, where $C\_enhanced = T + S$.

We operationalize this research problem through the following specific questions: (1) Do students receiving ERP-enhanced curriculum demonstrate significantly improved systems thinking capabilities compared to standard curriculum students? (2) Do ERP-enhanced curriculum students achieve superior employment outcomes including reduced time-to-placement, higher starting compensation, and increased management track placement rates? (3) Does ERP systems training enhance achievement of ABET Student Outcomes, particularly communication (Outcome 3), teamwork (Outcome 5), and lifelong learning (Outcome 7)? (4) What are the optimal pedagogical strategies for integrating ERP systems training within undergraduate engineering curricula without displacing essential technical content?

Key assumptions underlying this research include: (1) Systems competencies S are teachable through structured ERP-based learning activities; (2) ERP systems adequately represent integrated business processes characteristic of modern industrial organizations; (3) Student performance in ERP-based educational activities correlates with professional competency in real-world organizational contexts; (4) Undergraduate engineering students possess sufficient foundational business knowledge to engage meaningfully with ERP systems training when provided with appropriate scaffolding.

2. Enterprise Resource Planning Systems: Background and Context

Enterprise Resource Planning (ERP) systems are integrated software platforms that coordinate and manage core business processes across organizational functions. Modern ERP systems have evolved from transaction processing tools into comprehensive enterprise platforms incorporating multiple technological capabilities. Cloud-native architectures enable scalability, accessibility, and reduced infrastructure requirements. SAP provides predictive analytics, automated decision support, and intelligent process optimization. Internet of Things integration enables real-time asset monitoring, predictive maintenance, and supply chain visibility. Blockchain technology enhances traceability, transaction security, and supply chain transparency. Advanced analytics and business intelligence capabilities support data visualization, prescriptive analytics, and performance management.

Core ERP functional modules address essential business processes. Supply Chain Management coordinates materials procurement, inventory management, and logistics operations. Production Planning manages manufacturing resource planning, capacity scheduling, and shop floor control. Quality Management implements statistical process control, inspection protocols, and regulatory compliance tracking. Financial Controlling provides cost accounting, budget management, and financial reporting. Human Capital Management handles workforce planning, talent acquisition, and performance evaluation. These modules operate as integrated components sharing unified data repositories, enabling cross-functional visibility and coordinated decision-making.

3. Research Design and Methodology

3.1 Experimental Design and Participant Selection

This investigation employed a mixed-methods quasi-experimental design conducted at a major U.S. polytechnic institution over four academic semesters (Fall 2022 through Spring 2024). The study focused exclusively on undergraduate engineering students enrolled in required engineering management coursework during their junior and senior years. All participants were pursuing Bachelor of Science degrees in engineering disciplines including mechanical, electrical, industrial, civil, and chemical engineering.

Participant assignment to experimental and control groups utilized a cohort-based quasi-experimental approach rather than true randomization due to institutional constraints on curriculum modification. The control group (N=150 students) consisted of students who completed the standard engineering management curriculum during Fall 2021 through Spring 2023. These students represented four sequential cohorts (approximately 37-38 students per semester cohort) who received traditional engineering management instruction without ERP systems integration. The experimental group (N=150 students) consisted of students enrolled in the enhanced ERP-integrated curriculum during Fall 2022 through Spring 2024, also comprising four sequential cohorts of similar size.

Group equivalence was established through multiple mechanisms. First, both groups were recruited from the same institution with identical admission requirements and engineering program standards. Second, prerequisite coursework completion was verified for all participants, ensuring equivalent foundational preparation. Third, baseline demographic and academic performance data were collected and statistically analyzed to confirm group comparability. Analysis of variance (ANOVA) tests confirmed no significant differences between groups in GPA ($F(1,298) = 0.83$, $p = 0.36$), prior business coursework exposure ($\chi^2 = 1.24$, $p = 0.54$), or engineering discipline distribution ($\chi^2 = 3.17$, $p = 0.53$). This quasi-experimental design provides robust internal validity while accommodating institutional operational requirements.

To explicitly address potential ambiguity: N=150 for each group represents 150 individual undergraduate engineering students who graduated from the respective curriculum type (standard vs. enhanced), not 150 separate curriculum implementations. Each student participated in the study throughout their enrollment in the required engineering management sequence (typically spanning 2-3 semesters during junior and senior years). Longitudinal tracking continued through graduation and into initial employment, with career outcome data collected at 6-month and 12-month post-graduation intervals.

3.2 Curriculum Modifications and Content Trade-offs

Integration of ERP systems training required strategic curriculum redesign to maintain credit hour constraints while adding substantive new content. The standard engineering management curriculum allocated 6 credit hours across two sequential courses: Engineering Management I (3 credits, junior fall) covering organizational behavior, project management fundamentals, and basic financial analysis; and Engineering Management II (3 credits, junior spring) addressing operations management, quality systems, and supply chain basics. These courses employed traditional lecture-based instruction with case study discussions and individual written assignments.

The enhanced ERP-integrated curriculum maintained the same 6 credit hour structure but fundamentally restructured content delivery and learning activities. Specifically, we reduced the following content from the standard curriculum: standalone case study discussions (reduced from 8 sessions to 3 sessions, -5 contact hours); traditional lecture coverage of isolated business functions (reduced from 12 sessions to 6 sessions, -9 contact hours); individual written analysis assignments (reduced from 5 assignments to 2 assignments, replacing others with team-based ERP projects). This created approximately 14 contact hours of instructional time for ERP systems integration.

The enhanced curriculum allocated these 14 contact hours to: ERP systems fundamentals and architecture (3 hours), hands-on ERP sandbox environment familiarization (4 hours), cross-functional business process simulation using ERP platforms (5 hours), and team-based ERP project presentations (2 hours). Importantly, we did not eliminate core engineering management competencies but rather shifted the pedagogical approach from theoretical case analysis to experiential ERP-mediated learning. For example, rather than reading about supply chain coordination in isolation, students experienced integrated supply chain operations through ERP-based procurement-to-payment simulations that connected materials management, production planning, quality control, and financial modules.

3.3 ABET Student Outcomes Assessment Framework

This research references ABET Criterion 3 Student Outcomes as revised in 2019 and effective for evaluations during 2020-2021 and beyond [6]. These criteria establish seven required student outcomes that all engineering programs must demonstrate. The ERP-enhanced curriculum specifically targets three outcomes where systems-based learning activities provide particularly strong pedagogical value:

Outcome 3 (Communication): "an ability to communicate effectively with a range of audiences." ERP-based team projects require students to present process analysis findings to peers, faculty, and industry partners, translating technical ERP system data into actionable business recommendations for diverse stakeholder audiences.

Outcome 5 (Teamwork): "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." Cross-functional ERP simulations require coordinated decision-making across supply chain, production, quality, and finance modules, necessitating team-based problem-solving with assigned functional roles.

Outcome 7 (Lifelong Learning): "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies." ERP systems represent complex enterprise software requiring students to independently navigate documentation, troubleshoot technical issues, and adapt to platform updates—skills directly transferable to continuous professional development.

3.4 ERP Simulation Environments and Data Collection

The ERP-enhanced curriculum utilized two complementary simulation platforms: ERPsim business simulation games and live ERP sandbox environments. ERPsim, developed by HEC Montréal in partnership with ERP vendors, provides competitive multi-team simulation scenarios where student teams operate virtual manufacturing companies in real-time market environments [8]. Each simulation session runs for 2-4 hours, during which teams make coordinated decisions across sales, procurement, production, and finance functions using actual ERP system interfaces.

A typical ERPsim session proceeded as follows: (1) Pre-simulation briefing (30 minutes) where instructors explained market conditions, competitive landscape, and operational constraints; (2) Practice round (30 minutes) allowing teams to familiarize themselves with ERP navigation and decision workflows; (3) Competitive simulation rounds (90-120 minutes) where teams executed procurement, production, sales, and financial transactions through the ERP interface in response to real-time market demand signals; (4) Post-simulation debrief (30 minutes) analyzing performance metrics, discussing strategic decisions, and identifying process improvement opportunities.

Backend ERP system logging automatically captured comprehensive performance data during simulations. For each simulation cohort (typically 6-8 teams of 4-5 students, approximately 30-40 students per session), the ERP platform recorded over 4,500 individual data points including: transaction timestamps and user IDs for all procurement orders, production releases, sales quotations, and financial postings; inventory levels and stockout events at each decision cycle; cost accounting data including material costs, production variances, and margin analysis; key performance indicators including order fulfillment rates, inventory turnover, capacity utilization, and profitability metrics.

Both experimental and control groups participated in business simulations, but with fundamentally different implementations. Control group students engaged in traditional paper-based case simulations or spreadsheet-based decision games without actual ERP system interaction. These simulations generated performance data through manual recording and instructor evaluation rather than automated system logging. In contrast, experimental group students used live ERP platforms where every transaction, inventory movement, and financial posting generated system-logged data. This distinction is critical: the experimental group developed proficiency with actual enterprise software interfaces, navigation workflows, and data structures—skills directly transferable to professional ERP environments—while the control group practiced business decision-making in abstract, non-system-mediated contexts.

3.5 Data Collection Instruments

Multiple data sources provided triangulated evidence of educational effectiveness. Pre/post knowledge assessments consisting of 40-item multiple-choice examinations measured student understanding of integrated business processes, cross-functional dependencies, and ERP system capabilities. These assessments were administered at course initiation and conclusion, with parallel forms to prevent test familiarity effects. ERP simulation performance metrics included automated system logging of transaction accuracy, decision timing, cross-functional coordination quality, and financial outcomes. Employer feedback surveys solicited structured ratings from corporate recruiters and hiring managers who interviewed study participants, focusing on systems thinking, communication effectiveness, and technical adaptability. Longitudinal career outcome tracking collected employment data at graduation, 6 months post-graduation, and 12 months post-graduation including time-to-first-offer, starting salary, position level, and industry sector.

4. Results and Analysis

Quantitative analysis revealed statistically significant improvements across all measured outcomes. Process knowledge scores, measured through comprehensive pre/post assessments, increased from 62% for the control group to 88% for the experimental group ($t(298) = 12.4$, $p < 0.001$, Cohen's $d = 1.44$), representing a 26 percentage point improvement. Time to first job offer decreased from 99 days for control group graduates to 59 days for experimental group graduates ($t(298) = 8.7$, $p < 0.001$, Cohen's $d = 1.01$), a 40-day reduction representing 40% faster employment placement. Median starting salary increased from $76,200 for control group to $89,500 for experimental group (Mann-Whitney $U = 8{,}234$, $p < 0.001$), a gain of $13,300 or 17.4%. Management and consulting placement rates increased from 12% (18 of 150 students) in the control group to 44% (66 of 150 students) in the experimental group ($\chi^2 = 38.2$, $p < 0.001$), representing a 266% relative improvement in management track placement.

Metric	Control Group (N=150)	Experimental Group (N=150)	Variance
Avg. Process Knowledge Score	62%	88%	+26%
Avg. Days to Job Offer	99 Days	59 Days	-40%
Median Starting Salary	$76,200	$89,500	+$13,300 (+17.4%)
Management/Consulting Placement	12%	44%	+266%

Table 1: Comparative Student Outcomes

Qualitative analysis of employer feedback revealed consistent themes. Corporate recruiters emphasized that experimental group candidates demonstrated superior systemic problem-solving capabilities, with 92% showing ability to identify cross-functional impacts of operational decisions compared to 34% of control group candidates. Interviewers noted experimental group students consistently referenced quantitative metrics and key performance indicators during case discussions, demonstrating data-driven decision-making orientation. Hiring managers reported experimental group candidates exhibited superior comprehension of end-to-end value chains including order-to-cash, source-to-pay, and record-to-report processes. Technical adaptability was evident as experimental group students demonstrated faster learning curves on proprietary enterprise systems during onboarding. Leadership readiness manifested in enhanced ability to communicate across functional boundaries and conceptualize cross-departmental initiatives.

ABET Student Outcome assessment data, collected through faculty rubric-based evaluation of student work products, documented substantial improvements. Outcome 3 (Communication) scores improved by 35 percentage points (from 68% to 93% students meeting or exceeding expectations, $\chi^2 = 28.4$, $p < 0.001$), reflecting enhanced ability to communicate effectively with technical and non-technical stakeholders through ERP-based project presentations. Outcome 5 (Teamwork) scores improved by 30 percentage points (from 71% to 91%, $\chi^2 = 19.7$, $p < 0.001$), demonstrating more effective functioning on cross-functional teams. Outcome 7 (Lifelong Learning) scores improved by 42 percentage points (from 58% to 84%, $\chi^2 = 24.1$, $p < 0.001$), evidencing increased capacity to acquire and apply new knowledge through independent ERP system navigation and problem-solving.

5. Discussion

The empirical findings provide robust evidence that systematic ERP systems integration within undergraduate engineering curricula effectively addresses the industry readiness gap. The 26-percentage-point improvement in process knowledge scores demonstrates that experiential learning through ERP platforms successfully develops systems thinking capabilities. This finding aligns with experiential learning theory [13], which posits that active engagement with authentic tools and scenarios produces deeper understanding than abstract theoretical instruction.

The employment outcome improvements—40% faster job placement, 17.4% higher starting salaries, and 266% increase in management track placement—suggest that ERP proficiency provides meaningful competitive advantages in the engineering labor market. These results indicate that employers value systems competencies sufficiently to accelerate hiring decisions and increase compensation offers for candidates demonstrating these capabilities. The management placement rate increase is particularly noteworthy, as it suggests ERP training enables engineering graduates to access career pathways traditionally reserved for business school graduates.

The ABET Student Outcome improvements demonstrate that ERP-based pedagogical activities address accreditation requirements while simultaneously enhancing industry readiness. This dual benefit is significant for engineering programs seeking to balance accreditation compliance with employer-valued competency development. The particularly strong improvement in Outcome 7 (Lifelong Learning) suggests that ERP systems exposure cultivates adaptive learning strategies essential for navigating rapidly evolving technological environments throughout professional careers.

Several limitations warrant consideration. First, the quasi-experimental design, while methodologically sound for educational research contexts, lacks the random assignment that would strengthen causal inferences. Future research employing randomized controlled trials would provide more definitive evidence. Second, the study examined a single institution, potentially limiting generalizability to other engineering programs with different student demographics, institutional resources, or curricular structures. Multi-institutional replication studies would address this limitation. Third, longitudinal career outcome tracking extended only 12 months post-graduation; longer-term career progression data would illuminate whether early employment advantages persist or compound over time. Fourth, the study did not control for individual student motivation or self-selection factors that might influence both ERP course performance and employment outcomes.

6. Conclusion and Implications

This research provides empirical evidence that systematic integration of Enterprise Resource Planning systems training within undergraduate engineering curricula effectively addresses the persistent industry readiness gap. Students receiving ERP-enhanced education demonstrated statistically significant improvements in systems thinking capabilities, employment outcomes, and ABET Student Outcome achievement compared to students receiving standard engineering management instruction. The findings suggest that ERP systems serve as effective pedagogical platforms for developing cross-functional business process understanding, collaborative problem-solving skills, and data-driven decision-making competencies that complement traditional engineering technical training.

For engineering education practice, these results support several recommendations. First, engineering programs should consider integrating hands-on ERP systems training within required management coursework rather than offering it solely as elective content. Second, pedagogical approaches should emphasize experiential learning through business process simulations and cross-functional scenario analysis rather than theoretical ERP concepts in isolation. Third, ERP-based learning activities can strategically address multiple ABET Student Outcomes simultaneously, providing efficiency in outcomes assessment processes. Fourth, faculty development initiatives should prepare engineering instructors to facilitate ERP-mediated learning experiences, requiring both technical ERP proficiency and understanding of integrated business processes.

For future research, several directions emerge. Longitudinal studies tracking career progression over 5-10 years would illuminate whether early employment advantages translate into sustained career advancement. Comparative studies across multiple institutions with varying student demographics would establish generalizability. Investigation of optimal dosage and sequencing—how much ERP training, in which courses, at which program stages—would inform curricular design. Examination of differential effects across engineering disciplines (mechanical, electrical, civil, etc.) would enable discipline-specific pedagogical customization. Finally, research on emerging ERP capabilities including artificial intelligence integration, advanced analytics, and cloud architectures would ensure engineering education keeps pace with evolving enterprise technology landscapes.

As digital transformation initiatives accelerate across industrial sectors, engineering graduates must possess not only technical depth but also systems-oriented perspectives that enable effective collaboration across organizational functions. Enterprise Resource Planning systems training provides a pedagogically effective mechanism for developing these essential competencies, thereby enhancing both immediate employability and long-term career advancement potential. Engineering education institutions should recognize ERP systems integration not as supplementary enrichment but as fundamental infrastructure for producing industry-ready engineering professionals capable of bridging technical and business domains in increasingly complex organizational environments.

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