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Developing an international concept-based curriculum for pharmacology education: core concepts and concept inventories

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Abstract

Over recent years, studies have shown that science and health profession graduates have gaps in their fundamental pharmacology knowledge and the ability to apply pharmacology concepts in practice. This article reviews the current challenges faced by pharmacology educators, including the exponential growth in discipline knowledge and competition for curricular time. We then argue that pharmacology education should focus on essential concepts that enable students to develop beyond ‘know’ towards ‘know how to’. A concept-based approach will help educators prioritise and benchmark their pharmacology curriculum, facilitate integration of pharmacology with other disciplines in the curriculum, create alignment between universities, and improve the application of pharmacology knowledge to professional contexts such as safe prescribing practices. To achieve this, core concepts first need to be identified, unpacked, and methods for teaching and assessment using concept inventories developed. The International Society for Basic and Clinical Pharmacology Education Section (IUPHAR-Ed) Core Concepts in Pharmacology (CCP) initiative involves over 300 educators from the global pharmacology community. CCP has identified and defined the core concepts of pharmacology, together with key underpinning sub-concepts. To realise these benefits, pharmacology educators must identify, unpack, and develop methods to teach and assess core concepts. Work to develop concept inventories is ongoing, including the identification of student misconceptions of the core concepts and the creation of a bank of multiple-choice questions to assess student understanding. Future work aims to develop and validate materials and methods to help educators embed core concepts within curricula. Potential strategies that educators can use to overcome factors that inhibit adoption of core concepts are presented.

Introduction

A challenging time for pharmacology educators

This article focuses on the current challenges facing pharmacology educators across the globe as they try to develop and embed a strong pharmacology curriculum. New pharmacology educators face a backdrop of an ever-expanding knowledge base, interdisciplinarity pressure and the need to adapt pharmacology to fit multidisciplinary programmes, while simultaneously ensuring innovative and engaging delivery. We argue that concept-based curricula are a rational response to these challenges. We explore the development of concept-based curricula in other fields and discuss the development in this field to date, and consider the mutual benefits of this approach to pharmacology educators and future pharmacology graduates.

First and foremost, pharmacology educators must deal with the challenge posed by the ongoing inexorable increase in scientific disciplinary knowledge. Pharmacology graduates require an integrative comprehension of basic biological sciences such as biochemistry, physiology, and pathology, in addition to mathematical and physical sciences, to be adequately prepared for the modern-day workplace. They need to be able to combine this knowledge and integrate a substantial amount of information, as well as concepts about medicines and their uses into those fundamental conceptual frameworks. Finally, having completed each of these tasks, they must be able to apply the concepts of pharmacology and its underpinning disciplines in novel patient or medication-related contexts. The requisite body of knowledge has grown exponentially over the past century, and the resultant "*information overload*", entertainingly referred to as "curriculomegaly" by Guilbert [1], has exercised the minds of educators for many years [2]. It is unsurprising that this information glut has led to an overdependence on didactic teaching by academics and rote learning by students.

A range of strategies have been used to address this problem. The development of explicit core curricula has helped to define the knowledge that students require [3-5]. Student-centred approaches such as problem-based learning have been used extensively in medical education to change the focus from surface learning to application of knowledge in context. A move away from traditional information-transfer teaching and rote-learning studying to constructive study practices is occurring in some institutions [6]. These evidence-based initiatives have been highly effective [7] but can actually add to the challenge of finding sufficient *time-on-task,* given that learning-centred strategies themselves require a reduction in content in order to provide students with adequate time for both engagement and interaction.

Despite these important efforts, studies indicate that many current graduates lack fundamental pharmacological knowledge, particularly in the health professions [8]. Even though many fundamental pharmacology concepts have remained unchanged throughout the years [9, 10], they are frequently misunderstood by students when applying them in practice [11]. A study that assessed the pharmacology knowledge of medical and pharmacy students [12] found distinct knowledge gaps in these cohorts, including a deficit in "basic pharmacology knowledge" within the medical student cohort.

An additional challenge for pharmacology educators relates to their workplace context. With the rise in integration and amalgamation of dedicated pharmacology departments into broader higher education structures comes increasing complexity and the need to fit content into a shrinking curricular time allocation. This can lead to loss of the identity of one discipline in the quest to ensure broad coverage of a range of inter-linked disciplines [13]. These challenges are inter-related, increasing the degree of difficulty for potential solutions. Vallance and Smart [14] suggested that the consequences of this shift will be greater for pharmacology education and training than pharmacological research.

Further challenges exist for educators designing and customising pharmacology curricula for degree programmes across different student cohorts, including medical, dentistry, pharmacy, veterinary and nursing, science, and biomedical science degrees, and at undergraduate and postgraduate levels.

Given the aforementioned challenges, it is not surprising that novice educators struggle when designing foundational pharmacology courses. We argue that pharmacology educators should consider structuring "Pharmacology 101" courses around the big fundamental ideas of our discipline, namely the enduring core concepts that are required to solve problems and predict outcomes. We contend that this approach provides a conceptual framework within which new educators can help students harness the tools they will need as graduates who work with medicines. Such a move towards teaching the essential core curriculum, without oversubscribing content, is essential for students' ability to transfer the key pharmacology concepts into applied professional contexts such as safe prescribing practices and patient safety. Employing a concept-based curriculum (CBC) for teaching pharmacology would encourage educators to highlight interdisciplinary connections, helping students see the relevance and applications of core concepts of pharmacology in real-world contexts.

Core concepts and concept inventories in disciplines other than pharmacology – how have core concepts and concept inventories proven useful?

Progress and successes when adopting a concept-based curriculum approach have been most transformative in nursing education [15-17]. The broad notion of concept-based teaching is not new; in fact, concept-based curricula have existed for more than 60 years and originally focused on the development of complex thinking[18]. Instead of overwhelming students with an exhaustive list of topics leading to content saturation, a CBC concentrates on a limited number of essential concepts. This serves as the foundation upon which the subsequent learning is built, thus following the original 1960s theories of Ausubel [19], namely making learning more meaningful. Selecting the foundational 'stable' core concepts is a critical step when transitioning to CBC approaches in teaching.

A concept-based curriculum requires four major elements: identification and unpacking of the core concepts of the discipline; development of instruments to assess student attainment of core concepts (called concept inventories); validation of those inventories; and finally development of educator and student resources to enable attainment of the concepts.

Many other disciplines have identified and described underpinning core concepts. Over recent decades, fields such as physics [20], statistics [21], information technology [22], psychology [23, 24], physiology [25, 26], and microbiology [27, 28] have developed lists of core concepts and related assessments of concept attainment.

To assess student understanding of core concepts, concept inventories (CIs) are often used. While CIs are typically multiple-choice tests, and thus resemble traditional achievement tests, there are some crucial differences. Most importantly, the content and language CIs are developed on the basis of student thinking and incorporate student language and thinking", unlike the language of experts used in traditional achievement tests [29]. The beauty of the CI approach is that plausible distractors are based on student misconceptions or alternative conceptions and selecting any answer to the multiple-choice question (MCQ), be it correct or incorrect, provides the instructor with insight into the students' thinking [29]. Similar information could be obtained from interviews or essay questions; however, such methods are not always feasible in large classes and are less quantitative.

The Force Concept Inventory (FCI) was the first to be developed ([20]. This CI tests attainment of physics concepts, and continues to be used in physics education [30], and is now starting to incorporate learning from generative artificial intelligence [31]. CIs have been designed for many disciplines related to pharmacology including chemistry [32], biochemistry [33], and biology [34]. They can be used for a number of purposes such as pre-and post-testing student understanding before a teaching and learning activity, or to identify misconceptions so that teaching can be adjusted accordingly [35, 36]. Thus, CIs have led to improvements in education in physics and other STEM fields [37]. Given the benefits from core concept identification and assessment seen in other disciplines, a group of pharmacology educators are now working to deliver these outcomes. The remainder of this review focuses on this global initiative.

Establishing a global community of practice (CoP) for pharmacology

The International Society for Basic and Clinical Pharmacology Education Section (IUPHAR-Ed) has brought pharmacology educators together for over 30 years. Recently, there has been enormous growth in the level of international collaboration between pharmacology educators and the strategic nature of their work. The Pharmacology Education Project is perhaps the best exemplar of this community of practice [38]. The Pharmacology Education Project was developed as a simple, easily searchable, open-access website that contains an enormous range of curated, reliable pharmacology content for students, as well as instructors

Further advances in pharmacology education have been achieved through the pandemic-imposed flexibility and shift in global communication practices. In parallel with the move to online teaching, educators realised the potential for establishing a more inclusive approach to engagement and the widespread use of video conferencing capability promoted cross-continent research collaborations.

IUPHAR-Ed Core Concepts in Pharmacology (CCP) initiative.

Inspired by core concepts development in other disciplines, the pharmacology education community embarked on a project aimed at helping students master the most important concepts of pharmacology. In 2020, educators from Australia and New Zealand identified 20 core concepts of pharmacology education [39], which they then defined and unpacked [40]. The methodology and outcomes developed from this initial project provided a proof-of-principle that core concepts could be identified in pharmacology.

This work generated a conversation within the international pharmacology education community, including a session at the 2019 British Pharmacological Society meeting in Edinburgh. A seminal workshop amidst the pandemic in July 2021 set out some key objectives of the project:

> *This international project aims to transform pharmacology education by developing core concepts, a concept inventory, and education resources, to support students and educators in attaining the foundational principles of pharmacology.*

The workshop also tasked the first of many expert groups with a Delphi study to identify *"foundational pharmacology core concepts that all students who have taken a pharmacology course should understand and apply"*.

To generate outcomes relevant across the global community, an international Core Concepts of Pharmacology (CCP) project was formally established in late 2021 under the banner of the

IUPHAR-Ed (coreconceptspharmacology.org). The IUPHAR-Ed CCP project is ambitious, inclusive, and expansive. To date, over 300 educators from 23 countries across six continents have contributed. A research team consisting of 10-15 expert educators was established to design and oversee the project, and a series of expert groups were recruited to provide input at each stage of the project. The project design consists of four major outcomes; Core Concepts Development; Concept Inventory Development; Concept Inventory Validation; and Education Resource Development, each with sub-elements, as shown in Figure 1.

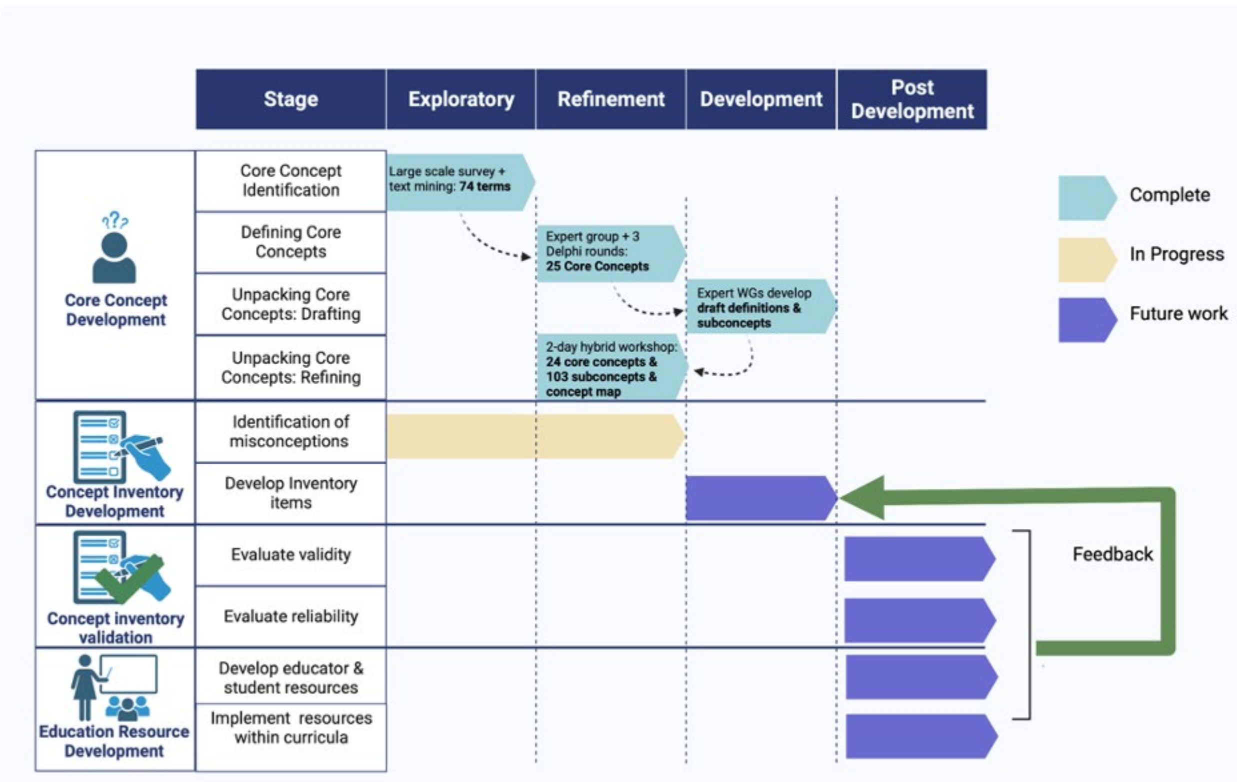

Figure 1: Core Concepts of Pharmacology Project Plan. The major outcomes of the project are shown on the left, and the columns indicate the stages involved in achieving those outcomes.

While depicted as linear, the process is iterative in nature. For example, the 'defining and unpacking' phase of the core concept development stage resulted in the change of the core concept 'drug-receptor interaction' to 'drug-target interaction', and the change of the core concept 'agonists and antagonists' to sub-concepts of 'drug-target interaction'. While the current framing of the project is 'foundational principles', we acknowledge there are many more layers to unpack as the knowledge base progresses into more complex pharmacology, potentially adding more sub-stages at each stage to explore advanced and threshold concepts in pharmacology.

Outcome 1. Core Concept Development (completed).

The first outcome, completed in 2022, was the identification of the core concepts that all students should remember and apply. To achieve this outcome, a research team designed and completed a study involving multiple sources of information and a wide range of expert opinions. The exploratory phase involved empirical data mining of the introductory sections of five key textbooks in parallel with an online survey of over 200 pharmacology educators from 17 countries across six continents, which resulted in a consolidated list of 74 candidate core concepts. The refinement phase involved three rounds of Delphi analysis involving 24 experts from 15 countries. Using five inclusion criteria, these experts produced a consensus list of 25 international core concepts of pharmacology education [41].

Next, the research team designed a Delphi process to produce definitions and unpack core concepts of the discipline [42]. In this study, 60 international pharmacology education experts worked in small groups to draft definitions for the core concepts and identify key sub-concepts via a series of online meetings and asynchronous work. These were refined in the second phase through a two-day hybrid workshop followed by an additional series of online meetings and asynchronous work. As part of the hybrid workshop, participants generated a set of concept maps to demonstrate the interconnectedness of the core concepts, which were then refined into a single overarching map (Figure 2) [43].

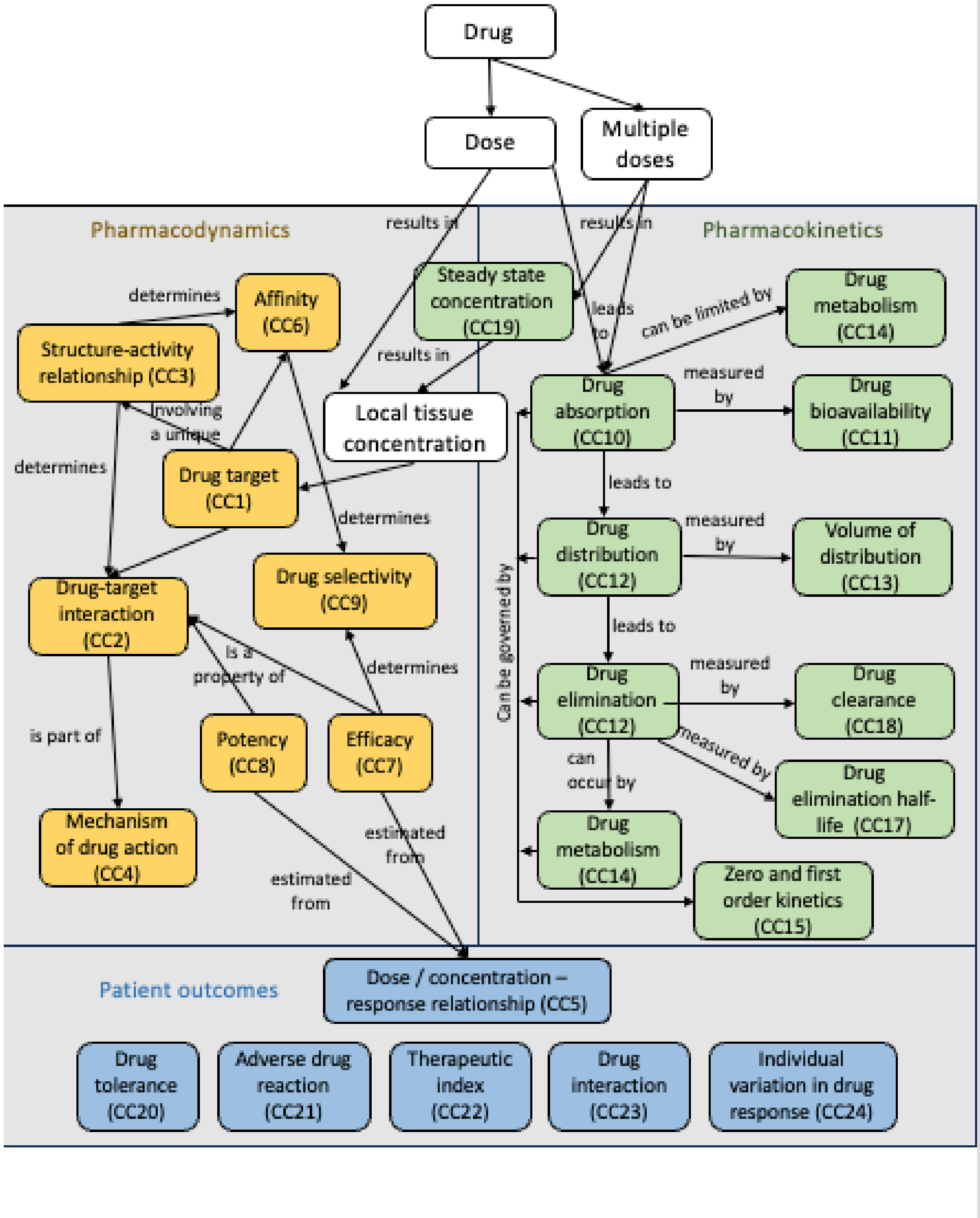

Figure 2. One example of a concept map showing the relationships between the core concepts of pharmacology. The concept of a drug is shown at the top, and following drug administration

there are pharmacokinetic (green) and pharmacodynamic (orange) parameters that determine the patient outcomes (blue).

Outcome 2. Concept Inventory Development (2023-2025).

A concept inventory is a validated instrument that uses multiple-choice questions to test student understanding and ability to apply a core concept. In 2023, the research team designed a process to produce two key datasets that will be used to construct the concept inventories that assess the core concepts of pharmacology. First, a study is currently underway to identify student misconceptions about each of the core concepts via student survey and interviews. Second, a multiple-choice question database has been established, which currently contains over 200 questions that assess one or more of the core concepts of pharmacology shown in Figure 2. These MCQs are currently being analysed. These two studies will provide MCQ stems that test students' ability to apply a core concept of pharmacology in a relevant context, with validated student misconceptions as distractors. Critically, the questions will not require recall of specific facts, rather the student will need to correctly apply the concept to solve a problem or predict an outcome.

Outcome 3. Concept Inventory Validation (2024/2025)

At this stage, the primary goal is to ensure the accuracy and effectiveness of the CI tools. This requires the application of standard validation and reliability methods to assess the items that represent the target content. Validity, one of the principal considerations, assesses the extent to which both evidence and theory support the interpretation of item scores for the intended purpose of the CI. It also determines the degree of confidence with which we can rely on the test results within specific circumstances [44]. Reliability is another essential component of the CI tool to ensure that the assessment consistently measures students' understanding of the targeted concepts. It determines whether the CI is functioning effectively. A properly functioning instrument generates consistent scores, with related items assessing the same construct, resulting in reliable and reproducible outcomes [45]. To achieve the accuracy and reproducibility of CI instruments, we will employ appropriate validation and reliability methods systematically, encompassing all relevant content and representing the target construct we aim to assess [46].

The validation process for CI instruments will integrate several psychometric properties, including content validity, construct validity, criterion validity, internal consistency, and reliability tests [45, 47]. Furthermore, item statistics, such as item difficulty and item discrimination, are integral to this process. These steps collectively contribute to a comprehensive and best-practice approach for CI development.

Outcome 4. Educator resource development and implementation of core concepts within curricula (2023-2026)

We will develop tools that help educators and curriculum developers embed core concepts within the curriculum and resources that can be used in teaching and learning. Given the importance of the core concepts in pharmacology, there will be instances in which educator and student resources aligned with these concepts already exist. We hope to facilitate the sharing of these resources through platforms and events during which educators can share existing resources. However, as was the case in physiology, we would also like to create resources that are tailor-made to support meaningful and active learning and help students to recognise, test and revise their current mental models [48]. Once these resources are created, we will need to validate them, which can be done using the Core Concept Inventories as an assessment tool.

In terms of curriculum development, many educators have already started and more will continue to embed the core concepts. Their experience will help guide the tools that we develop in this area. However, there will always be educators and curriculum developers who are reluctant to instigate change in the absence of evidence. Our role will be to identify factors that inhibit adoption of core concepts and use this information to develop tools that overcome such limitations. For those who want to get a head start on embedding the core concepts within their curriculum, we outline some potential strategies below.

Embedding Core Concepts within the Curriculum

Using the core concepts as the basis or cornerstone of a formal curriculum provides a theoretical framework for understanding how drugs work so that the learners will form connections with critical aspects of therapeutics. This could be particularly relevant within an integrated curriculum in which pharmacology does not appear as a separate discipline, creating the added risk that key concepts may be lost [49]. In this case, educators can thread core concepts throughout a structure based on organ systems and reinforced with many examples.

More broadly, though, any formal curriculum can be considered to include both explicit and hidden or implicit curriculum, with the latter also recognised as important [50]. Raising the core concepts of pharmacology from the hidden curriculum into the explicit curriculum may be one of the most important steps in helping ensure that students graduate with the required cognitive toolkit.

The move towards assessments focusing on understanding and applying knowledge rather than simple recall demonstrates the increasing value placed on higher-order thinking. In a health and life sciences course in The Netherlands, Wilhelmus and Drukarch [51] have shown that students tend to score better on ‘knows’ rather than ‘knows how’ questions and on pharmacodynamic rather than pharmacokinetics topics. It is tempting to speculate that a core concepts approach may help learners focus on application and understanding rather than rote memorisation of lists of drugs and their mechanisms, an idea articulated in the Vision and Change in Undergraduate Biology Education report [52].

Yet another way of thinking about curriculum is the Intended-Enacted-Experienced curriculum [53]. In this way of thinking, a core-concepts approach could be incorporated into the enacted part of the curriculum without any need to reform the formal or intended curriculum. In this case, the way the instructor enacts the curriculum, namely the way they explain the concepts and link them together, reflects the core concepts definitions. For example, using the core concept of drug target and then linking that to drug-target interactions and mechanism of action shows how these concepts are distinct but related, and this format could be illustrated with multiple examples (Table 2) of relevance to the cohort.

Table 2. Illustration of the relationship between certain core concepts shown with examples.

Drug	Drug target	Drug-target Interaction	Mechanism of action
Ipratropium	Muscarinic receptor	Competitive antagonism	In asthma, ipratropium antagonises the action of acetylcholine at muscarinic receptors in airways to reduce mucosal secretions.
Neostigmine	Acetylcholinesterase	Inhibitor	In myasthenia gravis: neostigmine inhibits acetylcholinesterase at the neuromuscular junction and reduces the breakdown of acetylcholine and the subsequent increase in synaptic acetylcholine concentration leads to increased muscle tone.

Pharmacology is included in a wide range of courses, including those for scientists training for the pharmaceutical industry and academic research, as well as health professions such as medicine, osteopathy, dentistry, veterinary science, pharmacy, nursing, midwifery, paramedics, physician assistants, podiatry, chiropractic, and dietetics. Some health professionals will go on to prescribe drugs, and these students will need additional knowledge about certain drug classes as well as the ability to apply clinical reasoning to real-world scenarios. By contrast, life scientists may focus more on the mechanistic detail or predicting potential drug targets' usefulness. Clearly, each of these groups will require teaching strategies that inspire engagement [54]. Nevertheless, the core concepts identified through this project could form the basis for all these courses.

It is important to consider how to make core concepts relevant and applicable for different student cohorts. This may involve using example drugs contextualised in case-based learning.

However, the approach may mean varying the levels of detail and distinct pedagogical approaches. For example, the core concept of structure-activity relationship (SAR) can be treated in a brief and fundamental manner, using the development of salbutamol from the chemical structure of adrenaline as an example, thus focusing on the clinical benefits of salbutamol over adrenaline. On the other hand, students potentially training for a career in drug discovery would require a greater understanding of structure-activity relationships, which could be obtained through more complex examples and the use of virtual reality or 3D computer simulations [55]. (Figure 3) shows an example of the adaptation of core concepts to specific teaching contexts.

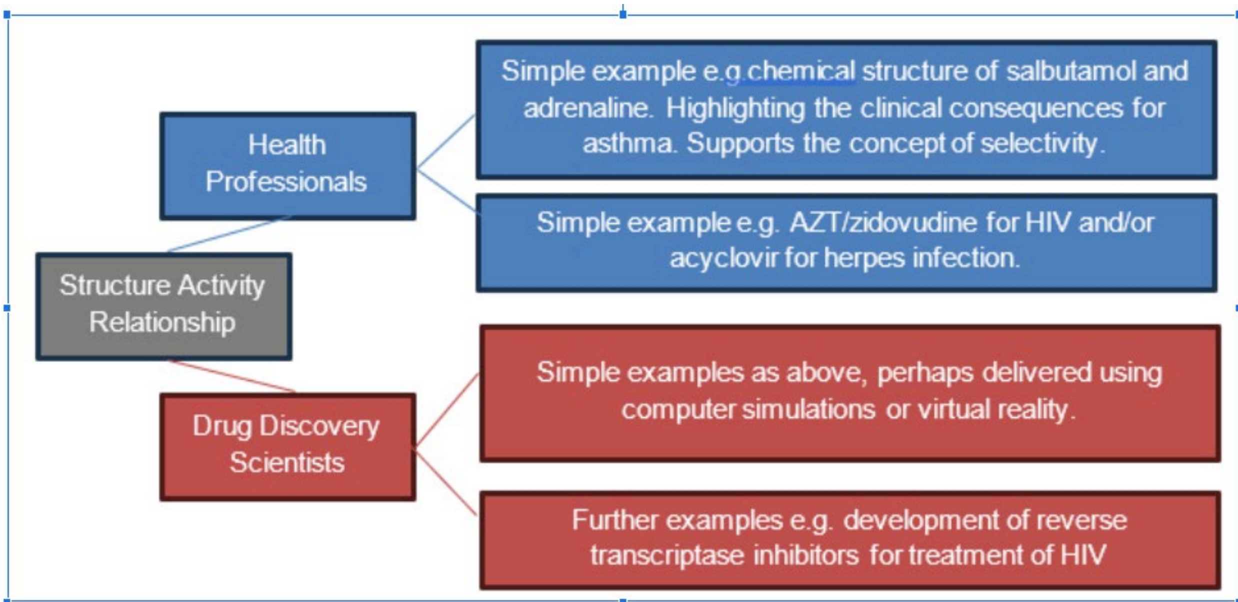

Figure 3. Adapting core concepts to cohort-specific teaching. An example of the different treatment of the core concept structure-activity relationships for health professionals and drug discovery scientists.

Conclusion

Core concepts and concept inventories have transformed the teaching, learning, assessment, and graduate outcomes of a multitude of STEM programmes. This review argues that it is time for a transformational change in pharmacology education. The combination of a rapidly expanding pharmacology knowledge base, an increase in integrated degree programmes, a decrease in stand-alone pharmacology departments, and the shift to more active and online learning, precipitate the need for development of core concepts and concept-based curricula in pharmacology education. The IUPHAR-Ed core concepts of pharmacology project is a global initiative working towards these goals.

Concept-based curricula can help to overcome some of the challenges educators face by providing a benchmark for student learning, with global standardisation of core pharmacology student knowledge attainment. This will support educators when prioritising the critical knowledge outcomes to focus on within their pharmacology curriculum. The establishment of a pharmacology concept inventory testing student depth of understanding and identifying misconceptions will assist students and educators to track learning outcome attainment. Continued engagement with the international community will ensure the collective development of globally relevant concepts and resources. This project has the potential to serve as a roadmap for educators to develop new and innovative curricular designs for pharmacology-related degree programmes.

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