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# A LEARNING ANALYTICS MODEL FOR COMPETENCY MAPPING IN ENGINEERING EDUCATION: AN EMPIRICAL STUDY

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## Abstract

This paper proposes and validates a Learning Analytics (LA) Model designed to objectively map professional competencies among engineering educators, leveraging comprehensive survey data from 371 faculty members from engineering institutes of Marathwada region of Maharashtra, India. The study applies a multi-stage analytical framework including descriptive statistics, dimensionality reduction (Principal Component Analysis), and K-Means clustering to transform raw data into a data-driven competency map. Results reveal strong self-reported proficiency in core pedagogical skills like teaching delivery and student engagement, but expose critical areas for institutional intervention in research and collaboration competencies. These data-informed insights provide immediate actionable intelligence for academic leaders, directly supporting the themes of Learning Analytics for Decision-Making and Adaptive Personalization in faculty development. The study offers a reproducible framework for improving teacher proficiency in technologically enhanced classrooms.

**Keywords:** Learning Analytics, Competency Mapping, Engineering Educators, Technology-Enhanced Teaching, Faculty Development, Data-Driven Decision Making

## 1. Introduction

A major change is occurring in the field of engineering education as a result of the quick advancements in digital technology, artificial intelligence, and data-driven pedagogical approaches. As educational establishments strive to align with global norms and the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), the role of engineering educators increasingly becomes relevant. They must stop being solely technical knowledge teachers and start promoting creativity, teamwork, and lifelong learning.

In this scenario, competence mapping turns into a tactical instrument for evaluating and enhancing teaching skills, enabling engineering institutions to identify their strong points, address their shortcomings, and align faculty development with their goals and industry norms. This connection is essential given the growing emphasis on integrating transversal competencies such as communication, cooperation, emotional intelligence, teamwork, and creativity into engineering curricula to meet industry demands (Walther & Radcliffe, 2007; Sánchez-Carracedo et al., 2022). However, traditional competency evaluation approaches sometimes lack impartiality, scalability, and practical insights (Cruz, Saunders-Smits, & Groen, 2020).

To address this empirical gap, this work develops and assesses a scalable Learning Analytics (LA) Model for competency mapping. LA, defined as the collection, analysis, and reporting of data about students and learning environments, offers a solid basis for analysing educator performance data and directing decision-making (Salas-Martínez & Ramírez-Martinell, 2025). Recent reviews have shown that it can enhance engagement, personalize learning, and promote faculty development programs within the institution (Kılıç & İzmirli, 2024; Bergdahl et al., 2024).

By employing this LA model to analyse survey responses from 371 engineering educators affiliated with engineering institutes in the Marathwada region of Maharashtra state, India, the study aims to discover reliable trends in teaching, research, and professional competencies. This LA paradigm offers a robust way to convert raw data into institutional information so that competency assessment transitions from descriptive reporting to prescriptive decision-making. The primary contribution is an evidence-based framework designed to help academic leaders and policymakers create more successful and flexible professional development programs for the digital revolution of higher education.

## 2. Literature Review

In engineering education, competency mapping has become more well-known as a tactical instrument for evaluating and improving faculty effectiveness and organisational effectiveness. Cruz, Saunders-Smits, and Groen (2020) conducted a systematic review that highlighted the need for standardized and scalable models in engineering education by noting the variety of competency frameworks and assessment techniques utilized worldwide. Garay-Rondero et al. (2024) looked more closely at competency-based evaluation methods and highlighted how relevant they are to the outcomes of higher education, particularly in situations involving complicated problem-solving.

Several researches have improved our understanding of competency mapping in India's technical education system. When Aishwarya (2016) examined faculty competencies in Madurai's engineering institutes, she discovered differences between the objectives of the institutions and actual teaching strategies. The use of competency mapping in academic and corporate contexts was the focus of Jain and Gandhi's (2021) pragmatic approach. Yadav and Nalawade (2011) studied engineers in the industrial sector of Maharashtra, offering insights on regional competency demands, while Pargaonkar and Yadav (2022) studied the role of competency mapping in career planning inside educational institutions.

In order to automate competency-based assessments, recent developments have brought in AI-powered solutions as SmartRubrics (Hochstetter-Diez et al., 2025). These developments are in line with the increasing focus on learning analytics, which allows educational institutions to gather and examine data to guide faculty development. In their thorough evaluations of learning analytics in higher education, Kılıç and İzmirli (2024) and Salas-Martínez & Ramírez-Martinell (2025) showed how it may improve institutional planning and teaching quality.

Digital competency is another crucial area of attention. Trujillo-Juárez et al. (2025) investigated micro course interventions for faculty upskilling and reskilling whereas Gallego Joya et al. (2025) and Osorio Vanegas et al. (2025) carried out systematic reviews on enhancing instructors' digital skills. Asagar (2025) offered a comparative analysis of digital competency frameworks, emphasizing the need for contextualized models in Indian education.

The conceptual contributions of Rüütmann (2023) and Jin and Hadgraft (2017) have highlighted the transdisciplinary and pedagogical aspects of engineering educator competences. These frameworks encourage the use of innovation, teamwork, and ethics into instructional strategies.

Lastly, a conceptual model for competency mapping was presented by Pankade and Mohture (2025), who also discussed its methodological concerns and many advantages. Their work lays the groundwork for integrating data-driven decision-making, digital transformation, and adaptive learning with learning analytics in competency assessment.

To sum up, competency mapping is a crucial strategic instrument for increasing faculty efficacy in engineering education. Regional studies provide useful, contextualized insights, while global reviews emphasize the need for uniform, scalable approaches. The combination of learning analytics with AI-powered evaluation (like SmartRubrics) is a sign of the future since it allows for data-driven planning and progress. Improving digital competency and implementing transdisciplinary frameworks continue to be crucial priorities in order to equip teachers for innovation and moral teaching. The foundation for the transition to an adaptive, data-informed approach to engineering faculty competency assessment is provided by this body of work.

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## 3. Methodology

### 3.1 Data Collection and Population

This empirical study employed a large-scale, cross-sectional survey design. The study population consisted of 371 full-time instructors from engineering schools in the Marathwada area of the state of Maharashtra. The primary instrument was a structured questionnaire that was based on recognized competency frameworks in engineering education (Cruz, Saunders-Smits, & Groen, 2020) and cited current developments in assessment tools (Hochstetter-Diez et al., 2025). The questionnaire covered more than 60 issues pertaining to five key professional domains: professional development, ethics, cooperation, research participation, and teaching efficacy. The replies were encoded using a 5-point Likert scale, with 1 denoting strongly disagree and 5 denoting strongly agree.

### 3.2 The Learning Analytics Model: Analytical Framework

The raw self-reported data was converted into an actionable competency map using the multi-stage Learning Analytics (LA) Model. This framework is acknowledged as a strategic facilitator for tailored instruction (Wong, 2017; Lidolf & Pasco, 2020) and is consistent with the LA research emphasis on employing data mining and visualization to enhance educational decision-making (Márquez et al., 2024; Drugova et al., 2024). The following consecutive techniques made up the methodological approach:

- To summarize the data, preliminary statistical analysis using means and standard deviations was carried out.
- A top competency rating based on mean scores was established using descriptive statistics.
- To find general performance trends, bar chart visualization was used, proving the need for more thorough segmentation.

## 4. Results and Discussion

### 4.1 Top Competencies and Descriptive Statistics

**The survey responses were analyzed. Descriptive statistics, including the mean, standard deviation, minimum, and maximum scores, were computed for each competency item. Descriptive statistics indicated that the survey instrument's internal reliability was good (Cronbach's $\alpha > 0.85$). Faculty members demonstrated a high level of self-efficacy in direct pedagogical skills such as student involvement and instructional delivery. However, there was a clear lack of expertise in the areas of research (particularly grant writing) and interdisciplinary teamwork that require external participation. This discrepancy shows how the college values academic performance more than outside intellectual opinions.**

**Based upon the average score, the top 10 competencies are mentioned in table 1. It represents the mapping and prioritizing core educators' competencies in engineering education system.**

**Table 1:** Mapping and Prioritizing Core Faculty Competencies in Engineering Education.

| Rank | Competency parameter | Rank | Competency parameter |
|---|---|---|---|
| 1 | Clear Topic Explanation | 6 | Moral Conduct |
| 2 | Prompt & Helpful Feedback | 7 | Student Engagement/Involvement |
| 3 | Active Student Listening | 8 | Professional Ethics Adherence |
| 4 | Industry-Relevant Course Material | 9 | Efficient Digital Tool Use |
| 5 | Cutting-Edge Teaching Methods | 10 | Clear Expectation Setting |

The findings highlight a well-rounded faculty profile that combines high professional and ethical standards with excellent classroom performance (such as student participation and listening). High rankings for courses that are relevant to the

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industry in keeping with known studies on effective pedagogy, contemporary pedagogy and materials such as "Cutting-Edge Teaching Methods" and "Efficient Digital Tool Use" highlight the necessity for faculty members who are dynamic, moral role models, and proficient communicators (Cruz et al., 2020; Biggs & Tang, 2011). A notable and crucial competency gap was found in areas needing external and institutional engagement, despite the descriptive analysis demonstrating excellent self-efficacy in basic educational abilities (clear explanation, timely feedback, and engagement). Faculty members specifically showed shortcomings in interdisciplinary collaboration and research (grant writing and high-impact publishing).

### 4.2 Competency Clustering and Profiling

The application of the LA Model's K-Means clustering algorithm successfully produced four faculty profiles, demonstrating the model's capacity for precise segmentation. Table 1 outlines the defining characteristics of each faculty cluster and their relevance for decision-making in institutional development, including mentorship, curriculum leadership, and training priorities.

Table 2: Cluster Profiles and Strategic Utility for Institutional Planning

| **Cluster Profile** | **Characteristics (Decision-Making Insight)** | **Utility for Institutional Planning** |
|---|---|---|
| Cluster 0:<br>Digital Trailblazers | High in all competencies, demonstrating mastery in digital pedagogy and research. | Utilized for Change Management; appointed as internal mentors and curriculum leaders. |
| Cluster 1: Engagement Experts | High in teaching and ethics; low in research and advanced digital tools. | Requires targeted Development in advanced research and new Adaptive Learning technologies. |
| Cluster 2:<br>The Generalists | Moderate scores across all domains; represents the largest population segment | Focus for Institutional Policy; primary recipients of mandatory core development programs. |
| Cluster 3:<br>The Traditionalists | Lowest scores in collaboration, research, and technology integration. | Demands Personalized Mentorship and foundational digital literacy to prevent digital exclusion. |

This segmented approach moves the institution beyond generic training, utilizing Learning Analytics to ensure that professional development investment is both efficient and outcome-focused.

### 4.3. Principal Component Analysis (PCA) and Faculty Clustering

The cleaned dataset, which included more than 57 competency questions with 5-point Likert scale ratings, was subjected to Principal Component Analysis (PCA) in order to reveal hidden patterns in educator competencies. As a dimensionality reduction method, PCA preserved a substantial amount of variation while converting the high-dimensional data into a more understandable two-dimensional space.

Figure 1 shows how Principal Component Analysis (PCA) was used to visualize 371 faculty members in a two-dimensional space. PC2 (10.3% variance) is related to engagement and ethics, whereas PC1 (22.6%) is mostly related to instructional clarity and digital usage. The K-Means clustering algorithm discovered four distinct competency profiles, which serve as the foundation for adaptive professional development programs. The Learning Analytics Model utilized in this study produced this graphic, which is a depiction of the Educator Competency Clusters following the application of Principal Component Analysis (PCA).

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The analysis extracted two principal components:

- **Principal Component 1 (PC1)** accounted for **22.6%** of the total variance.
- **Principal Component 2 (PC2)** explained an additional **10.3%**.

Together, these components captured approximately **32.9%** of the dataset's variability, offering a meaningful visual representation of educator competency profiles.

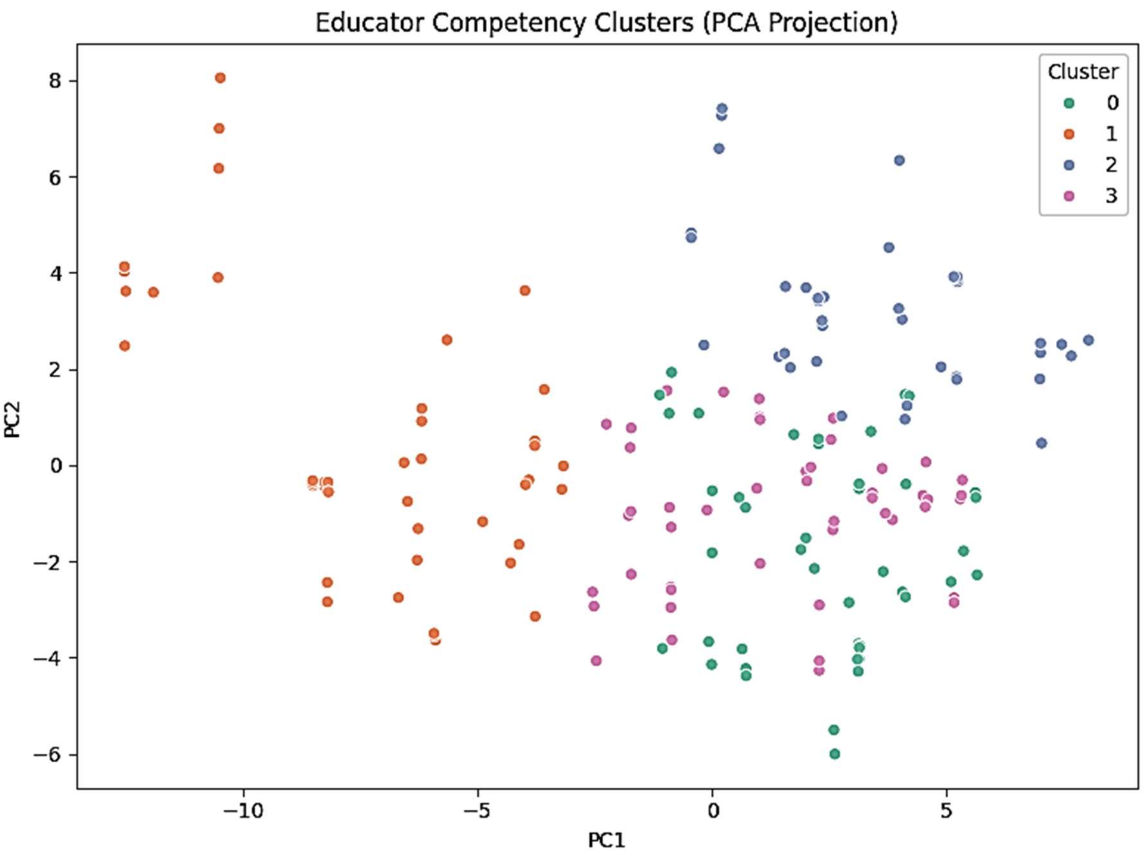


Figure 1. Educator Competency Clusters (PCA Projection)

Different grouping patterns were shown by the PCA scatter plot. One group demonstrated excellent instructional clarity, feedback delivery, and use of digital tools, all of which are consistent with contemporary educational approaches. Another group had strong ethical behavior and student involvement, which is indicative of values-driven instruction. A third group showed moderate levels of competency in every category, indicating profiles that were balanced but not specialized.

The last group highlighted areas for focused improvement by indicating lower research and collaboration scores. The table 2 categorizes faculty into four clusters based on their location in the PCA chart, color-coded for visual interpretation. It provides insights into their competency profiles and implications for targeted faculty development strategies.

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Table 2: Faculty Clusters Based on Principal Component Analysis: Visual Distribution and Developmental Implications

| Cluster | Color | Location on Chart | Meaning for Faculty Development |
|---|---|---|---|
| 0 | Orange/Coral | Primarily on the far left (negative PC1) and spread vertically. | These are likely your "Traditionalists" or the group needing the most support in areas like digital tools and research, as they score lowest on the competencies that load positively on PC1. |
| 1 | Teal/Green | Generally centered around the origin (0, 0) or slightly positive on PC1. | This may represent "The Generalists"—a large population with moderate scores across all domains, forming the core mass of the faculty. |
| 2 | Pink/Purple | Spread throughout the right half (positive PC1) and slightly clustered in the upper-right quadrant. | This group is strong in both key components, likely representing the "Digital Trailblazers" or "Engagement Experts" who excel in teaching, feedback, and digital tools. |
| 3 | Light Purple/Blue | Clustered on the right (positive PC1) and high (positive PC2). | These educators score high on both primary components, indicating strong overall professional and pedagogical competence. |

The segmentation of 371 educators into four distinct profiles using KMeans clustering validated the PCA-based grouping, enabling data-driven personalization in faculty development. This approach supports adaptive learning and strategic planning by aligning training with specific competency traits. The resulting Competency Map forms the foundation for targeted interventions, ensuring that institutional efforts are both statistically robust and tailored to individual educator needs in technology-enhanced learning environments (Salas-Martínez & Ramírez-Martinell, 2025).

This empirical study successfully validates a replicable Learning Analytics Model for competency mapping in engineering education. By utilizing PCA and K-Means clustering, the model objectively segments the faculty population, yielding the necessary actionable intelligence to support institutional Digital Transformation. This framework is a powerful tool for academic leaders seeking to move beyond anecdotal evidence and apply Learning Analytics for Decision-Making in Education. The research serves as a foundational step toward creating truly personalized and data-driven systems for faculty development.

### 4.4 Key Descriptive Findings and Initial Competency Gaps

Comprehensive data on faculty members' self-reported strengths and weaknesses were provided by the first phase of the LA Model. In a horizontal bar chart study, the top 20 items (out of over 57) showed consistent mastery of instructional tactics. The highest average scores for competencies such as "Listens actively to students," "Provides timely and constructive feedback," and "Explains concepts clearly and effectively" indicate that educators have strong student-centered teaching methods and pedagogical clarity. The "Designs industry-relevant course content" received high marks for responding to external engineering requirements.


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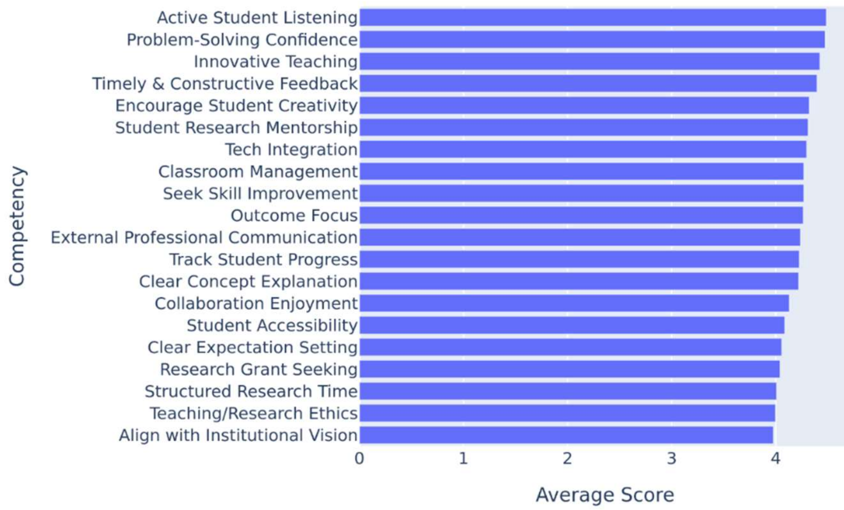


Figure 2. Top 20 Competencies essential for Engineering Educators by Average Score

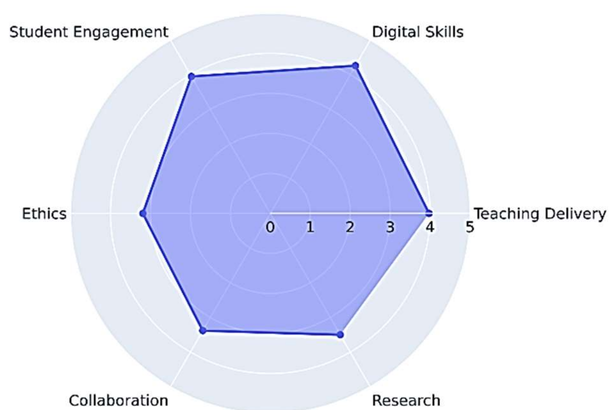


Figure 3. Competency Mapping Radar Chart.

Figure 3 Competency Mapping Radar Chart describes Comparative visualization of the aggregated mean scores across six strategic competency domains (Teaching Delivery, Digital Skills, Student Engagement, Ethics, Collaboration, and Research). The chart confirms strong pedagogical practices and visually highlights the critical competency gaps in Collaboration and Research competencies. This pattern aligns with broader trends where teaching is prioritized (Walther & Radcliffe, 2007; Sánchez-Carracedo et al., 2022) and underscores the need for balanced faculty development.

## 5. Strategic Insights and Conclusion

### 5.1 Strategic Insights for Decision-Making

The LA-derived Competency Map offers direct, actionable insights that fulfil the promise of data-driven academic management:

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- *Adaptive Resource Allocation*: Training budget allocation is now data-justified. Resources must be heavily weighted towards personalized micro-courses for Clusters 1 and 3, focusing on their specific deficits (e.g., dedicated workshops on research grant writing, rather than general software tutorials).
- *Mentorship Strategy:* Cluster 0 faculty should be leveraged formally within a mentorship program, providing peer-to-peer training that is demonstrably more effective than external workshops for practical skill transfer.
- *Policy Revision*: The persistent low scores in collaboration competence suggest that institutional policies regarding performance evaluation should be revised to assign greater weight to interdisciplinary projects and research outputs, fostering a culture of teamwork.
- *Digital Pedagogy Training*: While general digital skills are moderate, institutions must invest in advanced digital pedagogy training—including adaptive learning, gamification, and cloud-based platforms—to improve instructional flexibility (Osorio Vanegas et al., 2025; Gallego Joya et al., 2025). This training should be targeted at clusters showing deficits in digital integration.
- *Research Mentorship and Grant Seeking*: The consistently lower scores in research publication and grant acquisition necessitate formal intervention. Institutions should implement structured mentorship programs and targeted workshops (Sánchez-Carracedo et al., 2022), leveraging LA to identify high-potential faculty for strategic research investment (Salas-Martínez & Ramírez-Martinell, 2025).
- *Interdisciplinary and International Collaboration:* To address limited confidence in these domains, institutions should actively promote cross-departmental projects and global partnerships (Walther & Radcliffe, 2007), which are essential for preparing students for complex, real-world engineering challenges.
- *Feedback-Driven Teaching Improvement:* The high scores in active listening and student feedback seeking suggest a strong foundation for establishing formalized digital feedback systems and peer review mechanisms, enabling continuous improvement in teaching quality (Sharif & Atif, 2024).

The findings underscore the need for balanced faculty development strategies that integrate both pedagogical and research-oriented growth, setting the stage for the deeper segmentation provided by the clustering analysis.

Table 3 Cluster-Based Faculty Development Roadmap: Focus Areas and Targeted Strategies

| Cluster Name | Focus Areas | Recommended Strategies |
|---|---|---|
| Cluster 0:<br>The Traditionalists | Digital literacy, research skills, interdisciplinary collaboration | - Foundational workshops on educational technologies<br>- Mentorship in research methodology and grant writing<br>- Exposure to collaborative teaching models |
| Cluster 1:<br>The Generalists | Advanced pedagogy, adaptive learning, strategic alignment | - Core development programs in curriculum innovation<br>- Training on aligning teaching with institutional goals<br>- Introduction to analytics-driven teaching practices |
| Cluster 2:<br>Engagement Experts | Research engagement, global collaboration, digital tools | - Advanced training in research publication and grant seeking<br>- Workshops on international academic networking<br>- Adaptive learning technology integration |

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|---|---|---|
| Cluster 3: Digital Trailblazers | Leadership, mentoring, change management | - Leadership development programs<br>- Peer mentoring roles and curriculum design leadership<br>- Strategic planning and institutional innovation workshops |

## 6. Conclusion

This study successfully demonstrates the effectiveness of applying a multi-stage Learning Analytics Model to competency mapping for engineering educators, leveraging data from 371 faculty members. Through the application of Principal Component Analysis (PCA) and K-Means clustering, the research provided an objective and nuanced understanding of educator profiles, identifying key strengths in Teaching Delivery and significant gaps in Research Productivity and Interdisciplinary Collaboration.

The core contribution of this work lies in the integration of these data-driven techniques, which moved competency assessment beyond descriptive statistics to reveal distinct, actionable clusters. This segmentation is crucial for academic leaders seeking to design personalized training programs, foster collaborative research ecosystems, and implement feedback-driven teaching models.

Ultimately, this paper contributes a replicable model that supports the ongoing discourse on data-informed educational leadership. It provides the necessary intelligence for institutions to foster continuous improvement and accelerate Digital Transformation in Higher Education, directly enabling Learning Analytics for Decision-Making and Adaptive Personalization in faculty development. Future research should explore longitudinal tracking of competency growth, predictive modeling for faculty performance, and integration with institutional learning management systems to further enhance the model's impact.

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