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Basic sciences are non-negotiable: debunking three critical fallacies in engineering education

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1 Introduction

Engineering education faces persistent challenges stemming from prevalent misconceptions that prevent students from deeply grasping fundamental scientific principles (Ammar et al., 2024; Ferreira et al., 2024; Ivanov et al., 2024; Minichiello and Caldwell, 2021). Three fallacies particularly undermine educational quality: the perceived simplicity of basic sciences (Büdenbender-Kuklinski et al., 2024; Eleri et al., 2007; Galbraith and Haines, 2000; Greet et al., 2022; Lee et al., 2021; Omaish et al., 2021), the assumption that any engineering graduate is inherently qualified to teach foundational subjects (Mohammadpour and Maroofi, 2023; Ramolula and Nkoane, 2024; Schiering et al., 2023; Zhumabay et al., 2024) and the belief that each engineering specialization requires overly customized basic curricula (Cardella, 2008; Davis et al., 2017; Ferreira et al., 2024; Kent, 2003). These misconceptions diminish educational rigor, compromise institutional credibility, and impair graduates' ability to navigate complex professional scenarios.

The first misconception stems from oversimplified perceptions of core sciences, such as mathematics and physics. Often perpetuated by superficial teaching methods prioritizing quick problem-solving over conceptual understanding (Li and Schoenfeld, 2019), this approach discourages deeper engagement with fundamental concepts. Educational research consistently highlights that solid grounding in basic sciences correlates strongly with enhanced analytical skills and creativity in engineering problem-solving (Suherman and Vidákovich, 2022; Tariq et al., 2025).

Secondly, institutions widely believe that an engineering degree alone qualifies one to effectively teach foundational scientific courses (Artigue, 2020; Scott, 1908). However, contemporary educational research emphasizes the necessity of specialized pedagogical skills alongside subject-matter expertise (Zhang and Tian, 2024). Without these pedagogical competencies, instructors struggle to accommodate diverse learning styles, promote meaningful knowledge transfer, and maintain student engagement. Consequently, ineffective teaching in foundational courses fosters superficial study habits and undermines student retention and long-term performance.

The third misconception argues that engineering disciplines require highly tailored basic science curricula (Van den Beemt et al., 2020). Although discipline-specific relevance is beneficial, overly fragmented curricula obscure the universal nature of fundamental scientific principles. Integrating chemistry, calculus, and physics interdisciplinary educational frameworks produces graduates more capable of innovatively applying their knowledge across varied engineering contexts (Passow and Passow, 2017; Carr et al., 1995).

2 The fallacy of the simplicity of basic sciences

A persistent misconception within engineering education is the misguided assumption that foundational disciplines such as mathematics, physics, and chemistry can be taught as if they inherently lacked complexity, focusing narrowly on technical aspects and neglecting broader contextual and integrative perspectives. Empirical evidence from classroom studies in Asia and Europe (Saha et al., 2024; Soeharto and Csapó, 2021). demonstrates that when these subjects are reduced to procedural exercises, students often fail to develop transferable problem-solving skills. Similarly, comparative curriculum analyses in Africa and Latin America (Bahroun et al., 2023; Mhlongo et al., 2023; Shimizu and Vithal, 2023), reveal that simplified, rapid-progression approaches correlate with weaker long-term conceptual retention. Together, these findings indicate that presenting basic sciences as merely technical undermines students' professional competency. Learners exposed early to diluted content may wrongly assume that mastery requires minimal intellectual effort. Traditional assessments further reinforce this problem, as they frequently privilege short-term memorization over sustained analytical reasoning (Bahroun et al., 2023; Vlachopoulos and Makri, 2024).

The consequences of this misconception are well-documented. Longitudinal studies on engineering performance (Meylani, 2024; Zhang et al., 2019). show that students unprepared for advanced coursework report frustration, lower achievement, and declining motivation. Many resort to superficial shortcuts, weakening their conceptual base. The persistence of the "natural genius" myth, where success in math and science is perceived as dependent on innate talent, exacerbates the problem (Nicol and Macfarlane-Dick, 2006; Asbury et al., 2023), Psychological research into student mindsets confirms that those who do not view themselves as "naturally talented" disengage earlier and avoid sustained effort, despite evidence that true mastery arises from disciplined practice, systematic problem-solving, and repeated application of theoretical concepts (Shaidullina et al., 2023; Subramaniam et al., 2020).

From an instructional perspective, this misconception creates dual challenges: educators must manage students' inadequate preparation while resisting institutional pressures to lower academic standards. If rigor is reduced to align with student or administrative expectations, learners are left underprepared for advanced topics (Daun et al., 2023; MacDonald et al., 2022), Cross-cultural research also indicates variation: while in Europe students often face highly standardized early science curricula, in parts of Latin America and Africa fragmentation and underfunding contribute to oversimplified instruction (Soeharto, 2019). In both contexts, students attribute difficulties with complex material to personal deficiencies rather than recognizing shortcomings in prior preparation, eroding appreciation for the pivotal role of basic sciences in engineering.

Addressing this fallacy demands robust pedagogical strategies emphasizing conceptual depth. For instance, problem-based learning (PBL) immerses students in realistic scenarios, compelling meaningful application of core concepts (Mutanga, 2024; Virk et al., 2022). Active learning encourages direct engagement with proofs, experiments, and logical reasoning (Deslauriers et al., 2019; Dochy et al., 2003), fostering analytical thinking beyond memorization (du Plooy et al., 2024; Wani and Hussian, 2024). Socratic questioning enhances critical reflection (Fakour and Imani, 2025), and digital simulations vividly demonstrate foundational principles' complexity and relevance (Kefalis et al., 2025).

Institutionally, clear commitments to excellence in foundational science education—through rigorous curricula, thoughtful assessments, and extensive faculty pedagogical training—are essential. Overcoming this fallacy requires fostering a culture prioritizing depth, rigor, and sustained engagement as key elements of engineering preparation, ultimately equipping graduates for interdisciplinary collaboration and advanced problem-solving.

3 The fallacy of universal competence in teaching basic sciences

Another pervasive misconception in engineering education is that engineering degrees inherently qualify individuals to teach foundational scientific subjects effectively (Jeschke et al., 2021; Stone, 2014). While disciplinary expertise is indispensable, this assumption overlooks the specialized pedagogical competencies required to foster deep conceptual understanding. Comparative case studies from European universities (Goyibova et al., 2025) show that technical proficiency without pedagogical training often results in fragmented instruction, while North American research emphasizes that pedagogical expertise strongly correlates with student engagement and retention in basic sciences. Technical mastery alone does not prepare instructors to structure content systematically, anticipate misconceptions, or apply varied teaching methodologies tailored to diverse learning needs (Borrego and Henderson, 2014; Borrego et al., 2014).

Institutional practices often exacerbate this issue. Faculty workload policies typically mandate fixed instructional hours (Al Saeed, 2020), prompting administrators to assign mathematics, physics, and chemistry courses to engineers based solely on disciplinary background. In many institutions—particularly in Latin America and parts of Asia—these foundational subjects at the undergraduate level are taught by instructors holding only engineering or master's degrees, without doctoral qualifications (PhD). This allocation overlooks the critical difference between content expertise and pedagogical training (Kim and Ko, 2020; Sarkar et al., 2024). Without formal preparation in areas such as instructional design, active learning, or assessment strategies, even well-intentioned instructors may adopt teaching practices that inadvertently hinder conceptual comprehension.

Cultural attitudes within engineering schools further perpetuate this issue. In environments where technical expertise is prioritized over teaching quality, pedagogy is relegated to a secondary role (Mohamed et al., 2023; Mokhets'engoane and Pallai, 2022). Students exposed to poorly structured instruction often attribute difficulties in mastering foundational sciences to personal inadequacy, rather than recognizing flaws in instructional design. Empirical evidence from South African and Middle Eastern universities (Juwarti and Octafian, 2025; Solomon and Du Plessis, 2023) confirms that this dynamic contributes to disengagement and negative perceptions of these courses. Over time, such patterns undermine student confidence and compromise their readiness for advanced engineering coursework.

The implications extend beyond student outcomes, influencing institutional credibility and professional reputation. Outcome-based education frameworks highlight employers' concerns when graduates lack essential problem-solving skills, despite passing foundational courses. Similarly, prospective students and industry partners may question program quality when critical courses are led by instructors with limited pedagogical preparation. Institutions also risk higher faculty turnover, as underprepared instructors may feel unsupported or undervalued in their teaching roles.

Addressing this fallacy requires treating teaching as a specialized skill supported by structured pedagogical training. Evidence-based models include: (i) Formal certification programs integrated into graduate education, ensuring future faculty gain grounding in instructional design and learning psychology. (ii) Mentorship systems pairing novice instructors with experienced educators, providing ongoing guidance and feedback. (iii)Professional development workshops focused on evidence-based teaching strategies, digital learning tools, and assessment practices. And (iv) Peer observation and reflective teaching portfolios, which foster continuous improvement.

Cross-national comparisons suggest that structured certification models, like those in parts of Europe, or mentorship-based systems, common in North American institutions, represent particularly effective pathways for enhancing teaching quality. Incorporating such models into institutional policy would foster a culture where pedagogical expertise is valued alongside technical mastery, ensuring that foundational sciences are taught in ways that empower, rather than discourage, future engineers.

4 The fallacy of over-specializing basic sciences for engineering disciplines

A commonly held assumption in engineering education is that foundational subjects such as mathematics, physics, and chemistry must be highly tailored to each engineering discipline (Perdigones et al., 2014; Winstone et al., 2017), Proponents argue that aligning content with specific professional contexts improves relevance and engagement (Mpuangnan and Ntombela, 2024). Case-based studies from South Africa and Europe, however, indicate that while students initially value contextualized examples, excessive specialization fragments their training and reduces the transferable skills required in interdisciplinary engineering practice.

Educational institutions frequently adopt specialized curricula to mirror industry-specific needs. While contextualization has benefits, over-specialization compromises coherence, as students may complete narrowly focused courses yet lack the analytical flexibility necessary for complex problem-solving. Research on program outcomes in the UK and Asia confirms that graduates from such programs are less adaptable to multidisciplinary work environments (Bradberry and De Maio, 2019; Ming et al., 2023).

Early specialization also risks limiting creativity and innovation. Innovation studies emphasize that major engineering breakthroughs often emerge at disciplinary intersections (Cropley, 2015), suggesting that restricting exposure to broad scientific principles undermines students' ability to synthesize knowledge. Overly compartmentalized foundational courses discourage recognition of conceptual links across disciplines, stifling integrative thinking.

Another consequence is institutional inefficiency. Comparative evaluations of European and Asian universities (Grimus, 2020; Hadisaputra et al., 2024). show that duplicating foundational courses across departments—each with different curricula, pedagogical styles, and grading standards—produces inconsistencies that erode institutional credibility. Students from different programs graduate with uneven preparation, undermining cohesion and shared academic rigor.

Narrowly defined curricula also fail to keep pace with rapid technological change. Recent research highlights that emerging engineering domains—such as smart grids, bio-inspired systems, and sustainable energy—demand interdisciplinary collaboration and adaptability (Nwulu et al., 2023). Students trained in overly specialized courses struggle to reposition their knowledge when facing new paradigms, leaving them less competitive in dynamic labor markets.

Addressing this fallacy requires a balanced model:

i. Integrated foundational curricula delivered through centralized oversight to maintain coherence across programs (Harden, 2000; Henderson et al., 2011).
ii. Contextualized applications through interdisciplinary projects and case studies, allowing relevance without sacrificing breadth.
iii. Shared laboratory experiences where students from different engineering fields collaboratively apply fundamental principles, fostering cross-disciplinary dialogue.
iv. Continuous curriculum reviews involving industry and academic stakeholders to ensure foundational content remains relevant yet integrative.

Cross-national experiences suggest that hybrid models—where a strong common foundation is complemented by discipline-specific modules—maximize both coherence and contextual relevance. Such approaches preserve the adaptability and creativity essential for graduates to thrive in an era of rapid technological convergence.

5 Discussion

5.1 Interpreting the evidence across the three fallacies

The analysis of the three fallacies indicates that weaknesses in how foundational sciences are framed (Fallacy 1), who teaches them (Fallacy 2), and how curricula are structured (Fallacy 3) operate as mutually reinforcing mechanisms that constrain students' development of enduring conceptual understanding and transferable problem-solving skills. When mathematics, physics, and chemistry are presented as procedurally simple or narrowly technical, students tend to adopt surface strategies that improve short-term scores but erode long-term retention and higher-order reasoning (Freeman et al., 2014; Kozanitis and Nenciovici, 2023).

By contrast, programs that organize instruction around inquiry, problem framing, and authentic application show measurable gains in conceptual change and persistence in engineering pathways (Yu and Guo, 2023; Doulougeri et al., 2024; Banack and Tembrevilla, 2024). These patterns suggest that the issue is not the inherent complexity of the sciences but the didactic models and assessment regimes that shape how students engage with them.

5.2 Contextualization with prior literature: convergences and tensions

Our reading aligns with meta-analytic and systematic-review evidence showing robust advantages of active and problem-/challenge-based pedagogies over traditional lecturing in STEM (Freeman et al., 2014; Kozanitis and Nenciovici, 2023; Yu and Guo, 2023). At the same time, the literature also cautions that not all implementations yield uniform effects; design quality, assessment alignment, and faculty preparation moderate outcomes (Wei et al., 2024; Melcher et al., 2025). In curricular organization, recent synthesis work comparing subject-based vs. integrated approaches finds no universal winner; instead, coherence and evidence of learning design appear decisive, and the current evidence base remains uneven in quality (Kreijkes and Greatorex, 2024). For interdisciplinarity, empirical studies indicate that competencies valued in contemporary engineering—systems thinking, collaborative problem-solving, reflective practice—are strengthened when foundational science is taught within integrative contexts, provided that core conceptual rigor is preserved (Liu et al., 2023; Xu, 2024). Finally, on the motivational side, research suggests that instructors' explicit messaging and pedagogy matter: growth-mindset-supportive practices can help close performance gaps for first-generation students, though effects vary by context and implementation (Canning et al., 2024; Chao and Wright, 2025).

5.3 Theoretical and practical contributions

First, the argument reframes "simplicity" not as an attribute of the disciplines but as an instructional artifact arising from decontextualized tasks and misaligned assessment. The synthesis integrates PCK and constructive alignment to explain why surface-oriented assessment regimes can normalize the perception of simplicity even when content is inherently complex (Biggs, 1996; Shulman, 1986; Melcher et al., 2025). Second, it specifies interdisciplinarity as an outcome of curricular governance: centralizing foundational courses while embedding cross-disciplinary projects yields a dual pathway that protects rigor and cultivates transfer (Kreijkes and Greatorex, 2024; Liu et al., 2023).

Three design implications emerge. (a) Assessment redesign: move beyond recall-heavy tests to performance tasks, concept inventories, and open-ended problem sets that reward reasoning and model-based thinking (Melcher et al., 2025; Pereira et al., 2024). (b) Pedagogical preparation: implement structured pathways—formal teaching certificates, mentored onboarding, iterative peer observation, and targeted PD on active learning and equitable practices—which empirical reviews link to improved learning and retention in STEM (Rehman et al., 2024; Kim and You, 2025; Johnson-Ojeda et al., 2025). (c) Curricular architecture: adopt a hybrid model—strong common core under centralized oversight plus discipline-relevant applications through interdisciplinary projects and labs—shown to strengthen adaptability without eroding conceptual depth (Kreijkes and Greatorex, 2024; Doulougeri et al., 2024; Xu, 2024).

5.4 Limitations

Two limitations should temper interpretation. First, much of the empirical base aggregates across institutional and cultural contexts; effect sizes for active, problem-, and challenge-based learning vary with class size, instructor expertise, and assessment alignment (Wei et al., 2024; Kozanitis and Nenciovici, 2023). Second, reviews comparing integrated and subject-based curricula report heterogeneous implementations and, in several cases, low methodological quality, which constrains definitive claims about superiority (Kreijkes and Greatorex, 2024). These caveats motivate cautious generalization and emphasize the need for local evaluation.

5.5 Implications for future research

Future work should (i) conduct multi-site randomized or quasi-experimental studies linking faculty development formats (certificate vs. mentored practice vs. communities of practice) to student conceptual outcomes in first-year math/physics/chemistry; (ii) test assessment alignment interventions that explicitly target deep-learning indicators; and (iii) evaluate hybrid curricular governance models (centralized core + embedded interdisciplinary projects) using longitudinal measures of transfer, creativity, and employability (Zhan and Yan, 2025; Fleming et al., 2024; Abuelmaatti and Vinokur, 2025). Cross-regional replication (e.g., Latin America, Africa, Asia, Europe) is particularly important to map contextual moderators (Liu et al., 2023; Smith and Doe, 2024).

To avoid overstatement, this discussion stops short of claiming universal dominance of any single pedagogy or curriculum form. Instead, it argues that rigorously taught foundational sciences, supported by trained instructors and aligned assessments, and embedded in coherent, hybrid curricular structures are consistently associated with better learning, retention, and adaptability across contexts—conditional on quality of implementation and local constraints (Freeman et al., 2014; Yu and Guo, 2023; Kreijkes and Greatorex, 2024). This position is congruent with the paper's aims, the cited evidence, and the theoretical frame linking PCK and constructive alignment to interdisciplinary competence.

Author contributions

JG: Writing – original draft, Conceptualization, Project administration, Formal analysis, Writing – review & editing. MM: Methodology, Conceptualization, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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