Multi-dimensional Trajectories of Expertise in Engineering: Perspective from Epistemic Frame Theory*

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ABSTRACT

Modern electrical grid systems demand engineers capable of adaptive reasoning, systematic justification, and principled decision-making under uncertainty. However, while many graduates excel technically, they often struggle with these expert-level competencies, revealing gaps in our understanding of expertise development. To address this, we need to identify the granular cognitive and epistemic shifts that occur along the expertise continuum. Drawing on Epistemic Frame Theory, this study examines how epistemic frames shape the developmental trajectory of expertise across second-year, third-year, and final-year undergraduates, compared against field professionals (experts). In the study, participants completed an open-ended electrical grid design task in a computer-based environment. We applied Min-Max normalization to verbal protocols to neutralize verbosity bias and reveal latent structural shifts. Our findings highlight a two fundamental developmental trajectories. An ascending trajectory captures the adoption of a professional lens, wherein students transition from academic idealism to professional pragmatism and from reactive debugging to proactive modeling. Conversely, a descending trajectory reflects the shedding of novice habits, indicating a gradual disengagement from surface-level and trial-and-error strategies. Notably, experts' strategic silence emerged as a marker of proficiency. We observed that experts' silence is a signal of proficiency. The high-frequency behaviors in novices, such as visual monitoring and explicit naming of components, fade away as knowledge becomes tacit. These findings suggest that expertise is defined as much by what is shed (novice habits) as what is acquired (professional lens). These insights suggest that engineering curricula should incorporate earlier authentic practice to bridge the theoretical trap fostering the transition from explicit theoretical rules to implicit professional norms.

Keywords

Epistemic Frame Theory, Trajectory of Expertise, Continuum of Expertise, Min-Max Normalization, Engineering Education

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