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Competency Mapping for Engineering Educators: A Strategic Enabler for Innovation and Sustainable system under SDG

[1]Sandeep Pankade, [2]Ashish Mohture

[1]Associate Professor, [2]Associate Professor

[1]Department of Mechanical Engineering, [2] Institute of Management Research

[1]Maharashtra Institute of Technology, Chhatrapati Sambhajinagar, India, [2] MGM University, Chhatrapati Sambhajinagar, India

Abstract: In the context of Industry 4.0 and the global mandate for sustainability, engineering education must change from conventional models to those that actively foster innovation, resilient system, as articulated in Sustainable Development Goal 9 (SDG 9). This empirical study investigates the strategic role of competency mapping for engineering educators in driving this transformative agenda. Based on a quantitative, descriptive survey of 371 engineering teachers across institutions in the Marathwada region of Maharashtra state India, the research assesses current proficiency across five key domains: Technical, Pedagogical, Research, Industry Relevant, Innovation & Sustainability. The findings reveal significant competency gaps in areas critical to SDG 9, with the largest deficits observed in research (Gap=2.60), industry relevant (Gap=2.54), and innovation & sustainability (Gap=2.57) competencies on a 5.0 ideal scale. Furthermore, a correlation analysis indicates that Designation and Qualification are the primary predictors of SDG 9 aligned competencies, while industry experience shows a weak translation into academic innovation. The study concludes by proposing a policy framework for integrating systemic competency mapping and targeted professional development to strategically enhance institutional capacity, positioning engineering institutes as key enablers of national and global sustainability goals.

Index Terms **- Competency Mapping, Engineering Educators, Sustainable Development Goal 9 (SDG 9), Innovation in Education, Faculty Development Strategies.**

I. INTRODUCTION

The global community has recognized the key role of technological advancement, robust infrastructure, and inclusive industrialization in achieving long-term prosperity, encapsulated by the United Nations Sustainable Development Goal 9 (SDG 9): Industry, Innovation, and Infrastructure (UNECE, 2012; UNESCO, 2017). For India, a nation undergoing rapid industrial and digital transformation, the engineering education ecosystem is the primary engine for cultivating the human capital required to meet these objectives.

The current demands of Industry 4.0 and the necessity for sustainable practice necessitate a paradigm shift in the competencies expected of engineering educators (Esangbedo et al., 2024; Alhassani et al., 2025). Traditional teaching expertise is no longer sufficient; educators must possess a sophisticated blend of technical mastery, pedagogical innovation, robust research acumen, and industry-aligned capabilities (Cruz et al., 2020; Leslie, 2016). This evolving requirement mandates a strategic approach to competency mapping the systematic process of identifying, measuring, and developing the critical skills that align institutional goals with broader societal needs.

This paper presents an empirical analysis aimed at addressing a significant gap in the literature: the lack of large-scale data validating the specific competencies of engineering educators in relation to the SDG 9 mandate within regional contexts.

The specific objectives of this study are to:

- Quantify the current proficiency levels of engineering educators across five defined competency domains.
- Identify and analyse the competency gaps, particularly in areas critical for fostering innovation, industrial relevance, and sustainability (SDG 9 alignment).
- Examine the correlation between key demographic variables (Designation, Experience, Qualification) and performance in SDG 9-aligned competencies.
- Propose a data driven framework for faculty development that strategically addresses identified gaps to maximize contribution to SDG 9 outcomes.

II. Literature Review

Competency mapping is a well-established strategic tool for aligning capabilities with the dynamic needs of the industrial sector (Leslie, 2016; Lunev et al., 2023). A conceptual exploration of competency mapping methodology highlights its role in aligning human capital with strategic objectives through various techniques, including Behavioral Event Interviewing and job analysis questionnaires (Pankade & Mohture, 2025; Cruz et al. 2020) emphasized that a comprehensive competency framework must extend beyond technical skills to include crucial transversal competencies such as creativity, teamwork, and communication (Sánchez-Carracedo et al., 2018). However, they noted that current assessment methods often lack the standardization and validation necessary for rigorous implementation. The development of engineering competency models, such as those discussed by Leslie, 2016 and Rüütmann, 2023, serves as a necessary blueprint for evaluating and structuring curricula.

The strategic importance of integrating sustainability into education is underscored by global bodies (UNECE, 2012; UNESCO, 2017). Sánchez-Carracedo et al. (2022) advocate that engineering educators must change into change agents who embed sustainability principles directly into their teaching, thereby driving the objectives of SDG 9. Magraner et al. (2025) explicitly link sustainability development goals with specific learning outcomes and required competencies, suggesting a top-down curriculum reform is necessary. The foundation for these outcomes lies in widely agreed-upon frameworks for sustainability competencies (Brundiers et al., 2021; Wiek & Redman, 2022).

Furthermore, fostering innovation and resilient infrastructure (SDG 9) requires deep industry-academia collaboration (Esangbedo et al., 2024). Studies highlight the role of higher education institutions in mediating this collaboration (Esangbedo et al., 2024; Vuoriainen et al., 2025), yet there remains an underexplored dimension regarding the specific educator competencies needed to effectively facilitate such partnerships and translate industry knowledge into pedagogical innovation (Popli & Singh, 2024). Leadership and organizational support are also critical for enabling academics' participation in SDG-focused education (Högfeldt et al., 2023).

Despite the growing body of literature on competency frameworks (Cruz et al., 2020; Leslie, 2016) and the necessity of incorporating SDGs into engineering education (Sabri, 2025; Tafese & Kopp, 2025), a critical gap remains: there is a significant lack of empirical, large-scale studies that specifically quantify the current competency levels of engineering educators in the Innovation and SDG 9 context and analyse how professional and demographic attributes influence these levels. This study uniquely addresses this deficit by providing empirical validation through a large regional dataset, establishing a quantitative link between educator competencies, faculty profile, and the strategic goals of SDG 9.

III. Methodology

This study employed a quantitative, descriptive research design to assess the competency profile of engineering educators. The target population comprised faculty members across various engineering disciplines within government, private, and autonomous institutions in the Marathwada region of Maharashtra, India. A total of 371 valid responses were collected, ensuring a representative sample of the regional academic ecosystem.

A structured questionnaire was developed based on established competency frameworks (Cruz et al., 2020; Leslie, 2016) and adapted to include specific items related to SDG 9 alignment and Industry 4.0 skills (UNESCO, 2017). The instrument was sectioned to cover:

Demographic Details: Age, Gender, Qualification, Teaching Experience, Industry Experience, and Designation.

Competency Domains:

- **Technical Competency**: Subject expertise and emerging technology use.
- **Pedagogical Competency**: Innovative teaching methods and student engagement.
- **Research Competency**: Publication rate, grant procurement and project guidance.
- **Industry-Relevant Competency**: Consultancy, industrial training and curriculum relevance.
- **Innovation and Sustainability Competency**: SDG awareness, interdisciplinary integration and contribution.

Responses for competency items were measured using a 5-point Likert Scale (where 1=Strongly Disagree and 5=Strongly Agree). The survey was pre-tested for reliability.

The collected data were analyzed using SPSS and Microsoft Excel. The analytical procedures included:

1. **Descriptive Statistics**: Calculation of Mean (μ) and Standard Deviation (σ) for each competency domain to determine overall proficiency.
2. **Gap Analysis**: Calculation of the competency gap, defined as
$$\text{Gap} = \text{Ideal Score } (5.0) - \text{Observed Mean } (\mu)$$
3. **Correlation Analysis**: Bivariate Pearson correlation (r) was used to explore the linear relationships between the key demographic variables and the four primary SDG 9-aligned competencies (Research Publication Rate, Industry-Relevant Course Design, Encourage Interdisciplinary Study, and Social/Environmental Contribution).

IV. Result and Analysis

The survey responses were analyzed across five key competency domains: Technical, Pedagogical, Research, Industry-Relevant, and Innovation & Sustainability. The average scores (on a 5-point Likert scale) indicate moderate competency levels across most domains, with notable gaps in areas critical to SDG 9.

The table 1 presents the average scores and corresponding gaps for five key competency domains, highlighting discrepancies between current proficiency levels and the ideal benchmark score of 5.0.

Table 1: Competency Gap Analysis of Engineering Educators (N=371)

Competency	**mean**	**Std. Dev**	**Competency Gap** *(Ideal Score = 5)*
Technical Competency	3.01	0.83	1.99
Pedagogical Competency	2.91	0.81	2.09
Research Competency	2.40	1.07	2.60
Industry-Relevant Competency	2.46	1.11	2.54
Innovation and Sustainability Competency	2.43	1.10	2.57

The analysis indicates a moderate proficiency in foundational domains (Technical and Pedagogical) but reveals a critical deficit in the domains most essential for driving SDG 9. The largest gaps are observed in Research Competency (Gap = 2.60), Industry-Relevant Competency (Gap = 2.54), and Innovation and Sustainability Competency (Gap = 2.57). The high standard deviations across these lower-scoring domains suggest significant variability in the professional development and institutional support provided to faculty members.

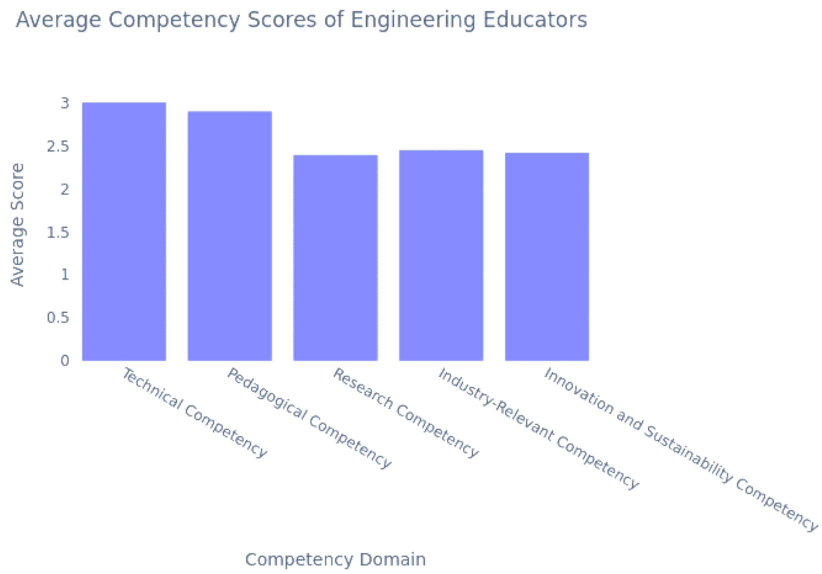

Figure 1: Average Competency Scores of Engineering Educators

Bar chart on figure 1 illustrating the average score (μ) for each of the five competency domains. The figure visually emphasizes the lower scores in Research, Industry-Relevant, and Innovation & Sustainability competencies, confirming the calculated gaps in Table 1.

Radar chart in figure 2 comparing the observed average scores (inner polygon) against the ideal score of 5.0 (outer edges). The chart graphically highlights the imbalanced competency profile of the educators, with the most significant deviation from the ideal occurring in the SDG 9-aligned domains.

A Pearson correlation analysis was conducted to understand how demographic factors influence engagement with the strategic SDG 9 competencies.

The correlation analysis yields several meaningful insights:

1. Designation (Seniority): This variable showed the strongest positive correlation with all three core innovation competencies: Research Publication ($r = 0.162$), Industry-Relevant Course Design ($r = 0.119$), and Interdisciplinary Study ($r = 0.123$). This suggests that senior faculty members (e.g., Associate Professors and above) are disproportionately responsible for driving the institution's innovation agenda.
2. Qualification (Advanced Degree): Qualification exhibits significant positive correlations with Industry-Relevant Course Design ($r = 0.159$) and Interdisciplinary Study ($r = 0.111$), indicating that educators with higher academic degrees are better equipped to implement modern, innovation-focused pedagogical approaches.

3. Teaching Experience and Research: Interestingly, Teaching Experience showed a modest negative correlation with Research Publication Rate (r = −0.111). This counter-intuitive finding suggests that increased teaching or administrative load over time may hinder research productivity, a potential systemic issue requiring policy intervention.
4. Industrial Experience: The minimal and non-significant correlations of Industrial Experience with Research (r = −0.027) and Industry-Relevant Course Design (r=0.083) is a critical finding. It strongly suggests a systemic failure in the current academic structure to effectively translate prior industrial knowledge into academic innovation, curriculum enhancement, and research output.

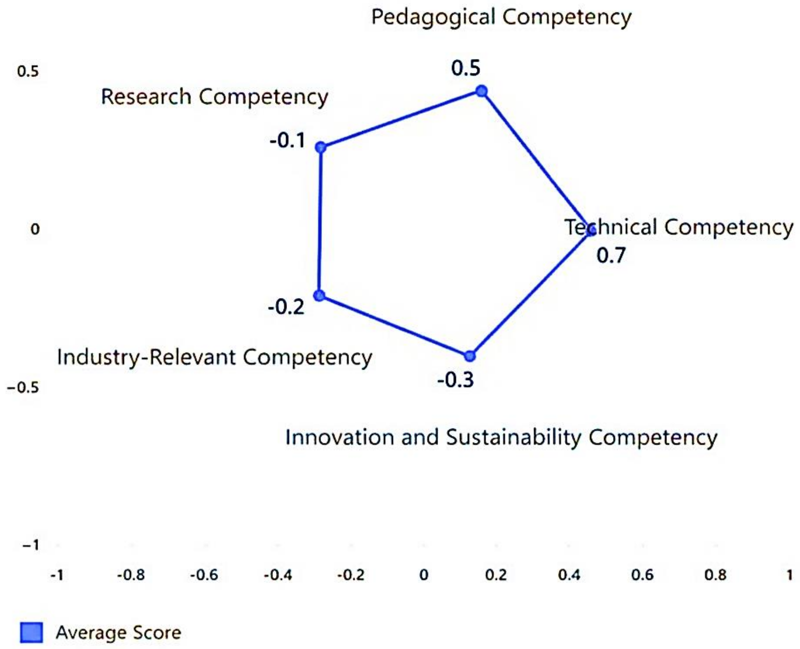

Figure 2: Radar Chart of Competency Profile

Table 2: Bivariate Correlation Matrix between Demographic Variables and SDG 9-Aligned Competencies (N=371)

Demographic Variable	Research Publication Rate	Industry-Relevant Course Design	Encourage Interdisciplinary Study	Social-Environmental Contribution
Designation	0.162	0.119	0.123	0.024
Teaching Experience	−0.111	-0.049	0.059	0.047
Industrial Experience	−0.027	0.083	0.004	−0.035
Qualification	−0.014	0.159	0.111	0.048

V. Discussion and Implications

The quantitative findings of this study point to an urgent need for institutional and policy-level reforms in engineering education. Notably, substantial competency gaps were identified in the areas of research, industry relevance, and innovation/sustainability—core pillars of Sustainable Development Goal 9 (SDG 9). These deficiencies suggest that the current engineering education framework is not adequately preparing graduates to support resilient infrastructure or innovation-led industrial growth.

This study highlights the strategic value of competency mapping as a tool for aligning engineering education with the objectives of SDG, which emphasizes industrial collaboration, innovation, and infrastructure development. Survey data from 371 engineering educators revealed that while technical and pedagogical competencies are moderately developed, there are significant shortfalls in areas critical to sustainable development and innovation. This indicates that foundational teaching skills are present, but the higher-order competencies needed to drive transformative change remain underdeveloped.

Further insights emerged from the correlation analysis, which examined how demographic variables influence competency development. Faculty designation was the most impactful factor, showing strong positive correlations with research output, industry-relevant curriculum design, and interdisciplinary collaboration. This suggests that senior faculty members, likely due to their experience, institutional roles, and access to resources, are more engaged in activities aligned with SDG. Similarly, higher academic qualifications were linked to stronger innovation-related competencies, indicating that advanced degrees may enhance educators' ability to integrate sustainability and interdisciplinary thinking into their teaching.

Interestingly, teaching experience showed a slight positive correlation with social and environmental contributions but a negative correlation with research productivity. This may reflect the increased administrative and instructional responsibilities that limit research engagement among more experienced faculty. Conversely, industry experience showed weak or negative correlations across most competencies, revealing a disconnect between industrial exposure and its effective integration into academic practice. This points to a missed opportunity in leveraging industry insights to enrich curriculum and foster innovation. Overall, the findings underscore the need for targeted interventions such as faculty development programs, strategic recruitment and promotion policies, and institutional support systems that cultivate competencies aligned with SDG. Engineering institutions must actively foster research capabilities, industry engagement, and sustainability awareness among educators to build a workforce equipped to contribute meaningfully to national and global development goals.

The largest competency gap (Gap=2.60) in Research underscores a critical barrier to achieving SDG 9. Innovation is inherently linked to research output (Högfeldt et al., 2023). Without strengthening the research competencies of faculty (e.g., grant writing, high-impact publication, and doctoral supervision), engineering institutions will remain passive participants rather than active drivers of technological and sustainable change.

The findings highlight a deep chasm between academia and industry. The low scores in Industry-Relevant Competency (Gap=2.54) are compounded by the finding that prior industrial experience offers little predictive power for innovation-aligned academic output (Table 2). This necessitates a radical change in faculty engagement models, moving beyond traditional industrial visits to requiring:

- *Mandatory Consultancy Projects*: Facilitating real-world problem-solving (Popli & Singh, 2024).
- *Industry Sabbaticals*: Providing structured, high-impact re-exposure to industrial practices (Esangbedo et al., 2024; Vuoriainen et al., 2025).
- *Curriculum Co-design:* Actively involving faculty in co-designing courses with industry partners (Esangbedo et al., 2024).

The strong predictive power of Designation and Qualification suggests that investment in advanced degrees (e.g., Ph.D.) and accelerated mentoring of junior faculty into leadership roles are high-leverage policy interventions. Furthermore, the negative correlation between Teaching Experience and research output necessitates policy reforms to:

- *Reduce Administrative Burden*: Reallocating non-academic responsibilities to dedicated staff, freeing senior faculty for high-impact research.
- *Incentivize* Applied Research: Prioritizing projects that directly contribute to SDG 9 outcomes (e.g., low-carbon construction, smart grid technology) over general publication quantity.
- *Targeted Retraining*: Implementing bespoke workshops for experienced faculty on integrating sustainability, digital tools, and interdisciplinary teaching (Wadzuk & Minerva, 2025).

VI. Conclusion

This empirical study successfully mapped the competency landscape of engineering educators in the Marathwada region and quantitatively linked existing gaps to the strategic goals of SDG. The research definitively confirms that significant deficits exist in competencies related to research, industry engagement, and innovation/sustainability, which are the core enablers for resilient infrastructure development.

The findings offer a clear mandate for engineering institutions to adopt a systemic, data-driven approach to faculty development. By prioritizing targeted interventions to close the identified gaps, particularly in leveraging prior industrial experience and mitigating the administrative burden on experienced researchers, institutions can strategically enhance their human capital. This transformation will empower educators to become active architects of an innovative, inclusive, and sustainable future, thereby solidifying the vital contribution of higher education to meeting national and global development objectives. Future research should explore qualitative aspects of competency development, investigating the specific organizational culture and incentive structures that either facilitate or impede the translation of industrial experience into academic innovation.

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