

Integrating Online Resources and Generative Artificial Intelligence in Pharmacology Education: Implications for Curriculum Design and Assessment in Higher Education

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Abstract

Digital resources and generative artificial intelligence (GenAI) are reshaping pharmacology education, yet adoption is often fragmented and insufficiently aligned with disciplinary learning outcomes. This narrative review synthesizes international evidence on online learning tools and GenAI in pharmacology and related health disciplines, informed by constructivism, cognitive load theory, and the Technological Pedagogical Content Knowledge framework. Literature was thematically analysed and contextualized within Irish higher education practice. Findings indicate that simulations and case-based digital resources enhance conceptual understanding and clinical reasoning when embedded within coherent pedagogy. GenAI offers opportunities for personalized practice and formative feedback but introduces risks related to accuracy, academic integrity, and cognitive offloading. In response, this paper proposes a discipline-informed framework aligning learning outcomes, pedagogy, assessment, and governance. The framework emphasizes authentic assessment, staff capability, and ethical oversight, offering transferable principles for safety-critical and professionally regulated disciplines navigating generative AI.

Keywords: Pharmacology education; digital learning; curriculum design; assessment; GenAI

1. Introduction

Pharmacology is a conceptually dense and clinically critical discipline that requires students to integrate molecular mechanisms with therapeutic decision-making. This creates pedagogical challenges including cognitive overload, fragmented knowledge transfer, and difficulty applying foundational science in clinical contexts. In response, digital learning resources such

as simulations, virtual laboratories, and case-based platforms have become increasingly embedded in pharmacology curricula, aiming to promote active learning and clinical reasoning.

More recently, generative artificial intelligence (GenAI) has emerged as a transformative educational technology, offering adaptive feedback, automated scenario generation, and personalized learning support. However, empirical guidance on its pedagogically sound integration remains limited, particularly in safety-critical disciplines such as pharmacology, where misinformation, superficial learning, and ethical governance present significant risks. This study addresses this gap through a narrative literature review examining how online resources and GenAI influence pharmacology education, with specific attention to curriculum design, digital pedagogy, and assessment. By synthesizing international evidence and situating findings within the Irish higher education context, this paper proposes a discipline-informed framework to guide responsible technology integration in pharmacology teaching.

2. Methods

A structured narrative review was conducted to synthesise evidence on digital technologies and generative AI in pharmacology and health professions education. Literature searches were performed in PubMed, Scopus, and Google Scholar using combinations of keywords including pharmacology education, digital learning, simulation, generative AI, and assessment. Searches were iterative and supplemented by reference tracking of relevant articles.

Inclusion criteria comprised peer-reviewed studies and scholarly literature published primarily between 2015 and 2025 that addressed (i) digital or simulation-based pharmacology education, (ii) generative AI in higher or health professions education, or (iii) curriculum design and assessment in pharmacology or related disciplines. Seminal theoretical works were included to provide conceptual grounding. Studies were excluded if they focused solely on technical AI development without educational application, addressed non-health disciplines without clear transferability, or lacked conceptual or methodological clarity.

Consistent with narrative review methodology, formal quality appraisal tools were not applied. Instead, sources were selected based on relevance, recency, and conceptual contribution. This approach allows flexibility in synthesising an emerging field but introduces limitations, including potential selection bias and reduced reproducibility. Findings were synthesised thematically across four domains: theoretical foundations, digital resources, generative AI, and curriculum and assessment.

3. Theoretical Framework

Digital transformation in pharmacology education must be grounded in learning theory (Figure 1). Constructivism emphasizes active knowledge construction through application and

reflection (Vygotsky & Cole, 1978). In pharmacology, this supports case-based learning and simulations where students apply mechanistic knowledge to therapeutic scenarios.

Connectivism extends constructivism into digitally networked environments, highlighting learning through external information sources and professional networks (Siemens, 2008). Cognitive Load Theory (Sweller, 1988) is especially relevant given pharmacology's intrinsic complexity; well-designed multimedia can reduce extraneous load and support schema development.

These perspectives are operationalised through the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which emphasizes alignment between disciplinary content, pedagogy, and technology.



Figure 1. Theoretical foundations for digital pharmacology education, illustrating the intersection of constructivism, connectivism, cognitive load theory, and TPACK in curriculum design.

4. Digital Resources and Generative AI in Pharmacology Education

Digital resources play a central role in contemporary pharmacology teaching, supporting active learning and clinical reasoning. Virtual laboratories and interactive simulations enable exploration of pharmacokinetics, pharmacodynamics, and receptor interactions in risk-free environments (Peeters, 2019; Rayamajhi et al., 2024). Three-dimensional molecular visualisation tools further support understanding of drug–target interactions, particularly in areas such as pharmacogenomics and structure-based drug design (Szarek et al., 2025).

Case-based e-learning modules provide clinically contextualised scenarios requiring integration of contraindications, comorbidities, and drug–drug interactions. These approaches enhance knowledge retention and support transfer to clinical reasoning (Baños et al., 2002; Edwards et al., 2019). Learning management systems underpin blended and flipped classroom models, combining asynchronous content with in-class application. Effective implementations emphasise interactivity, feedback, and clinical relevance (DiPiro et al., 2023).

Generative AI extends these digital approaches by enabling personalised learning, automated question generation, simulated patient cases, and adaptive feedback (Mir et al., 2023). In pharmacology, AI-generated scenarios can expose students to complex clinical situations such as polypharmacy and renal dosing, supporting preparation for practice (Richardson et al., 2020).

However, these opportunities are accompanied by significant risks. Large language models may generate inaccurate or outdated information, which is particularly problematic in a safety-critical discipline (Kasneci et al., 2023). Overreliance on AI may undermine independent reasoning and raise concerns regarding academic integrity. Additional challenges include lack of transparency, potential bias, and unclear accountability.

Current scholarship positions AI as an augmented learning partner rather than a replacement for disciplinary expertise (Wartman & Combs, 2018). Accordingly, its use should be carefully integrated within pedagogically aligned activities and supported by faculty oversight to ensure accuracy and maintain professional standards.

5. Curriculum design and Assessment

Backward design provides a useful framework for integrating technology, beginning with desired competencies such as interpreting pharmacokinetic data or managing adverse drug reactions (Cline et al., 2023; Wiggins & McTighe, 2005). Digital tools are then selected to support these outcomes (Table 1).

Table 1. Practical Recommendations for Educators and Institutions

Domain	Recommendation	Example
Curriculum	Align technology with learning outcomes	Simulation for PK/PD
Pedagogy	Prioritise active learning	Case-based scenarios
Assessment	Authentic, application based formats	Oral case defence, OSCE-style tasks
AI Use	Restrict to supervised formative use	AI-generated quizzes with faculty validation
Governance	Develop clear institutional AI policies	AI guidelines
Staff Development	Structured training	AI literacy workshops
Equity & Access	Ensure inclusive digital access	Universal Design for Learning principles

Blended learning is now common in pharmacology, with pre-class digital materials introducing core concepts and in-person sessions emphasizing application. Evidence indicates improved engagement and higher-order learning in such models (Aljaber et al., 2023; Lichvar et al., 2016).

Assessment must extend beyond factual recall to evaluate clinical reasoning. Digital tools enable authentic assessment through simulations and adaptive quizzes, while GenAI can personalize formative feedback (Zheng et al., 2022). However, AI also complicates academic integrity. Consequently, educators are increasingly adopting oral examinations, case-based assessments, reflective writing, and digital portfolios that emphasize justification and synthesis (Kassab et al., 2020).

To demonstrate the practical application of the framework, an extended example is presented. This illustrates how learning outcomes, pedagogy, digital technologies, and assessment can be aligned within a clinically relevant pharmacology context. The intended learning outcome is that students will safely prescribe anticoagulant therapy by integrating pharmacokinetic knowledge, patient-specific factors, and clinical guidelines.

In the pre-class phase, students engage with structured digital resources that introduce core concepts while managing cognitive load. These include interactive modules on coagulation pathways, concise video explanations of pharmacokinetics and dosing, and AI-supported formative quizzes providing immediate feedback. This stage supports schema development and prepares students for application-based learning.

In-class sessions focus on case-based learning to develop clinical reasoning. For example, students analyse a case involving an elderly patient with renal impairment and evaluate anticoagulant selection, dosing, and contraindications. Small-group discussion followed by facilitated debriefing enables students to justify decisions and engage in reflective dialogue.

Simulation-based learning extends this application through virtual patient scenarios in which conditions evolve dynamically, such as bleeding complications or drug interactions. Students must reassess treatment decisions in response to changing clinical information, supported by feedback from both the simulation environment and instructor guidance.

Assessment is aligned with learning outcomes and emphasises higher-order reasoning. Students complete oral case-based assessments requiring justification of therapeutic decisions, alongside reflective writing that supports critical evaluation of reasoning. Simulation-based assessment may also be used to evaluate applied competence, prioritising synthesis and application over recall.

Generative AI is integrated in a controlled manner to support learning, including the generation of additional case variations and formative feedback. All AI-generated outputs are reviewed by faculty to ensure accuracy and maintain disciplinary integrity.

Overall, this example demonstrates how the framework enables alignment between learning outcomes, pedagogy, technology, and assessment, supporting clinical reasoning while maintaining scientific rigour and ethical standards in pharmacology education.

6. Institutional Context: Ireland and the University Galway

Irish higher education has accelerated digital adoption following the COVID-19 pandemic, supported by national strategies promoting blended learning and staff upskilling. At the University of Galway, pharmacology is transitioning from predominantly lecture-based delivery toward case-oriented and blended approaches across medicine, pharmacy, and biomedical science programs.

While foundational infrastructure is established, systematic integration of advanced simulations and GenAI remains limited. Current AI use is largely informal and unsupported by institutional policy. Additional challenges include faculty confidence, alignment with Irish clinical guidelines, and digital equity.

Student feedback indicates strong interest in interactive learning formats, suggesting readiness for further innovation. Strategic investment, localised content development, and clear governance structures are required to realize this potential.

7. Discussion and Conclusion

Digital resources can enhance pharmacology education when integrated within a theory-informed, outcomes-aligned framework. Simulation-based and case-oriented approaches are particularly effective in supporting the application of mechanistic knowledge to clinically relevant scenarios, addressing the challenge of translating foundational science into practice. Blended learning further supports this integration by shifting content acquisition outside the classroom and prioritising in-class application.

Generative AI introduces opportunities for personalisation and feedback but also raises significant pedagogical and ethical concerns. In a safety-critical discipline such as pharmacology, risks related to misinformation, overreliance, and academic integrity are especially important. AI should therefore be positioned as a supplementary tool within structured, faculty-guided learning rather than an independent source of knowledge, with clear expectations regarding verification and accountability.

Assessment requires adaptation. Recall-based formats are increasingly vulnerable to AI-assisted completion and are limited in evaluating clinical reasoning. Greater emphasis on application-focused approaches, including oral examinations, case-based assessment, simulation, and reflective tasks, enables more valid assessment of higher-order cognitive skills while supporting academic integrity.

Effective implementation depends on institutional and educator readiness. Staff require development in digital pedagogy, simulation design, and AI literacy, while governance must

address ethical use, data reliability, and equitable access. Universal Design for Learning principles remain important to ensure inclusivity.

Although focused on pharmacology, these findings extend to other conceptually complex and professionally regulated disciplines, particularly those requiring integration of knowledge and applied decision-making.

Overall, digital resources and generative AI offer significant potential to support experiential learning and adaptive feedback. However, their value depends on integration within a discipline-informed framework that prioritises learning outcomes, authentic assessment, and ethical responsibility. Digital technologies should augment—rather than replace—critical thinking and professional judgement. Moving from incremental adoption toward strategic, institutionally supported integration will be critical to realising their full educational potential.

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