

Medical versus science students: Knowledge, perceptions and learning of core pharmacology concepts

Zina Alfahl^{1,2}  | Rachel Lynch³ | Cara O'Dwyer³ | John P. Kelly³

¹Antimicrobial Resistance and Microbial Ecology Group, School of Medicine, University of Galway, Galway, Ireland

²Centre for One Health, Ryan Institute, University of Galway, Galway, Ireland

³Discipline of Pharmacology, School of Pharmacy and Medical Sciences, University of Galway, Galway, Ireland

Correspondence

Antimicrobial Resistance and Microbial Ecology Group, School of Medicine, University of Galway, Galway, Ireland.

Email: zina.alfahl@universityofgalway.ie

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Aims: Pharmacology is a core discipline underpinning both medical and biomedical science education, essential for understanding drug action, safety and therapeutic efficacy. This study compared pharmacology knowledge, perceptions and learning experiences between second-year medical and science students to evaluate how effectively each curriculum supports acquisition of internationally defined core pharmacology concepts.

Methods: A mixed-methods design was employed, involving pre- and post-module surveys and curriculum mapping against the global pharmacology core concept framework. Quantitative data were analysed using chi-squared tests, while qualitative responses were evaluated thematically. Participants included students enrolled in MD214 Introduction to Pharmacology (medical) and PM208 Fundamental Concepts in Pharmacology (science) at the University of Galway.

Results: Medical students demonstrated stronger baseline and post-module understanding of pharmacokinetic and pharmacodynamic principles, particularly in applied pharmacokinetics such as drug–drug interactions and variability in drug response. Science students showed significant improvement over time, reflecting effective conceptual learning. Both cohorts reported positive perceptions of module relevance and teaching effectiveness (mean scores 7.7–8.9/10) and moderate to high confidence in mastering core concepts. YouTube and textbooks were the most common supplementary resources. Curriculum mapping showed alignment with 23 of 24 core concepts in the medical module and 20 in the science module.

Conclusions: Medical students exhibited greater initial competence and perceived relevance, whereas science students benefited substantially from targeted instruction. Findings highlight the value of concept-based, contextually integrated pharmacology teaching and support continued curriculum development guided by international core concept frameworks.

KEYWORDS

core concepts, curriculum development, medical education, pharmacology education, science students, undergraduate education

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1 | INTRODUCTION

Pharmacology is a cornerstone discipline in both medicine and biomedical sciences, requiring students to grasp the fundamental principles of pharmacodynamics (PD) and pharmacokinetics (PK) to support future clinical decision-making.¹ A solid understanding of drug action and adverse drug effects is essential for medical students as they progress towards prescribing roles and equally important for science students who may pursue research, pharmaceutical development or allied biomedical careers.² Insufficient knowledge in pharmacology has been linked to inappropriate prescribing, reduced therapeutic efficacy and patient safety concerns among new medical graduates.^{3,4} Despite its importance, concerns remain regarding the adequacy of pharmacology education across disciplines. Medical students often report feeling underprepared in safe and effective prescribing, suggesting persistent gaps in pharmacology teaching despite intensive curricula.^{3,5} Science students, in contrast, may receive a broader but less clinically contextualized exposure to pharmacology, which can make understanding complex PK and PD concepts particularly challenging.⁶ These differences raise questions about how effectively pharmacology teaching equips students in different programmes for their future professional roles.

Recent educational research has highlighted the value of core concepts in guiding curriculum design. Core concepts are defined as foundational, discipline-specific ideas that students must not only recall but also apply across contexts.⁷ For example, in physiology education, frameworks built around concepts such as homeostasis have transformed teaching and assessment, supporting deeper learning and transfer of knowledge.⁸ Similar efforts in pharmacology have recently culminated in the identification of global consensus 'core concepts' grouped into PD and PK domains, with the aim of standardizing and strengthening pharmacology education internationally.^{7,9} However, while the core concept framework provides an organizing structure, little empirical work has compared how effectively students in different disciplines acquire and apply these concepts. At the University of Galway, science students study pharmacology in PM208 Fundamental Concepts in Pharmacology module, while medical students complete MD214 Introduction to Pharmacology module. Both modules are 6-week, second-year modules, but they differ in focus: PM208 emphasizes theoretical biomedical underpinnings, whereas MD214 embeds pharmacology within a clinically oriented curriculum. Comparing these modules provides an opportunity to examine how students with different educational trajectories perceive and acquire pharmacology knowledge and how well existing teaching aligns with published core concepts. This study aims to compare the understanding of key pharmacology concepts between undergraduate medical and science students and to identify factors influencing differences in knowledge. Findings will be used to inform evidence-based teaching strategies that enhance learning outcomes and improve the effectiveness of pharmacology education across disciplines.

What is already known about this subject?

- Pharmacology education underpins safe and effective prescribing but differs substantially between medical and biomedical science programmes.
- International 'core concept' frameworks aim to standardize pharmacology teaching and promote clinical relevance.
- Comparative evidence on how these frameworks translate into learning outcomes across disciplines is limited.

What this study adds?

- Medical students demonstrate stronger baseline and post-module understanding of clinically applied pharmacokinetic and pharmacodynamic concepts.
- Science students achieve significant conceptual improvement through structured, targeted instruction.
- Embedding internationally defined core concepts enhances conceptual understanding, supports safer prescribing and strengthens integration between biomedical and clinical pharmacology education.

2 | METHODS

2.1 | Study design and ethics

This was a comparative, mixed-methods study conducted to evaluate pharmacology knowledge, perceptions and learning experiences among undergraduate medical and science students. Data were collected through pre- and post-module surveys containing both quantitative and qualitative items. In addition, module lecture materials were analysed to assess coverage of internationally defined pharmacology core concepts.

Ethical approval was obtained from the University of Galway Research Ethics Committee (REC ID: 2024.08.010). Participation was voluntary and no identifiable personal data were collected. Students were assured that their responses would remain confidential and would not impact their academic progression.

2.2 | Participants and setting

Participants were second-year undergraduate students enrolled in one of two pharmacology modules: PM208 Fundamental Concepts in Pharmacology (science students, $n = 250$) and MD214 Introduction

to Pharmacology (medical students, $n = 200$). The two student cohorts are enrolled in distinct programmes with differing curricular structures. Medical students follow a prescribed, clinically oriented curriculum with limited optionality, in which pharmacology forms a compulsory component of training towards prescribing competence. In contrast, science students are enrolled in a broader biomedical science programme, where pharmacology is one of several foundational disciplines and may not represent a sole or long-term area of specialization for all students. These structural differences may influence baseline knowledge, learning approaches and motivation. Both modules consisted of a 6-week block of teaching focused on PD and PK. All students attending the first and final lectures of each module were invited to participate.

2.3 | Survey instrument

Two paper-based surveys (Supporting Information) were developed for this study. Survey 1 was administered in Week 1 (start of module) and Survey 2 in Week 6 (end of module). Each survey took approximately 10 min to complete. Surveys were administered in person during scheduled lectures. The baseline survey (Survey 1) was completed at the beginning of the first lecture of the module to capture baseline knowledge and perceptions prior to any formal pharmacology teaching. The follow-up survey (Survey 2) was completed at the end of the final lecture to capture knowledge and perceptions following completion of the module. In-class administration was used to maximize response rates, as online survey participation in similar cohorts has been consistently low. While in-class survey administration increased participation and reduced attrition, it may have introduced limitations such as time pressure or social desirability bias; however, surveys were anonymous and participation was voluntary to mitigate these effects.

Both surveys included multiple-choice questions (MCQs) assessing pharmacology knowledge, in addition to MCQs used for demographic information. References to MCQs in Section 3 relate specifically to questions assessing pharmacology knowledge unless otherwise stated. Survey 1 comprised four sections: demographics (programme, gender, age group), prior learning to assess baseline pharmacology knowledge, perceptions of pharmacology and learning preferences, while Survey 2 comprised five sections: demographics, perceptions and experience with the pharmacology module, pharmacology knowledge, learning resources and suggestions for improvements and career relevance. Both surveys included MCQs and open-ended questions designed to capture qualitative insights.

2.4 | Data collection

Data collection was conducted between September and November 2024. Invitations were circulated via Canvas, the institute's Learning Management System. Completion of the survey was taken as implied consent.

2.5 | Curriculum mapping

The curriculum mapping was conducted using the consolidated set of 24 core pharmacology concepts described by White et al., which represents a global consensus framework that builds upon and refines the earlier core concepts proposed by Santiago et al. References to both publications are included to acknowledge the developmental progression of the core concepts initiative. Mapping decisions were therefore based on the harmonized framework presented by White et al., rather than parallel or independent application of both lists.

To assess alignment with internationally defined pharmacology core concepts, lecture materials from both modules were mapped against the 24 core concepts defined by Santiago et al. and White et al.^{7,9} Mapping was conducted independently by two researchers with expertise in pharmacology education. Each lecture was reviewed in full, and a core concept was recorded as present if it was explicitly addressed within the lecture content, either through direct explanation or applied examples. Following independent mapping, results were compared, and any discrepancies were resolved through discussion until consensus was achieved. This consensus-based approach was used to ensure consistency and transparency in mapping decisions across both modules. Inter-rater reliability statistics were not calculated, as the purpose of the mapping was descriptive rather than inferential.

Although one of the authors was involved in the international initiative that defined the pharmacology core concepts, it is important to acknowledge that the modules evaluated in this study were designed and delivered prior to the publication of the final core concept framework. As such, curriculum mapping was conducted retrospectively to describe alignment rather than to evaluate intentional curriculum modification. To minimize potential bias, mapping decisions were made independently by multiple researchers and resolved through consensus discussion.

2.6 | Data analysis

Two researchers (R.L. and C.O.) independently input the survey data into a structured Excel sheet, with discrepancies resolved through discussion until consensus was reached. Quantitative data from the survey were analysed using GraphPad Prism version 10. Frequencies and percentages were calculated for categorical variables. Pharmacology MCQ responses were classified as correct or incorrect, and changes over time were analysed using chi-squared tests (Fisher's exact test where appropriate). Comparisons between medical and science cohorts were also conducted.

Qualitative data from the open-text responses were analysed thematically. An integrated analytic approach was adopted: initial coding was guided by the survey domains (e.g., relevance, feedback), with additional themes emerging inductively from the data. Codes were organized into categories, and where appropriate, the frequency of occurrence for each category was calculated to provide a quantitative sense of prevalence. This integration of qualitative thematic analysis

with simple frequency counts reflects an approach that incorporates elements of content analysis. Emerging themes were refined through iterative review and discussion among the research team to ensure they accurately reflected the breadth of student perspectives. Representative quotations were selected to illustrate each theme. Percentages reported later in the results section refer to the proportion of participants whose responses contained each theme, thereby providing additional context to the thematic findings.

3 | RESULTS

3.1 | Participant characteristics

Overall, 176 science students (PM208) and 171 medical students (MD214) completed the baseline survey (Survey 1); follow-up responses for Survey 2 were reduced to 58 in PM208 and 121 in MD214. The reduction in follow-up responses reflects attendance at the final lecture rather than formal withdrawal from the study. Survey 1 was completed during the first lecture of the module, when attendance was high, whereas Survey 2 was completed during the final lecture, when attendance was lower due to competing academic commitments and scheduling constraints. This reduction was more pronounced in the science cohort. Demographic characteristics were broadly similar across cohorts, with most respondents (59%) aged between 20 and 24 years. A higher proportion of science and medical students were female (74% and 66%; respectively).

3.2 | Students prior learning

The survey included two questions addressing students' prior knowledge and previous coursework in pharmacology. Most students from both groups (81%) reported not having completed any prior coursework in pharmacology.

The open-ended question exploring what prior knowledge students felt would support them throughout the module was analysed thematically. The most common theme, reported by 38% of students, was a combination of chemistry and biology from their Leaving Certificate or first-year university studies. Chemistry alone accounted for 23% of responses, while 15% of students indicated prior pharmacology coursework or modules. Other themes included biology (8%), general science (7%), psychology (2%) and neuroscience (1%). These findings highlight that most students enter the module without formal pharmacology coursework, relying primarily on foundational knowledge in chemistry and biology.

Although most participants reported no prior formal coursework in pharmacology, the two cohorts differ in their broader educational backgrounds and entry pathways. Entry to the medical programme typically requires strong prior academic performance in chemistry and biology, and the cohort includes a proportion of students—particularly those entering via international or graduate pathways—who have already completed a prior degree. By second year, medical students

have also experienced clinically contextualized teaching and early exposure to patient-centred learning. In contrast, the science cohort represents a more mixed academic background, comprising primarily undergraduate students alongside a subset of postgraduate entrants, with training focused on foundational chemistry, biology and molecular sciences and limited exposure to clinical application. These contextual and cohort differences are important to consider when interpreting baseline knowledge and learning gains observed between groups.

3.3 | PD knowledge outcomes between medical and science students

The PD component of the surveys consisted of one open-ended question and two MCQs. The first PD question asked students to explain the mechanism of action of a bronchodilator. Thematic analysis revealed that the most common correct theme identified in Survey 1 was bronchodilation or widening of the airways, reported by 28% of PM208 compared to 47% of MD214 respondents. This increased in Survey 2 to 39% and 52% of PM208 and MD214 respondents, respectively.

For the second question, students were asked to identify the more potent drug based on a dose–response relationship graph. Science students demonstrated a significant improvement from 83% correct at baseline to 98% at follow-up ($p = 0.0004$). Medical students also improved, from 94% to 99%, although this difference was not statistically significant ($p = 0.1184$). Between cohorts, medical students outperformed science students at baseline ($p = 0.0249$), but no significant difference was observed at follow-up ($p > 0.05$). The greater relative improvement observed among science students likely reflects lower baseline exposure to applied pharmacological concepts, allowing for a larger measurable gain following structured instruction, whereas medical students demonstrated higher baseline performance with less scope for statistically significant improvement.

For the third question which focused on drug binding mechanisms, both cohorts performed well at baseline and no significant changes were observed at follow-up. Science students scored 91% at baseline and 92% at follow-up ($p > 0.05$), while medical students scored 96% at baseline and 97% at follow-up ($p > 0.05$). Between-group differences were not statistically significant at either timepoint ($p > 0.05$).

Overall, both groups demonstrated good foundational knowledge of PD concepts at baseline, with further improvements following the modules. Medical students showed a slightly stronger initial understanding, particularly in drug potency, but by Week 6 both cohorts performed at a comparable level.

3.4 | PK knowledge outcomes between medical and science students

The PK component of the surveys consisted of one open-ended question and two MCQs. The first questions focused on why insulin must

be injected rather than taken orally. Responses revealed that the most common and correct theme was that insulin is degraded in the gastrointestinal tract by acids or enzymes. At baseline, 24% of science students and 54% of medical students answered the correct answer. This increased slightly to 28% for science students and decreased to 41% for medical students ($p > 0.05$) by Week 6. The second most common theme in week one was 'faster/direct entry into the bloodstream', reported by 41% of science students and 23% of medical students; however, this decreased markedly by Week 6 to 9% and 3%.

The second PK question focused on interpreting a PK graph to identify how one drug affects the absorption, metabolism, half-life or elimination of another drug. Science students demonstrated a statistically significant improvement between Weeks 1 and 6 ($p = 0.0021$), whereas the change in medical students' responses was not statistically significant ($p > 0.05$). No significant difference was observed between science and medical students in Week 1 ($p > 0.05$); however, by Week 6, medical students performed significantly better ($p = 0.0002$).

The third PK question focused on gender differences in blood alcohol concentration. No significant difference in responses between Weeks 1 and 6 for science or medical students ($p > 0.05$). However, a statistically significant difference was observed between the groups in both Weeks 1 and 6 ($p < 0.0001$), with medical students consistently outperforming science students.

Overall, medical students consistently outperformed science students in PK knowledge, with significant differences observed in graph interpretation and gender-related PK questions. Science students showed improvement over time in one PK concept, while changes in other areas were not statistically significant.

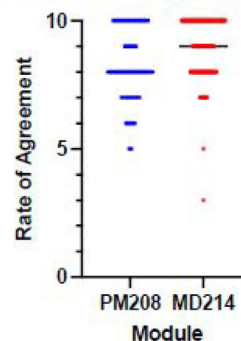
3.5 | Perceptions and experience with the pharmacology module

Survey 2 explored students' perceptions of the relevance of the module content and the effectiveness of the teaching methods. Students generally rated the module content as highly relevant to their future careers, with a mean agreement score of 8.2/10 for the PM208 and 8.9/10 for the MD214 as shown in Figure 1a. Agreement regarding the effectiveness of teaching methods was slightly lower but remained positive, with mean scores of 7.7/10 for PM208 and 8.2/10 for MD214 (Figure 1b). Overall, medical students rated both the relevance of the content and the effectiveness of teaching methods slightly higher than science students, suggesting a stronger perceived value of the module in relation to their future professional practice.

3.6 | Learning resources and suggestions for improvement

Students were asked to self-report their confidence following module completion, the supplementary learning resources they used to support their understanding of pharmacology, and their suggestions for improving the learning experience.

(A) The module content was relevant to my future career:



(B) The teaching methods used were effective:

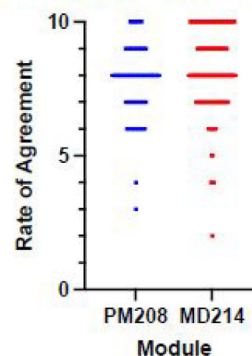


FIGURE 1 Student agreement ratings on (a) relevance of module content and (b) effectiveness of teaching methods for PM208 and MD214 modules.

3.6.1 | Level of confidence after module completion

As part of their overall learning experience, students were asked to report their level of confidence in having achieved the core pharmacology learning outcomes following completion of the module. Confidence levels in mastering the core concepts of pharmacology were generally positive across both cohorts. As shown in Figure 2, confidence levels were broadly similar between cohorts, with the majority of students in both groups reporting moderate to high confidence in achieving the intended learning outcomes following module completion. These results suggest a broadly consistent perception of competence between the two student groups upon module completion.

3.6.2 | Additional learning materials utilized

When asked about supplementary resources, YouTube videos were the most frequently cited additional learning tool, with 19% of PM208 students and 25% of MD214 students reporting their use. Textbooks were also a common resource referenced in student responses, highlighting the continued relevance of traditional learning materials in pharmacology education. Other resources mentioned

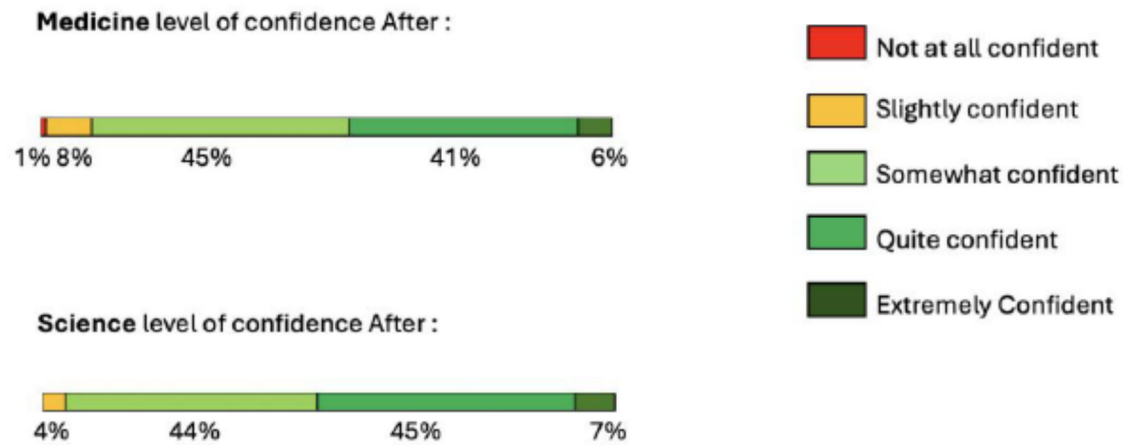


FIGURE 2 Students' self-reported confidence in having acquired core pharmacology concepts following completion of the PM208 (science) and MD214 (medicine) modules.

TABLE 1 Thematic analysis of supplementary learning resources reported by PM208 (science) students following completion of the module ($n = 58$).

Themes	Frequency (%)
No additional resources/missing items	23 (40%)
Textbooks	13 (22%)
YouTube videos	11 (19%)
Other tools (ChatGPT, Zoom, previous papers)	4 (7%)
Library resources	3 (5%)
Research databases	2 (3.5%)
Quizlet and other online study tools	2 (3.5)

TABLE 2 Thematic analysis of supplementary learning resources reported by MD214 (medical) students following completion of the module ($n = 121$).

Themes	Frequency (%)
No additional resources/missing items	38 (31%)
YouTube videos	30 (25%)
Online websites (e.g., DrugBank, Quizlet, Ninja Nerd, bootcamp)	17 (14%)
Textbooks	12 (10%)
Anki flashcards	10 (8%)
ChatGPT	7 (6%)
Peer/group learning	5 (4%)
Google	2 (2%)

included lecture notes, online articles, and question banks, indicating a diverse approach to independent learning (Tables 1 and 2). A small proportion of students in both cohorts reported using generative AI tools (e.g., ChatGPT) as supplementary learning resources, with slightly higher reporting among medical students (6%) compared to science students (7% reporting other tools including ChatGPT).

3.6.3 | Suggestions for improvement

Students from both cohorts provided constructive feedback on how the modules could be enhanced. The most reported suggestion across both groups was the inclusion of more interactive lectures to improve engagement and support deeper understanding of core pharmacology concepts. The addition of further practice questions was also frequently requested, reflecting a shared desire for greater opportunities to apply knowledge and consolidate learning.

While many suggestions overlapped, differences in emphasis were observed between cohorts. Science students more frequently highlighted the need for clearer organization of lecture content and greater integration of applied or clinically relevant examples to aid conceptual understanding. In contrast, medical students more often emphasized the value of revision-focused resources and question-based learning to support knowledge consolidation.

Despite these suggested improvements, both cohorts expressed substantial positive feedback regarding the quality of teaching and overall module experience, indicating high levels of satisfaction with content delivery while identifying opportunities for further enhancement through interactive and practice-based approaches.

3.7 | Mapped core concepts

The core pharmacology concepts identified in the introduction were systematically tracked throughout each module by reviewing lecture materials and marking concepts as they appeared. The medicine module (MD214) addressed 23 of the 24 core concepts, demonstrating comprehensive coverage, while the science module (PM208) addressed 20 of the 24 core concepts. This mapping highlights that both modules incorporate most key pharmacology concepts, with the medicine module providing slightly broader coverage. These findings suggest a strong alignment of module content with the intended core pharmacology framework, particularly in MD214 (Table 3).

TABLE 3 Mapping of internationally defined pharmacology core concepts to lecture content in the MD214 (medical) and PM208 (science) modules.

Core concept	Theme	MD214	PM208
CC1	Drug target	✓	✓
CC2	Drug–target interaction	✓	✓
CC3	Structure–activity relationship	✗	✗
CC4	Mechanism of drug action	✓	✓
CC5	Dose/concentration relationship	✓	✓
CC6	Drug affinity	✓	✓
CC7	Drug efficacy	✓	✓
CC8	Drug potency	✓	✓
CC9	Drug selectivity	✓	✓
CC10	Drug absorption	✓	✓
CC11	Drug bioavailability	✓	✓
CC12	Drug distribution	✓	✓
CC13	Volume of distribution	✓	✓
CC14	Drug metabolism	✓	✓
CC15	First- and zero-order kinetics	✓	✓
CC16	Drug elimination	✓	✓
CC17	Drug elimination half-life	✓	✓
CC18	Drug clearance	✓	✓
CC19	Steady-state concentration	✓	✓
CC20	Drug tolerance	✓	✗
CC21	Adverse drug reaction	✓	✗
CC22	Therapeutic index	✓	✗
CC23	Drug interaction	✓	✓
CC24	Individual variation in drug response	✓	✓

Note: Green ticks indicate concepts explicitly covered in lecture materials, while red crosses indicate concepts not identified. PD concepts are highlighted in yellow, PK concepts in orange.

4 | DISCUSSION

This study compared pharmacology knowledge, perceptions and learning experiences between undergraduate medical and science students at the University of Galway. The study provides an evidence-based comparison of how different educational contexts shape students' understanding of pharmacology core concepts. Overall, medical students demonstrated stronger initial and post-module understanding of both PD and PK principles and reported slightly higher satisfaction with teaching and perceived career relevance. However, both cohorts showed improvements across several knowledge domains, suggesting that the modules effectively reinforced core pharmacology principles despite differences in disciplinary focus.

Consistent with previous research, medical students outperformed science students in pharmacology knowledge, particularly in PK concepts involving interpretation of drug: drug interactions and variability in response.^{3,5,10,11} This may reflect the clinically contextualized nature of the MD214 module, which facilitates the application of pharmacology to real-world therapeutic scenarios, an approach shown to enhance retention and transfer of knowledge.^{10,12} In contrast, science students, who typically encounter pharmacology through theoretical or molecular frameworks, may have less

opportunity to connect pharmacological mechanisms with clinical implications, making some PK principles more abstract and challenging to master.

The improvement in science students' performance between baseline and week six, particularly in graph interpretation, suggests that targeted instruction and repeated exposure to applied PK content can effectively enhance conceptual understanding. These findings align with evidence that active learning and contextual examples support deeper conceptual grasp in pharmacology education.^{9,13} Both groups demonstrated strong baseline understanding of PD principles, such as drug potency and binding, indicating that these foundational topics are well-covered across curricula. Differences in programme structure and assessment context may also contribute to the observed learning patterns. Medical students progress through a tightly structured curriculum with consistent clinical framing and uniform progression requirements, whereas science students engage with pharmacology alongside multiple scientific disciplines and may have greater flexibility in future subject focus. As a result, motivation, perceived relevance and learning strategies may differ between cohorts, potentially influencing both baseline performance and learning gains. These contextual factors should be considered when interpreting comparative outcomes.

The majority of students started their module without prior formal coursework in pharmacology, relying primarily on basic chemistry and biology knowledge. Foundational knowledge in chemistry and biology was frequently cited as most beneficial, underscoring their role as cognitive scaffolds for learning pharmacological concepts such as drug–receptor interactions and metabolism.¹⁴ Differences in educational background and learning context may help explain the observed patterns in knowledge acquisition. Medical students demonstrated higher baseline performance, particularly in applied pharmacology questions, which may reflect earlier exposure to clinically contextualized teaching and integrative learning approaches. In contrast, science students, while strong in foundational scientific knowledge, may initially lack applied pharmacological frameworks. This could explain the greater relative improvement observed in science students for certain concepts, such as dose–response interpretation, once targeted pharmacology instruction was introduced. These results suggest the importance of explicit integration between early-stage bioscience education and later pharmacology modules to facilitate conceptual continuity.

Students across both cohorts reported positive perceptions of module relevance and teaching quality. The high mean agreement scores for both relevance and teaching effectiveness reflect strong student engagement and satisfaction. Similar findings have been reported in other studies, where interactive, clinically linked pharmacology teaching improved motivation and perceived value.^{5,15} Confidence levels post-module were moderate to high, with comparable patterns across cohorts, suggesting that both modules effectively enhanced self-assurance in core pharmacology concepts. Furthermore, medical students reported stronger agreement that the module aligned with their future career path compared to science students. This difference is not unexpected, as medical students typically follow a clearly defined professional trajectory in which pharmacology and prescribing competence are central. In contrast, science students often pursue a diverse range of career pathways, making it more difficult to assess the relevance of a single discipline to a specific future role. Differences in perceived relevance should therefore be interpreted considering these structural distinctions rather than as an indicator of differential educational value.

In terms of self-directed learning, students most frequently used YouTube videos and textbooks as supplementary resources. The prevalence of online learning tools mirrors global trends towards multimodal and digital learning in pharmacology.¹⁶ However, a notable proportion of students (31%–40%) reported using no additional resources, suggesting potential for better guidance on self-study strategies.

Students' qualitative feedback emphasized a desire for more interactive lectures and greater opportunities for practice questions. These preferences align with prior literature demonstrating that case-based discussions, quizzes and active learning techniques improve conceptual retention and engagement.¹⁷ Requests for increased clinical examples, particularly among science students, reinforce the value of context-based teaching to enhance relevance and knowledge transfer.

Curriculum mapping revealed that both modules covered the majority of internationally defined pharmacology core concepts.^{7,9} The MD214 module addressed 23 of 24 concepts, while PM208 covered 20, indicating substantial alignment with global recommendations. Notably, the missing concepts in PM208, tolerance, adverse drug reactions and therapeutic index, are clinically oriented, highlighting a potential gap in translational application within the science curriculum. Incorporating these areas could strengthen conceptual integration and prepare science students for advanced study or research involving pharmacotherapeutics. Notably, structure–activity relationships (SARs), a recognized core pharmacology concept, was not explicitly addressed in either the medical or science modules examined. While SARs are fundamental to understanding drug design and molecular interactions, their absence from both curricula may reflect the differing priorities of undergraduate pharmacology education, which often emphasizes PK, PD and therapeutic application over medicinal chemistry-focused concepts. This observation suggests that differences in core concept coverage may align not only with programme type but also with broader distinctions between scientific and clinical perspectives on what constitutes essential pharmacological knowledge. Such differences should be interpreted as reflections of curricular emphasis rather than deficiencies and highlight the flexibility required when applying core concept frameworks across diverse educational contexts. These findings underscore the need for balanced, concept-driven pharmacology curricula that bridge theoretical and clinical perspectives. Embedding the core concept framework across both science and medical programmes may enhance consistency and depth of learning. Furthermore, integrating digital tools, formative assessments and interactive pedagogy could further support student engagement and knowledge retention. Cross-disciplinary collaboration between medical and science educators may also facilitate shared resources and co-taught sessions that enhance conceptual understanding from multiple perspectives.

An emerging finding from the thematic analysis was the reported use of generative AI tools, such as ChatGPT, as supplementary learning resources by a small number of students in both cohorts. Although usage was not widespread and was not explored in depth in this study, this trend reflects broader shifts in student learning behaviours and the increasing integration of AI-assisted tools in higher education. Differences in reported use between cohorts may reflect variation in learning strategies, assessment demands or confidence in applying AI tools. Further research is warranted to examine how generative AI is used in pharmacology education, including its impact on conceptual understanding, self-directed learning and academic integrity.

More broadly, these findings should be considered within the evolving landscape of pharmacology education internationally. Ongoing concerns regarding prescribing competence among medical graduates, alongside increasing calls for concept-based and clinically integrated teaching, have prompted renewed focus on how pharmacology is taught across health and biomedical programmes. At the same time, biomedical science degrees serve diverse educational and career pathways, requiring curricula that balance foundational scientific understanding with applied relevance. The present study

illustrates how internationally defined core concepts can provide a shared framework to support coherence and comparability across disciplines, while still allowing for programme-specific emphasis. In this context, differences observed between cohorts are not deficiencies, but reflections of distinct educational missions and learning trajectories.

The study has several limitations. Firstly, the response rate for the follow-up survey was lower among science students, which may limit the generalizability of findings. This attrition may have reduced statistical power and limited the generalizability of post-module comparisons. However, the direction and magnitude of observed learning gains were consistent with baseline patterns and prior literature, suggesting that the main conclusions regarding differential baseline knowledge and learning trajectories remain robust. Secondly, while the survey captured short-term learning outcomes, it did not assess long-term retention or application of pharmacology knowledge. The reliance on self-reported confidence and perceptions also introduces potential response bias. Thirdly, the study did not formally capture detailed information on individual entry pathways, prior tertiary education (e.g., premedical training) or assessment pass marks, which may differ between medical and science programmes. These factors could influence student preparedness, motivation and engagement with pharmacology content. Future studies incorporating detailed academic background data and assessment context would allow more precise examination of how programme structure and entry routes shape pharmacology learning outcomes. Finally, prior educational exposure was self-reported and not formally quantified; therefore, differences in background learning context could not be directly controlled for and may have influenced baseline performance and learning gains.

5 | CONCLUSION

In summary, this study demonstrates that medical students show stronger pharmacology understanding, particularly in applied PK concepts, while science students benefit significantly from instructional exposure over time. Both groups reported high satisfaction with teaching and perceived relevance of pharmacology to their future careers. Curriculum mapping confirmed that both modules are well aligned with international core concept frameworks, though opportunities exist to strengthen clinically oriented content in the science module. These insights provide a foundation for refining pharmacology education across disciplines to promote integrated, concept-based learning and improved student preparedness for professional practice.

AUTHOR CONTRIBUTIONS

Conceptualization: Zina Alfahl and John P. Kelly. **Methodology:** Zina Alfahl and John P. Kelly. **Investigation:** Zina Alfahl and John P. Kelly. **Formal Analysis:** Zina Alfahl, Rachel Lynch, Cara O'Dwyer and John P. Kelly. **Writing—Original Draft:** Zina Alfahl. **Writing—Review & Editing:** Zina Alfahl and John P. Kelly. **Supervision:** Zina Alfahl and John P. Kelly. **Resources:** Zina Alfahl and John P. Kelly. **Visualization:** Zina Alfahl, Rachel Lynch, Cara O'Dwyer and John P. Kelly.

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AI and AI-assisted technologies were not used in the writing process for this manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data underlying this article are available in the article.

ORCID

Zina Alfahl  <https://orcid.org/0000-0002-9557-1732>

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