



Contents lists available at ScienceDirect

## Exploratory Research in Clinical and Social Pharmacy

journal homepage: [www.elsevier.com/locate/rcsop](http://www.elsevier.com/locate/rcsop)

## Mapping Australian pharmacy school curricula for content related to pharmacogenomics

Maija-Liisa Venugopal<sup>a</sup>, Faith R. Yong<sup>a</sup>, Natalia Krzyzaniak<sup>a</sup>, Adam La Caze<sup>a</sup>, Christopher Freeman<sup>a,b,\*</sup><sup>a</sup> School of Pharmacy, Faculty of Health and Behavioural Sciences, The University of Queensland, Woolloongabba, QLD 4102, Australia<sup>b</sup> Metro North Hospital and Health Service, Herston, Australia

## ARTICLE INFO

## Keywords:

Pharmacogenomics  
Genetics  
Curriculum  
Education  
Pharmacy

## ABSTRACT

**Background:** Pharmacogenomics (PGx) is a rapidly growing field which promises to deliver personalized, more effective medications tailored to genetic information. Although the pharmacy profession is expected to lead the translation of pharmacogenomics into widespread clinical implementation, there is a reported lack of preparedness among its members. Assessing pharmacogenomic-related training in Australian pharmacy program curricula may highlight educational gaps and provide guidance for curricula revision.

**Objective:** To examine pharmacogenomic content in Australian tertiary pharmacy program curricula.

**Methods:** We reviewed the curriculum of 22 Australian registrable pharmacy degrees, including 16 Bachelors of Pharmacy programs (with or without honors) and six Masters of Pharmacy programs, for content related to pharmacogenomics and genetics. This was done by screening the publicly available electronic course profiles on each institution's website and searching for key terms such as "pharmacogenomics," "pharmacogenetics," "genes," and "genetics". Three mapping activities were completed to assess the breadth and depth of pharmacogenomic training according to; 1. Bloom's taxonomy, 2. Author-assigned domains comprising; Enabling science, Translational science and Clinical implementation, and 3. Pharmacogenomic competencies from the National Human Genome Research Institute (NHGRI).

**Results:** A total of 18 (82%) pharmacy registrable degree programs incorporated pharmacogenomics and/or genetics in their curricula. Four programs (18%) offered standalone PGx courses and 10 (45%) contained integrated PGx content in other science-related courses (i.e. pharmaceutical biology, biochemistry, microbiology etc.). Mapping activities showed that most learning objectives related to the "Understand" level of Bloom's taxonomy (61%), the "Basic Genetic Concepts" domain of NHGRI's competencies (64%) and "Enabling science" (84%).

**Conclusions:** Most Australian pharmacy registrable degrees have incorporated pharmacogenomic content in their curricula however, the scope of training is limited. Revisions to course curricula should be made to incorporate additional education with a focus on application-based training of clinical pharmacogenomics.

## 1. Introduction

The field of pharmacogenomics (PGx) is an important branch of precision medicine which aims to study the relationship between genes and drug response.<sup>1</sup> An increasing number of prescribers are opting to use pharmacogenomic tests to tailor dose and drug selection based on genetic information; genetic tests are thought to lead to safer, more effective treatment and decrease overall healthcare costs.<sup>2</sup> The Clinical Pharmacogenomic Implementation Consortium (CPIC) and the pharmacogenomics knowledgebase (PharmGBK) websites facilitate the use of these tests by providing evidence-based guidelines which aid the interpretation of genetic data and by offering practical recommendations for drug and dose adjustments.<sup>3</sup> Currently, pharmacogenomic tests analyse genes related to approximately 40 known drug-metabolising enzymes and can provide

metabolic information on a wide range of drug classes including; anti-depressants, opioids, anti-inflammatory analgesics, antibiotics, antivirals and antineoplastic medicines among others. Although evidence suggests pharmacogenomic testing will become more prevalent in the future, widespread implementation has been slow.<sup>4</sup> Major barriers to its adoption into clinical care include at the forefront, inadequate evidence to prove its clinical utility, and a lack of education and experience among prescribers, as well as the cost of the test to the patient.<sup>4</sup> Pharmacists have an extensive knowledge of pharmacokinetics and pharmacodynamics, which can be influenced by genetic differences. Thus, pharmacists may be well positioned to implement PGx services during patient consultation and medication management reviews within the community, particularly as evidence regarding the clinical utility of pharmacogenomic tests increases.<sup>5</sup> Since pharmacists also serve as educators to the public and health professionals,

\* Corresponding author.

E-mail address: [c.freeman4@uq.edu.au](mailto:c.freeman4@uq.edu.au) (C. Freeman).<http://dx.doi.org/10.1016/j.rcsop.2022.100192>

Received 28 April 2022; Received in revised form 5 October 2022; Accepted 8 October 2022

Available online xxx

2667-2766/© 2022 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

they are thus ideally located in the health ecosystem to share knowledge of pharmacogenomics for routine use.<sup>5</sup> However, the preparedness of healthcare providers (including pharmacists) to implement PGx services may be limited.<sup>6,7</sup>

There is ongoing awareness of the need to improve pharmacogenomic-related training in pharmacy degrees. The American Society of Health-System Pharmacists (ASHP) believe pharmacists hold a fundamental responsibility to spearhead the translation of pharmacogenomics into clinical care.<sup>8</sup> McMahon and Tucci (2011) surveyed a group of pharmacists from Victoria, Australia, to assess self-perceived knowledge of clinical pharmacogenomics and found that while respondents agreed that pharmacogenomics is an important part of current and future practice, many consistently report feeling ill-prepared to recommend and conduct pharmacogenomic tests.<sup>9</sup> A more recent investigation, conducted in the United States (US) by Coriolan et al. (2019), found only a minority of pharmacy students who participated in the study perceived pharmacogenomics to be a relevant part of their education.<sup>10</sup>

The Australian Pharmacy Council (APC), the accrediting body for pharmacy programs across New Zealand and Australia, does not list pharmacogenomics in their accreditation standards.<sup>11</sup> There are also no Australian-specific pharmacogenomic guidelines in place for students and practicing pharmacists. However, in 2016, the United States' National Human Genome Research Institute (NHGRI) published a list of 15 pharmacogenomic competencies for pharmacists (see Table 2).<sup>12</sup> The stated goal for these NHGRI competencies, when implemented into program curricula, was to ensure that pharmacy students are “practice-ready” with regard to integrating pharmacogenomics in their practice, upon graduation.<sup>12</sup> Adoption of these professional competency standards were expected to provide learners in US pharmacy degrees with the appropriate knowledge and skills to confidently conduct pharmacogenomic tests in practice.<sup>12</sup> It is unknown whether Australian pharmacy education similarly prepares the future pharmacist workforce.

## 2. Objectives

1. Determine the number of Australian registrable pharmacy degrees which have included pharmacogenomic-related content in their curricula; and
2. Analyse and assess the associated breadth and depth of PGx training in Australian registrable pharmacy course learning objectives.

## 3. Methods

In this study, we used curriculum mapping to examine current pharmacogenomic education in Australian in registrable pharmacy degrees.

Curriculum mapping is an established pedagogical methodology in secondary and tertiary education to focus on the organisation of curricula and learning patterns throughout programs of study,<sup>13,14</sup> and to explore what content is taught and actually learned in courses, among other outcomes. It has multidisciplinary use (e.g. medical, education, biology) to identify gaps in competencies being taught.<sup>14</sup> Curriculum mapping has been used in preliminary studies to facilitate the inclusion of specific topics into strategic planning for formal medical education such as palliative care and cultural competency,<sup>15,16</sup> and has been recommended for use in pharmacy education.<sup>17</sup> Curriculum mapping can be approached in several different ways for different purposes, for example, in collaborative curriculum mapping in teaching teams to improve gaps between what students actually learn and what teachers are teaching.<sup>14,18–21</sup> Whilst curriculum mapping normally involves multiple types of data collection from students and teachers, we used the method for a preliminary exercise to establish PGx content currently being taught as well as to identify gaps in PGx competencies in

pharmacy courses in Australia. Within Australia, there are currently 22 pharmacy registrable degree programs accredited by APC. This includes 16 Bachelor of Pharmacy programs (with or without honors) and 6 Masters of Pharmacy programs.<sup>22</sup> We reviewed each program's curricula in 2021 for content related to pharmacogenomics by extracting the publicly available course profiles on each institution's website (step 1 – see Fig. 1). All mapping activities were conducted between March–July 2021. The NHGRI competencies current at February 2021 were used in this study.<sup>23</sup>

Pharmacogenomic and genetic content was identified by manually searching for key terms such as “pharmacogenomics,” “pharmacogenetics,” “genes” and “genetics.” For each course profile which included these keywords, the following data was extracted: the institutions name, course title, course description/syllabus; whether the course was an elective or part of core curricula; and relevant PGx learning outcomes, activities and assessments. See Appendix 2 for the sample data extraction form. Only course profiles current in 2021 were included. Where available, the number of assessments and learning activities which related to genetic and pharmacogenomic learning objectives were recorded. Learning activities and assessments were only recorded if they were explicitly linked to pharmacogenomic-related learning objectives.

Pharmacy programs were then categorised into four groups: “standalone pharmacogenomics” and “standalone genetics” (if the relevant focus was primarily pharmacogenomics or genetics), or “integrated pharmacogenomics” and “integrated genetics” (if pharmacogenetics or genetics content was integrated into other topics). Pharmacy programs which did not provide public access to course profiles were not included in the study. If a course was offered at multiple locations and the course profile was the same, only data from the primary campus location was extracted.

To assess the scope of pharmacogenomic-related content, one author (\*) extracted learning objectives identified in the course profile screening (step 2). To focus analysis on pharmacogenomics and genetics, broader learning objectives were removed (i.e. learning objectives related to microbiology, chemistry, or pathophysiology of disease). Details about assessments (e.g. essays, exams), learning activities (e.g. tutorials, lectures) and other modes of content delivery (e.g. online modules) were also extracted.

Three mapping activities were completed to analyse the learning objectives, learning activities and assessments in respect to PGx (step 3).

### 3.1. Mapping activity 1: bloom's taxonomy

The first mapping activity entailed categorising learning objectives according to the revised version of Bloom's Taxonomy, a widely known hierarchical model which is used to structure effective learning objectives, assessments and learning activities.<sup>24</sup> The revised version of Bloom's taxonomy presents two dimensions: Knowledge, and Cognitive Process (Remember, Understand, Apply, Analyse, Evaluate and Create).<sup>24</sup> (See Fig. 2) The Cognitive dimension comprises six levels focussing on educational proficiencies, which span from basic memorisation to critical evaluation and creation. Within the Knowledge dimension are four categories: factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge.<sup>25</sup>

Bloom's Taxonomy's revised list of measurable verbs were used to help classify each learning objective into the correct cognitive category.<sup>26</sup>

The knowledge domains were categorised by (\*\*) and (\*\*\*) independently according to Krathwohl's definitions.<sup>25</sup> Basic knowledge (e.g. DNA structure) was classed as ‘factual knowledge’, and concepts that required groups of basic knowledge to comprehend (e.g. how genetics play a role in human disease) were classed as ‘conceptual knowledge’. ‘Procedural knowledge’ included skills and tasks that pharmacists versed in pharmacogenomics would be able to complete (e.g. communicating

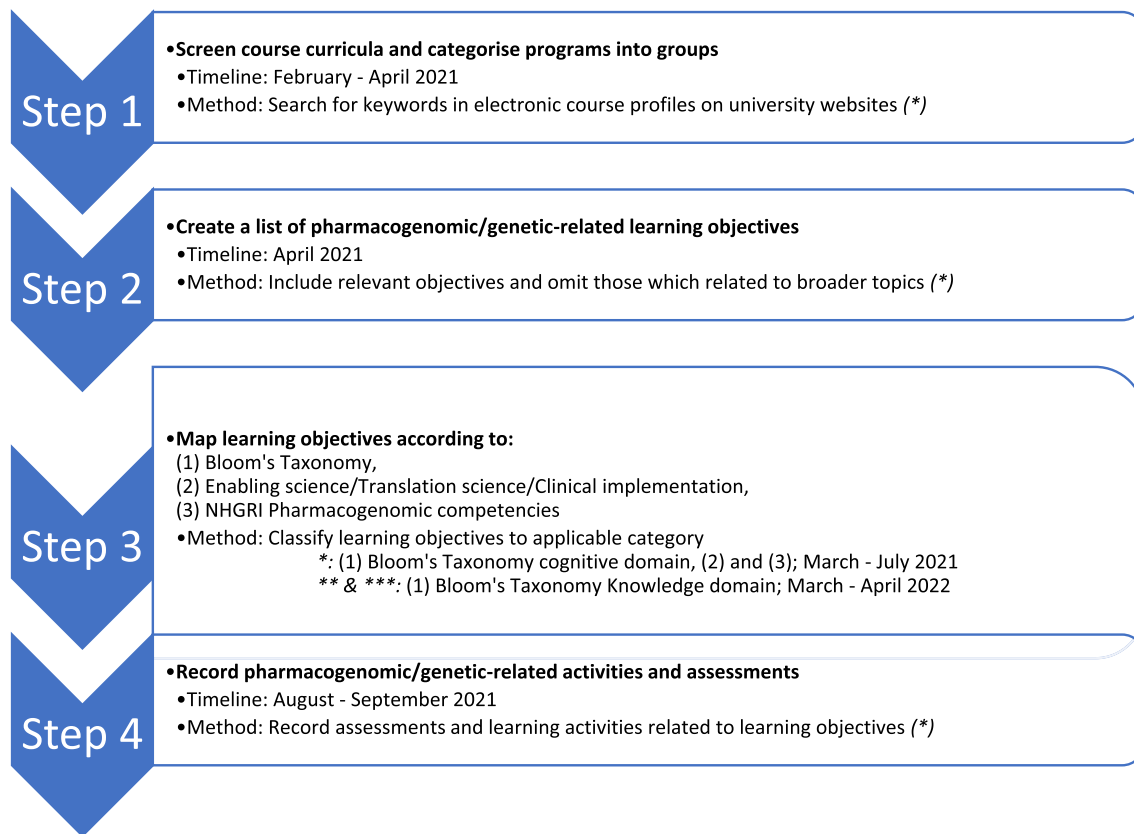


Fig. 1. Flow map of data analysis: a visual summary of the steps taken to analyse pharmacogenomics and genetic-related content in Australian pharmacy degree curricula.

familiarity with ethical arguments in the use of pharmacogenomics). ‘Metacognitive knowledge’, in the context of pharmacists and pharmacogenomics, was assigned to learning objectives related to self-awareness in the context of the health system and their working environment, and knowledge about cognitive tasks and their context (e.g. ‘working ethically, responsibly, autonomously and reflexively as a learner and as a scientist’). This coding was discussed by (\*\*) and (\*\*\*) after independent coding, until consensus was reached.

3.2. Mapping activity 2: author-assigned domains

For the second mapping activity, the learning objectives were categorised by two authors (\*\* and \*\*\*) into three author-assigned domains – Enabling Science, Translational Science and Clinical Implementation. Enabling Science was defined as content focused on the understanding of foundational pharmacogenomic and genetic concepts, Translational Science was content considered to be directed at the development of skills that can be applied in practice situations, and Clinical Implementation was described as an advanced level of knowledge and skill, enabling the effective application of pharmacogenomics into clinical settings. This mapping activity was done to further understanding of the level of PGx training in pharmacy degree curricula.

3.3. Mapping activity 3: NHGRI competencies

Lastly, the third mapping activity aimed to identify gaps in curriculum design. Australian pharmacy program learning objectives were matched to PGx competencies outlined by the NHGRI by two authors (\*\*\*\* and \*\*\*\*\*). The four relevant NHGRI subdomains (see Table 2) were: Basic Genetic Concepts, Genetics and Disease, Pharmacogenetics/Pharmacogenomics, and Ethical, Legal, and Social Implications (ELSI).<sup>12</sup>

A summary of the analysis process is depicted in Fig. 1.

4. Results

Of the 22 accredited registrable pharmacy degree programs in Australia, 18 (82%) programs comprising 44 courses were found to contain pharmacogenomic- or genetics-related content in their course profiles and were included in our analysis. A total of 4 universities were excluded from the analysis as they did not have course information accessible on a

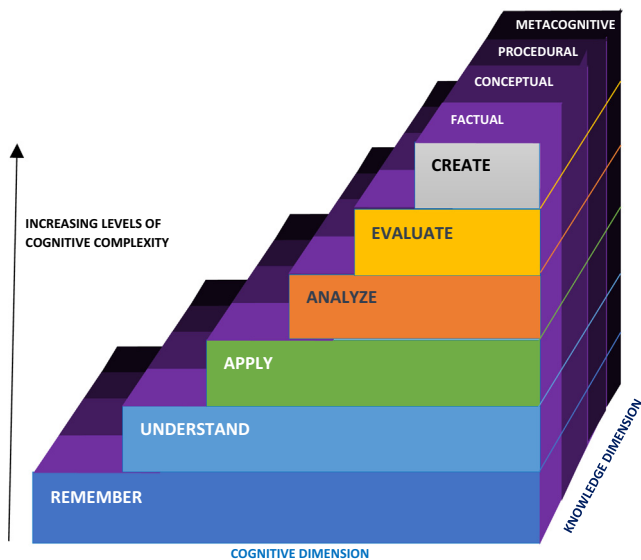


Fig. 2. Visualisation of the revised Bloom's Taxonomy hierarchy, adapted from Krathwohl 2002<sup>25</sup>.

**Table 1**  
Summary of Australian pharmacy degrees with pharmacogenomic- or genetics-related content.

Australian pharmacy degree	Number of courses
Standalone PGx course, n = 4	
Charles Darwin University	1
James Cook University	1
University of Newcastle	1
University of Technology Sydney (Masters)	1
Integrated PGx content, n = 12	
Charles Sturt University	1
Griffith University	1
La Trobe University	3
Queensland University of Technology	1
RMIT University	1
University of Sydney	1
University of Tasmania	1
University of Technology Sydney (Masters)	1
Curtin University (Masters)	1
University of Sydney (Masters)	1
Standalone genetics course, n = 4	
Charles Sturt University	1
Griffith University	1
University of Newcastle	1
University of Queensland	1
Integrated genetics content, n = 24	
Charles Sturt University	3
Curtin University	1
James Cook University	1
La Trobe University	1
RMIT University	1
University of Canberra	3
University of Newcastle	1
University of New England	5
University of South Australia	3
University of Sydney	2
University of Tasmania	1
Curtin University (Masters)	1
University of Queensland	1

**Table 2**  
Number of NHGRI competencies fulfilled by learning objectives.

NHGRI competencies	Number of learning objectives
Basic Genetic Concepts	
(B1) To demonstrate an understanding of the basic genetic and genomic concepts and nomenclature.	45
(B2) To recognize and appreciate the role of behavioural, social, and environmental factors (lifestyle, socioeconomic factors, pollutants, etc.) to modify or influence genetics in the manifestation of disease.	1
(B3) To identify drug- and disease-associated genetic variations that facilitate development of prevention, diagnosis, and treatment strategies; to appreciate differences in testing methodologies and the need to explore these differences in drug literature evaluation.	–
(B4) To use family history (minimum of 3 generations) in assessing predisposition to disease and selection of drug treatment.	–
Genetics and Diseases	
(G1) To understand the role of genetic factors in maintaining health and preventing disease.	8
(G2) To assess the difference between clinical diagnosis of disease and identification of genetic predisposition to disease (genetic variation is not strictly correlated with disease manifestation).	–
(G3) To appreciate that pharmacogenomic testing may also reveal certain genetic disease predispositions (e.g., Apo E4 polymorphism).	–
Pharmacogenetic/Pharmacogenomics	
(P1) To demonstrate an understanding of how genetic variation in a large number of proteins (e.g., drug transporters, metabolising enzymes, receptor targets) influence pharmacokinetics and pharmacodynamics related to pharmacologic effect and drug response.	13
(P2) To understand the influence of ethnicity in genetic polymorphisms and associations of polymorphisms with drug response.	–
(P3) Recognize the availability of evidence-based guidelines that synthesize information relevant to genomic and pharmacogenomic tests and selection of drug therapy (e.g., Clinical Pharmacogenetics Implementation Consortium).	–
Ethical, Legal and Social Implications	
(E1) To understand the potential physical and psychosocial benefits, limitations and risk of pharmacogenetic and pharmacogenomic information for individuals, family members, and communities, especially with pharmacogenetic and pharmacogenomic tests that may relate to predisposition to disease.	3
(E2) To understand the increased liability that accompanies access to detailed genomic patient information and maintain their confidentiality and security.	2
(E3) To adopt a culturally sensitive and ethical approach to patient counselling regarding genomic and pharmacogenomic test results.	–
(E4) To appreciate the cost, cost-effectiveness, and reimbursement by insurers relevant to genomic or pharmacogenomic tests, for patients and communities.	–
(E5) To identify when to refer a patient to a genetic specialist or genetic counsellor.	–

publicly available website (see Table 1). Four programs (18%) offered at least one standalone PGx course and 10 (45%) had integrated PGx content in other courses. The most common course titles with integrated PGx content were “Pharmacokinetics” and “Pharmacology.” One program offered a standalone PGx course as an elective, while all other PGx-focused courses were part of the degree's core curricula. Fourteen (64%) programs contained basic genetics content, delivered either as a standalone course (18%) or as integrated content (59%) in courses such as biochemistry, chemistry, biology, pharmacokinetics, or human physiology. Five (23%) programs incorporated more than one integrated genetics course in their curricula and 10 (45%) offered both pharmacogenomic and genetics related courses. See Appendix 1 for the details of included courses.

#### 4.1. Mapping activity 1: bloom's taxonomy

One hundred and fifty-three pharmacogenomic and genetics learning objectives were identified from the course profiles. Most learning objectives (65%) corresponded to the “Understand” level of Bloom's Taxonomy (see Fig. 3). The main topics of these objectives involved demonstrating knowledge of the key principles of pharmacokinetics, pharmacodynamics and basic genetics. Some involved more specific objectives, such as “appreciate the genetic basis for drug action and disposition in different disease states”.<sup>27</sup> Less than 10% of the learning objectives were classified into the five remaining levels of Bloom's Taxonomy (i.e. Remember, Apply, Analyse, Evaluate, and Create). Overall, 46% of the learning objectives were classified as Conceptual Knowledge, 27% as Factual Knowledge, 24% as Procedural Knowledge, and 3% as Metacognitive Knowledge.

#### 4.2. Mapping activity 2: author-assigned domains

Eighty-four percent of learning objectives corresponded to the Enabling Science domain, 12% to Translational Science and 4% to Clinical Implementation. (Fig. 4) Enabling Science objectives focused on understanding the role of metabolising enzymes in drug response and demonstrating knowledge of DNA expression. At the next level, Translational Science

**Table 3**  
Types of learning activities and assessments used in PGx and genetics courses.

	Standalone PGx n = 3*	Integrated PGx n = 10	Standalone genetics n = 3	Integrated genetics n = 17*
<b>Learning Activities</b>				
Lectures – f2f or virtual	2 (67%)	9 (90%)	3 (100%)	16 (94%)
Tutorials/workshops	3 (100%)	10 (100%)	2 (67%)	12 (71%)
Pre-recorded videos, sessions etc.	2 (67%)	1 (10%)	0	0
Self-guided learning	1 (33%)	0	0	1 (6%)
Online modules/resources	1 (33%)	2 (20%)	1 (33%)	3 (18%)
Laboratory/practical	0	0	2 (67%)	8 (47%)
<b>Assessments</b>				
	Standalone PGx n = 4*	Integrated PGx n = 10	Standalone genetics n = 3	Integrated genetics n = 19*
Presentations/oral examinations	2 (50%)	3 (30%)	0	2 (11%)
Tutorial/workshop or in-semester quizzes/tasks	3 (75%)	7 (70%)	0	12 (63%)
Exams/tests	3 (75%)	9 (90%)	3 (100%)	17 (89%)
Essay/reports/literature review/proposal/case report	2 (50%)	6 (60%)	2 (67%)	6 (32%)
Online tests	1 (25%)	3 (30%)	2 (67%)	4 (21%)
Practical/laboratory exams/quizzes	0	3 (30%)	2 (67%)	4 (21%)
Practical/laboratory tasks/worksheets	1 (25%)	3 (30%)	1 (33%)	4 (21%)
Participation	0	2 (20%)	1 (33%)	0
Readings	0	0	1 (33%)	0

\* The 'n' may differ between learning activities and assessments due to lack of course details reported on publicly available resources.

learning objectives referred to the critical evaluation of the ethical considerations of genome sequencing technologies and the demonstration of proficient communication skills to explain test results. Clinical Implementation objectives included applying dosage individualisation strategies to control inter-patient variability in drug response and appraising genetic testing options based on individual patient factors. Over two-thirds of objectives relating to Clinical Implementation were offered by one institution's elective course titled "Genomics in Healthcare".

#### 4.3. Mapping activity 3: NHGRI competencies

Seventy-two (47%) learning objectives addressed at least one of the 15 pharmacogenomic competencies as defined by the NHGRI. Sixty-four percent were classified in the Basic Genetics Concepts domain, 11% in Genetics and Diseases, 18% in Pharmacogenetics/Pharmacogenomics and 7% in Ethical/Legal/Social Implications.

#### 4.4. Learning activities and assessments

The majority of the course profiles included information on the learning activities used to deliver content (see Table 3). The most commonly used mediums included lecture series and tutorials/workshops. Standalone and integrated genetics courses also held laboratory or practical classes for students.

When considering the types of assessments used, the most common across each course type were examinations, tutorial/in-class assessments as well as written projects. Due to the laboratory/practical components of genetic-focused courses, assessments also included laboratory-based exams and tasks.

See Table 4 in Appendix 1 for the full list of learning objectives and categorisations.

## 5. Discussion

The application of genomic data to improve patient outcomes is becoming increasingly prevalent.<sup>28</sup> Given this change, it is important that pharmacists are equipped with the appropriate skills needed to implement pharmacogenomics into clinical care.<sup>8</sup> The purpose of this study was to ascertain the current state of pharmacogenomic education in Australian pharmacy registrable programs. We found that more than half of the

programs included basic genetics teaching within their curricula. Approximately the same number of programs incorporated pharmacogenomics content into other science-related courses, or as a standalone course. Upon further analysis into the specific teachings of each course, the extent of pharmacogenomic training appears to be limited in scope.

In this study, most learning objectives were categorised into the second level of Bloom's taxonomy's cognitive domain, 'Understand'. Bloom's taxonomy has had widespread use in pedagogy and interdisciplinary education.<sup>13,29-32</sup> Our study utilised the revised version of Bloom's taxonomy, which may have better utility in planning.<sup>33</sup> Whilst the majority of the learning objectives were categorised into Factual and Conceptual Knowledge, it was encouraging to see that more than 20% of the objectives referred to Procedural Knowledge. However, in order for the pharmacist provider to understand the wider personal, societal and community implications of PGx services and their own place in this change, a greater proportion of Metacognitive Knowledge would be preferable, possibly carrying clinical and implementation implications.<sup>34</sup> It should be noted that in the wider literature outside of Bloom's taxonomy, 'metacognition' holds a differing definition (i.e. "thinking about thinking" or "a critical analysis of thinking").<sup>35</sup>

The purpose of the second mapping activity was to explore the spectrum of translated knowledge of pharmacogenomics being taught in Australian tertiary pharmacy courses. A high proportion of learning objectives were classified under the 'Enabling Science' category, indicating that the level of pharmacogenomic education in pharmacy programs remains focused on the basic sciences as opposed to clinical application. This finding mirrors what Murphy et al. (2010) discovered in US pharmacy programs, over a decade ago.<sup>36</sup> While students should develop basic comprehension of pharmacogenomics and genetics through these courses, they may have the opportunity to develop and practice skills in applying pharmacogenomic knowledge to the kinds of cases that arise in clinical practice. In the US, the ASHP states that students should be able to recommend pharmacogenomic tests when necessary, interpret results, and alter drug and dosing regimens based on current guidelines.<sup>8</sup> Moreover, students should also be capable of communicating the benefits and limitations of pharmacogenomic tests to patients and healthcare professionals in order to promote its safe and effective use.<sup>8</sup>

Coriolan et al. reported that pharmacy students at a US university felt that they had low confidence in their abilities to use PGx in practice, due to varying levels of exposure to PGx content during their degree.<sup>10</sup> A similar

**Table 4**  
Integrated PGx Content in courses and related learning objectives.

Institution	Integrated PGx Content in Course	Learning Objectives	Bloom's Taxonomy (Cognitive domain, Knowledge domain)	Category	NHGRI PGx competencies
Charles Sturt University	PHRM341 – Pharmacokinetics	1. Be able to understand the biological and pharmaceutical factors influencing the absorption, distribution, metabolism and elimination of drugs;	Understand, Factual Knowledge	Enabling Science	–
		2. Use calculations to demonstrate the importance of pharmacokinetics in determining the bioavailability and disposition of drugs;	Understand, Procedural Knowledge	Enabling Science	–
		3. Demonstrate an appreciation the differences in individuals which influence drug action (pharmacogenetics and pharmacogenomics).	Understand, Conceptual Knowledge	Enabling Science	P1
Griffith University	2018PHM – Pharmacology	6. Be able to outline a number of pharmacokinetic models, including: single compartment, multiple compartment, and non linear-pharmacokinetics.	Understand, Procedural Knowledge	Enabling Science	–
		1. Describe the concepts of pharmacogenomics affecting individual patient response to medicines	Understand, Conceptual Knowledge	Enabling Science	–
		2. Discuss the concepts of pharmacokinetics to understand drug dosing regimens	Create, Conceptual Knowledge	Enabling Science	–
		3. Explain the concepts of pharmacodynamics which describe drug action	Understand, Conceptual Knowledge	Enabling Science	–
		4. Apply pharmacological principles to interpret drug information	Apply, Procedural Knowledge	Enabling Science	–
		6. Interpret adverse drug reactions and drug interactions which influence drug action	Evaluate, Procedural Knowledge	Enabling Science	P1
		7. Recall basic principles of toxicology in context to drugs	Remember, Procedural Knowledge	Enabling Science	–
La Trobe University	PHA2PGB – Pharmacology	1. Use an understanding of the variability within and between populations to interpret effects on drug metabolism.	Understand, Procedural knowledge	Enabling Science	B1
		2. Evaluate how the variability in pharmacogenetics can cause toxic levels of drugs to circulate.	Evaluate, Conceptual Knowledge	Enabling Science	B1
		3. Assess different causes of pharmaceutical toxicity including physiological change during human development, as a result of drug overdose or in a range of diseases	Evaluate, Conceptual Knowledge	Enabling Science	–
	PHATHB – Pharmacy Practice and Therapeutics B (Metabolic and Endocrine)	5. Discuss how immunogenetics gives rise to clonal variation to fight infection and how immunopharmacotherapies can be used to target disease.	Create, Procedural Knowledge	Enabling Science	–
		3. Describe and explain the relationship between drug actions and therapeutic outcomes, specifically in the amelioration of disease states associated with the endocrine system or body metabolism.	Understand, Procedural Knowledge	Enabling Science	–
		4. Describe the absorption, elimination and metabolism of endocrine and gastrointestinal drugs and relate this to clinical practice and how pharmacogenetics affects this.	Understand, Procedural Knowledge	Enabling Science	B1
Queensland University of Technology	CBS444 – Molecular Basis of Medicines	4. Describe the absorption, elimination and metabolism of these classes of drugs and relate this to clinical practice and how pharmacogenetics affects this.	Understand, Procedural Knowledge	Enabling Science	B1
		5. Anticipate, and rationalise interaction between drugs (including over-the-counter (OTC preparations)	Understand, Procedural Knowledge	Enabling Science	–
		2. Describe and apply knowledge of drug metabolism pathways and pharmacokinetics involved in dosing regimens, interactions, and toxicities.	Understand, Conceptual Knowledge	Enabling Science	–
RMIT University	PHAR1012 – Clinical Development of New Medicines	3. Demonstrate knowledge in drug analysis and analytical instruments.	Understand, Conceptual Knowledge	Enabling Science	–
		4. Analyse the mechanism of action of a variety of drugs, their adverse effects and the implications of drug interactions.	Analyse, Conceptual Knowledge	Enabling Science	–
University of Sydney	PHAR2813 – Therapeutic Principles	2. Evaluate prospects for new approaches in therapeutics.	Evaluate, Procedural Knowledge	Enabling Science	–
		1. Demonstrate an understanding of the body as a complex adaptive biological system in relation to biochemistry/biotechnology	Understand, Conceptual Knowledge	Enabling Science	–
		2. Demonstrate an understanding of the pharmacological mechanisms of action and the properties drugs display as biologically active molecules in living systems	Understand, Conceptual Knowledge	Enabling Science	–
		3. Demonstrate an understanding of pharmaceutical factors impacting on therapeutic efficacy	Understand, Conceptual Knowledge	Enabling Science	–
		4. Apply an understanding of basic and applied sciences to the management and solution of pharmaceutical and clinical problems, including metabolism and enzymatic degradation of drugs	Apply, Procedural Knowledge	Enabling Science	–

University of Tasmania University of Technology Sydney (Masters)	CSA414 – Clinical Pharmacokinetics 96,007 – Drug Disposition	<i>No relevant learning objectives</i> 1. Identify the factors contributing to inter-patient variability in the clinical response to pharmacotherapy and/or non-pharmacological strategies 2. Explain factors governing drug response  3. Describe and calculate the pharmacokinetic, pharmacogenetic and pharmacodynamic parameters which affect therapeutic efficacy and response 4. Describe the genetic basis governing drug efficacy: metabolising enzymes, drug receptors, signalling mechanisms and drug transporters 5. Describe the mechanism of drug metabolism, factors affecting metabolite disposition and the role of metabolism in clinical drug interactions 6. Describe the sources of variability in drug response  7. Describe the scientific basis of and apply dosage individualisation strategies to control for variability in drug response 8. Describe the causes of toxicity and adverse drug reactions  10. Describe the various routes of drug administration, and factors governing the dosage form choice and route of administration 11. Describe how a drug's physicochemical properties relate to drug action and therapeutic outcome 12. Describe how a drug's physicochemical properties relate to drug disposition 13. Conduct required pharmaceutical calculations 14. Describe the role of drug receptors and signalling pathways in governing therapeutic response 15. Describe approaches for the clinical management of toxicity and adverse drug	Apply, Conceptual Knowledge N/A	Enabling Science – N/A Enabling Science P1
			Understand, Conceptual Knowledge	Enabling Science –
			Factual Knowledge	Enabling Science –
			Understand, Procedural Knowledge	Enabling Science –
			Understand, Conceptual Knowledge	Enabling Science P1
			Understand, Conceptual Knowledge	Enabling Science –
			Understand, Factual Knowledge	Enabling Science –
			Understand, Procedural Knowledge	Clinical Implementation –
			Understand, Factual Knowledge	Enabling Science –
			Understand, Procedural Knowledge	Enabling Science –
			Understand, Conceptual Knowledge	Enabling Science –
			Evaluate, Procedural Knowledge	Enabling Science –
			Understand, Factual Knowledge	Enabling Science –
			Understand, Conceptual Knowledge	Translational Science –
			–	–
Curtin University (Masters)	IMED5007 – Clinical Pharmacokinetics and Medicinal Chemistry	NONE LISTED IN PUBLIC COURSE PROFILE	–	–
University of Sydney (Masters)	PHAR5715 – Metabolism and Pharmacokinetics	1. LO1. understand the theoretical and practical concepts of drug pharmacokinetics involved in drug dosage, design and adjustment 2. LO2. understand how drugs are absorbed, distributed and eliminated from the body (i.e. how drugs behave in the body with respect to time) 3. LO3. understand the concepts that control the action of drugs in terms of intensity and duration of effect 4. LO4. evaluate the quality of pharmacokinetic and pharmacodynamic information from different sources, including the effect of age, disease and different physiological conditions on the pharmacokinetics of drugs 5. LO5. appreciate the genetic basis for drug action and disposition in different disease states  6. LO6. appreciate the sources of pharmacokinetic, pharmacodynamic and genetic variability that contribute to variability in drug response 7. LO7. understand how pharmacokinetic, pharmacodynamic and pharmacogenetic variability is characterised as well as factors affecting drug efficacy 8. LO8. apply an understanding of basic and applied sciences to the management and solution of pharmaceutical and clinical problems 9. LO9. appreciate how a rigorous understanding of drug interaction mechanisms may be used in clinical decision making 10. LO10. know how therapeutic drug monitoring may be used to optimise patient care in a variety of clinical settings	Understand, Conceptual Knowledge	Enabling Science –
			Understand, Factual Knowledge	Enabling Science P1
			Understand, Conceptual Knowledge	Enabling Science P1
			Evaluate, Procedural Knowledge	Enabling Science –
			Remember, Factual Knowledge	Enabling Science –
			Remember, Factual Knowledge	Enabling Science –
			Understand, Factual Knowledge	Enabling Science –
			Apply, Procedural Knowledge	Enabling Science –
			Remember, Factual Knowledge	Enabling Science –
			Remember, Factual Knowledge	Enabling Science –

## Standalone basic genetic courses

Institution	Standalone basic genetic course	Learning Objectives	Bloom's Taxonomy (Cognitive domain, Knowledge domain)	Category	NHGRI PGx competencies
Charles Sturt University	BMS240 – Human Molecular Genetics	1. Be able to distinguish between the processes of mitosis and meiosis and their implications in terms of the inheritance of genetic material;	Understand, Factual Knowledge	Enabling Science	B1
		2. Be able to describe Mendelian inheritance patterns	Understand, Factual Knowledge	Enabling Science	B1
		3. Be able to describe and differentiate between different modes of inheritance	Understand, Factual Knowledge	Enabling Science	B1
		4. Be able to describe how genetic information is stored in chromosomes and how chromosomes can be mutated	Understand, Factual Knowledge	Enabling Science	B1
		5. Be able to describe the structure of DNA	Understand, Factual Knowledge	Enabling Science	B1
		6. Be able to describe and apply the flow of genetic information from DNA through to expression as cellular constituents and structure	Understand, Factual Knowledge	Enabling Science	B1
		7. Be able to describe basic DNA mechanisms of replication, translation and transcription	Understand, Factual Knowledge	Enabling Science	B1
		8. Be able to outline how mutations result from alterations in DNA structure	Understand, Factual Knowledge	Enabling Science	B1
		9. Be able to describe standard molecular technologies and the newer technologies of proteomics and genomics	Understand, Factual Knowledge	Enabling Science	–
		10. Be able to describe the role of epigenetics in human inheritance	Understand, Conceptual Knowledge	Enabling Science	–
		11. Be able to describe how genetics plays a role in human disease	Understand, Conceptual Knowledge	Enabling Science	G1
		12. Be able to describe how mutations play a role in several human genetic diseases (with a focus on cancer)	Understand, Conceptual Knowledge	Enabling Science	G1
Griffith University	1005MSC – Genes and Diseases	1. Demonstrate understanding on how cellular and genetic information is relayed and how alteration to these processes lead to human disease such as cancer.	Understand, Conceptual Knowledge	Enabling Science	G1
		2. Communicate an understanding of the basic concepts of genetics, including Mendelian genetics, DNA and chromosome structure and gene expression and apply that knowledge to real life problems and case studies.	Apply, Conceptual Knowledge	Enabling Science	B1
		3. Interpret and solve simple problems arising from changes in genetic and biochemical processes at the cellular level, especially as these may relate to the activities of whole organisms.	Evaluate, Conceptual Knowledge	Enabling Science	B1
		4. Communicate familiarity with the range of ethical arguments relating to controversial procedures dealing with cell-level biology and biotechnology.	Apply, Procedural Knowledge	Translational Science	–
		5. Analyse and critically evaluate the scientific evidence to support evolution and the history of life on earth.	Analyse, Conceptual Knowledge	Enabling Science	–
		6. Work in pairs or small groups and demonstrate an acceptable level of competence with a range of analytical techniques used in cytology (the study of cells) microscopy, staining, blood typing and genetics.	Understand, Procedural Knowledge	Translational Science	–
University of Newcastle	HUBS1202 – Human Genomics and Biomolecular Analysis	1. Fundamental understanding of the structural features of proteins and nucleic acids.	Understand, Factual Knowledge	Enabling Science	B1
		4. Understand human genomic structure, function and analysis	Understand, Factual Knowledge	Enabling Science	B1
		5. Understand basic Mendelian genetics	Understand, Factual Knowledge	Enabling Science	B1



University of Queensland	BIOL1020 – Genes, Cells & Evolution	<i>Generic skills</i>				
		1. Identify and describe how cellular, genetic, and evolutionary processes impact everyday human life, including (but not limited to) effects on human health, agriculture and food security, and biodiversity.	Apply, Conceptual Knowledge	Enabling Science	B1	
		2. Demonstrate proficiency in scientific communication by summarising and explaining (both orally and in writing) results or concepts taken from source materials (written, visual, or aural) prepared for scientists.	Understand, Procedural Knowledge	Translational Science	–	
		<i>Molecular &amp; Cellular biology</i>				
		5. Explain how cells are able to coordinate the basic molecular building blocks of life in order to divide, replicate, and survive.	Understand, Conceptual Knowledge	Enabling Science	–	
		<i>Genes to traits</i>				
		6. Demonstrate understanding of the physical nature of the gene and molecular processes underlying the Central Dogma of molecular biology.	Understand, Conceptual Knowledge	Enabling Science	B1	
		7. Compare and contrast the gene regulatory mechanisms between bacteria and eukaryotes.	Analyse, Conceptual Knowledge	Enabling Science	B1	
		<i>Inheritance and evolution</i>				
8. Describe how the physical packing of DNA (into linear or circular chromosomes or plasmids) and the associated mechanisms of DNA copying create observable patterns of phenotypic trait inheritance.	Understand, Conceptual Knowledge	Enabling Science	B1			
9. Explain and compare processes contributing to genetic variability, including but not limited to: mutation, recombination, transformation, gene flow, horizontal gene transfer, gene and genome duplication, genetic drift, and natural selection.	Understand, Conceptual Knowledge	Enabling Science	B1			
<b>Courses with integrated genetic concepts</b>						
Institution	Course with integrated genetic concepts	Learning Objectives	Bloom's Taxonomy (Cognitive domain, Knowledge domain)	Category	NHGRI PGx competencies	
Charles Sturt University	MCR101– Introduction to Microbiology	1. Be able to describe the structure and function of microorganisms;	Understand, Factual Knowledge	Enabling Science	–	
		1. Be able to describe the structure and function of the four major classes of biological macromolecules (proteins, carbohydrates, lipids, and nucleic acids) and understand the relationship between structure and function;	Understand, Conceptual knowledge	Enabling Science	–	
	BMS – Disease Processes	2. Be able to demonstrate knowledge of the role of genetic factors in the development of both monogenic disorders and multifactorial human diseases;	Understand, Conceptual Knowledge	Enabling Science	G1	
		5. Be able to describe and demonstrate knowledge of the biomedical rationale of routinely encountered laboratory and point-of-care tests;	Understand, Conceptual Knowledge	Translational Science	–	
		6. be able to interpret results presented in routine pathology laboratory reports;	Understand, Procedural Knowledge	Translational Science	–	
7. be able to perform point-of-care tests	Create, Procedural Knowledge	Clinical Implementation	–			
Curtin University	PHRM2003 – Biochemical Principles in Pharmacology	1. Describe the biochemical processes underpinning normal metabolism and disease states	Understand, Factual Knowledge	Enabling Science	–	
		2. Describe the basic principles of molecular genetics in diseases	Understand, Factual Knowledge	Enabling Science	B1	
James Cook University	BMI1000 – Introductory Biochemistry and Microbiology	1. Demonstrate the acquisition of fundamental scientific knowledge of; cellular structures, cellular reproduction and genetics; cellular metabolism, transport and motility; microbial function and communication; innate and adaptive immune system function and its role in infection and disease;	Understand, Factual Knowledge	Enabling Science	B1	
		4. Generate data and statistics from experimental procedures. Analyse scientific evidence and have the ability to draw logical conclusions;	Create, Procedural	Enabling Science		

(continued on next page)

Table 4 (continued)

Courses with integrated genetic concepts						
Institution	Course with integrated genetic concepts	Learning Objectives	Bloom's Taxonomy (Cognitive domain, Knowledge domain)	Category	NHGRI PGx competencies	
La Trobe University RMIT University	BIO1CO – Biology of Cell and Organism	1. Distinguish and/or describe and discuss the morphological and metabolic features of different cell types.	Knowledge Analyse,	Enabling Science	–	
		3. Explain the basic processes involved in DNA replication, transcription and translation in prokaryotic and eukaryotic systems	Factual Knowledge Understand, Conceptual Knowledge	Enabling Science	B1	
	BIOL2272 – Biology of the Cell	4. Relate the role of DNA in the control of cell division and reproduction	Understand, Conceptual Knowledge	Enabling Science	B1	
		5. Recognize the fundamental aspects of inheritance and relate this to how genes pass on particular characteristics	Remember, Conceptual Knowledge	Enabling Science	B1	
		6. Describe the biological processes of mitosis and meiosis	Understand, Factual Knowledge	Enabling Science	B1	
		8. Recognize basic metabolic processes in a cell and how such processes are regulated	Remember, Conceptual Knowledge	Enabling Science	–	
University of Canberra	483 – Concepts in Biology	1. Apply knowledge of basic concepts in the areas of cellular function, metabolism, genetics and evolution to interpret biological phenomena;	Apply, Conceptual Knowledge	Enabling Science	B1	
		2. Collect, record, analyse and interpret biological data related to these concepts and communicate these interpretations both in writing and orally; and	Create, Procedural Knowledge	Translational Science	–	
		3. Design and conduct experiments which examine some of these concepts.	Create, Procedural Knowledge	Translational Science	–	
	6530 – Biochemistry	4. Demonstrate knowledge of the processes and regulation of DNA expression and replication;	Understand, Factual Knowledge	Enabling Science	B1	
		6510 – Introduction to Microbiology	No relevant learning objectives	N/A	N/A	N/A
		PHAR2203 – Gastrointestinal Health and Solid Dosage Formulations	9. Describe the role of pharmacodynamics and pharmacokinetic factors as determinants of drug response in gastrointestinal and hepatobiliary conditions.	Understand, Conceptual Knowledge	Enabling Science	–
10. Describe the process of drug metabolism by the liver including genetic variation in pharmacokinetics and pharmacodynamics.	Understand, Conceptual knowledge		Enabling Science	B1		
University of New England	BCHM210 – Introductory Molecular Biology and Biochemistry	2. Articulate the mechanisms of DNA replication, transcription and translation and relate general principles of molecular biology to genetic engineering;	Understand, Conceptual Knowledge	Enabling Science	B1	
		3. Analyse the relationship of structure and function in the cell's macromolecules: nucleic acids, proteins, carbohydrates and lipids;	Analyse, Conceptual Knowledge	Enabling Science	–	
		4. Explore the role of enzymes as catalysts in biological systems and outline the control of enzyme activity;	Understand, Conceptual Knowledge	Enabling Science	–	
		PHAR340 – Pharmacokinetics	1. Define and describe the core principles of pharmacokinetics, the pharmacokinetic parameters that arise from these principles and the circumstances to which they apply;	Understand, Conceptual Knowledge	Enabling Science	–
	2. Utilize pharmacokinetic equations to solve for parameters associated with simulated clinical scenarios;		Apply, Procedural Knowledge	Enabling Science	–	
	3. Define and describe the impact of disease/disorder status and genetics on the pharmacokinetics of drug use; and		Understand, Conceptual Knowledge	Enabling Science	P1	
	4. Define and describe the role of surrogate endpoints, biomarker and safety biomarker monitoring in the therapeutic use of drugs.		Understand,	Enabling	P1	

				Conceptual Knowledge	Science	
	PHAR370 – Molecular Basis of Therapeutics	1. Describe the mechanisms of action of anticancer drugs, describe the impact of genetic markers in cancer treatment and discuss the development of drug resistance and the role of the choice of anticancer drugs in this process;		Understand, Conceptual Knowledge	Enabling Science	B1
		3. Describe the processes involved in Phase 1 and Phase 2 drug metabolism in humans and relate these processes to drug interactions, the occurrence of individual differences in metabolism, and the detoxification and toxicification of clinically used substances;		Understand, Conceptual Knowledge	Enabling Science	–
		5. Critically apply knowledge of structure/pharmacokinetic relationships to new and unfamiliar molecular structures; and		Apply, Procedural Knowledge	Enabling Science	–
	PSIO120 – Introductory Human Physiology II	4. Demonstrate an understanding of the broad concepts of human genetics including the structure and function of DNA, cell division for cell replication and human reproduction, and inheritance patterns; and		Understand, Conceptual Knowledge	Enabling Science	B1
	PSIO230 – Pathophysiology	4. Apply an understanding and describe the contribution of genetics to the pathophysiological conditions discussed as well as to the process of carcinogenesis and neoplasia; and		Apply, Conceptual Knowledge	Enabling Science	B1
University of South Australia	PHAR2006 – Pharmacokinetics and Biopharmaceutics	To apply prior knowledge of the absorption, distribution and elimination of drugs in the design and evaluation of the dosage regimens of drugs. Mechanisms for the genetic and environmental basis for inter-subject differences in the metabolism and transport of drugs in the body. Metabolite kinetics. Non-linear pharmacokinetics. Pharmacokinetic-pharmacodynamic relationships. Therapeutic regimens and dosage adjustments in disease states, in the young and in the elderly. Pharmacokinetic drug interactions. Bioavailability and bioequivalence. Evaluation of the biopharmaceutical performance of dosage forms.		Apply, Procedural Knowledge	Enabling Science	B1
	PHAR3025 – Dosage Form and Design 4	No relevant learning objectives		N/A	N/A	N/A
	PHAR4018 – Advanced Therapeutics	To further develop the application of pharmacotherapeutics principles and knowledge. Content will include: specialised infectious diseases and their public health implications; inherited diseases; transplant medicine; oncology; genotyping and medicine provision.		Evaluate, Conceptual Knowledge	Enabling Science	B1
University of Sydney	BIOL1008 – Human Biology	No relevant learning objectives		N/A	N/A	N/A
	PHAR2811 – Drug Discovery and Design A	1. Explain the difference between qualitative and quantitative measurements, and obtain quantitative measurements of metabolite concentrations and enzyme activities in an accurate and reproducible manner		Understand, Procedural knowledge	Translational Science	–
		4. Describe enzyme action, including the important enzyme inhibition mechanisms, and calculate the associated quantifying descriptors		Understand, Conceptual knowledge	Enabling Science	–
		5. Describe major components of amino acids and protein structure, and give diagrammatic representations		Understand, Procedural knowledge	Enabling Science	–
		7. Describe the complexity of the eukaryotic genome and its structure in detail and identify the key constituent elements		Understand, Conceptual knowledge	Enabling Science	B1
		8. Outline the specific processes by which genetic information is transmitted from one generation to the next and analyse the flow of this information within the cell		Understand, Conceptual knowledge	Enabling Science	B1
		9. Describe and evaluate the steps involved in gene transcription and translation and evaluate the different ways by which gene expression can be regulated		Understand, Conceptual knowledge	Enabling Science	B1
		11. Compare and contrast the integration of anabolic and catabolic processes in the cells, and predict how perturbations to these processes, including fuel selection and genetic mutation, affect the cell and whole organism		Evaluate, Conceptual knowledge	Enabling Science	–
University of Tasmania	CSA225 – Medicinal Chemistry and Drug Development	3. Describe basic / advanced biological pathways of metabolism and excretion of drugs, and factors that influence these processes in determining the biological activity of drugs.		Understand, Conceptual knowledge	Enabling Science	–
Curtin University (Masters)	IMED5009 – Pharmaceutical Biology	1. Describe the biochemical processes underpinning normal metabolism and those relevant to the drug treatment of various disease states		Understand, Conceptual knowledge	Enabling Science	–
		3. Describe the basic principles of molecular genetics in healthy and disease states of the human host and the differences in genetics for pathogenic microorganisms; GC1		Understand, Conceptual knowledge	Enabling Science	–
University of Queensland	PHRM3021 – Dosage Form and Design B1	2. Demonstrate knowledge of and an ability to apply principles of drug transport and delivery, optimisation of dosage form and design, non-sterile specialised drug delivery systems, gene delivery, design of drug analogues and prodrugs		Understand, Conceptual knowledge	Enabling Science	G1

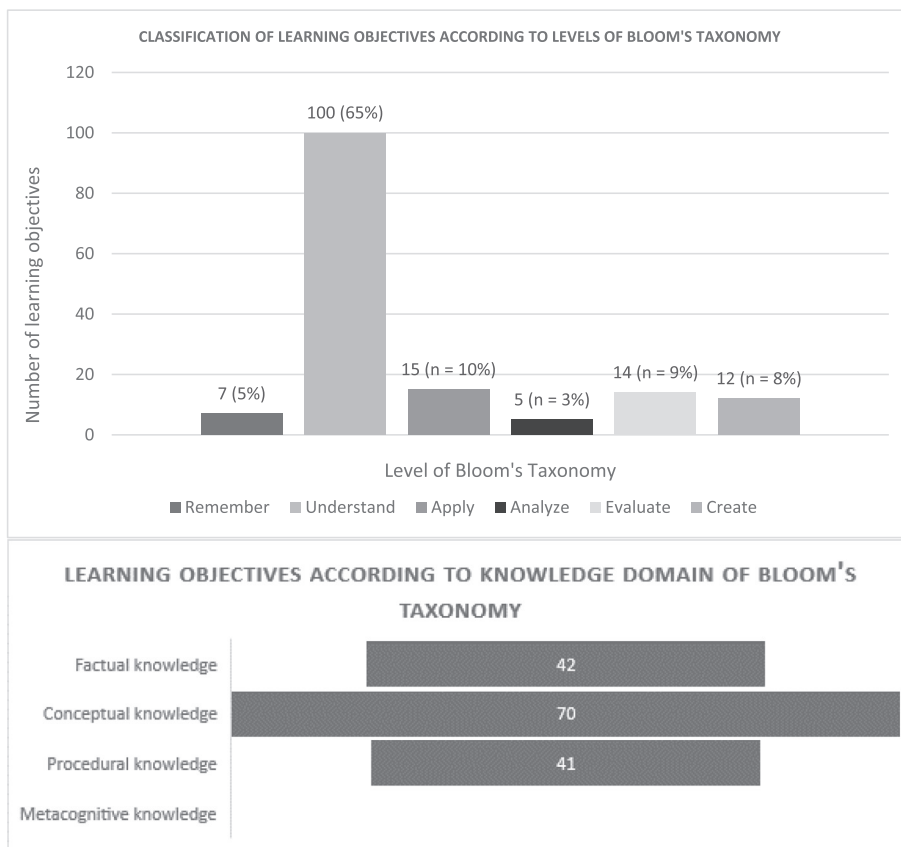


Fig. 3. Learning objectives classified according to the revised Bloom's Taxonomy cognitive and knowledge domains.

study by Arafah et al. highlighted that due to the limited knowledge and understanding of PGx by students, there was a lack of interest in implementing PGx testing in clinical practice.<sup>37</sup> The findings in these studies may apply to the Australian setting, with the majority of coursework in this study found to focus on foundational concepts. Results from a survey-based study in 2015 evaluating the extent of PGx teaching in Australian pharmacy programs concluded that there was a perceived gap in PGx teaching, with poor awareness of the Clinical Pharmacogenomics Implementation Consortium (CPIC) dosing guidelines, and PGx testing requirements for

government subsidised medicines.<sup>38</sup> In order to facilitate the translation and implementation of pharmacogenomic knowledge in clinical pharmacy settings, learning objectives could be revised to progress from mere 'understanding' to experiential and practical-based skills that may better prepare students for clinical practice and for meeting future professional competencies.

NHGRI's pharmacogenomic competencies were created and endorsed by a group of 10 US pharmacy-related organisations to guide pharmacogenomics education and clinical application for both students and practicing pharmacists.<sup>12</sup> The results of this study show that less than half of the learning objectives address at least one of the 15 NHGRI pharmacogenomic competencies. Most of them were classified under the Basic Genetic Concepts (B1) and Pharmacogenetics/Pharmacogenomic (P1) domains. This underscores the need for the revision of Australian pharmacy registrable pharmacy curricula to incorporate more comprehensive pharmacogenomic training. While some programs have integrated sufficient foundational PGx education, few have addressed the need to train students in the application of pharmacogenomics.

The majority of content was delivered to students via lectures and tutorials, and was most commonly assessed via examinations, tutorial tasks and written projects. The aim of this study was to provide a descriptive overview of PGx content in pharmacy courses. Thus, considerations relating to the appropriateness of learning activities and assessments in measuring student competencies against the learning objectives is out of the scope of this study and precludes the formation of a judgement. Furthermore, there was insufficient data in course profiles outlining the number of hours dedicated specifically to pharmacogenomic concepts. These differences may have an impact on overall student competencies. Future research in this field is needed to determine whether the way PGx content is delivered to students and assessed is appropriate and effective.

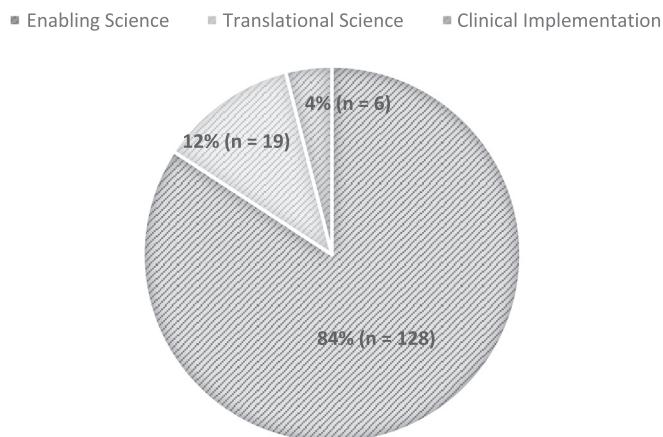


Fig. 4. Proportion of learning objectives mapped to Enabling Science, Translational Science, and Clinical Implementation.

### 5.1. Implications

If pharmacogenomic-based medication management is more commonly incorporated into clinical practice, future pharmacists in Australia may require further training to implement related services in clinical care. Revision of pharmacy degree curricula and continuing professional education is therefore required. We suggest, as a first step, to incorporate pharmacogenomic concepts into National Competency Standards Framework for Pharmacists in Australia,<sup>39</sup> considering relevant international standards and guidelines, and suitably recognised within an accreditation. Further research should also consider whether pharmacogenomics is best delivered as a standalone course or integrated into related topics. Proposed educational models include adding PGx practice-based content into didactic lectures and active learning exercises for pharmacy students about to graduate.<sup>40</sup> This may include web-based phenotyping exercises, student-led debates about ethical considerations, and interpreting genotyping reports in the context of clinical cases.<sup>40</sup> Experiential education strategies should also be incorporated during student placements where possible, and future research should examine the efficacy of PGx learning programs. However, it may be difficult to translate international guidelines and teaching methods to the Australian context, due to fundamental differences within Australia's education and healthcare system.<sup>41</sup>

Whilst the sparse amount of pharmacogenomic evidence for changes in clinical outcomes is a major barrier to implementation, many clinical pharmacogenomic studies are currently being undertaken. It is likely to be only a matter of time until the pharmacist workforce is called upon to provide such pharmacogenomic services. This suggests that training of the pharmacist workforce in advance would be prudent.

### 5.2. Limitations

One author (\*) extracted the data from publicly available websites, and categorised the majority of the learning objectives. The amount of information available on electronic course profiles varied between programs. Therefore, it is possible that some courses were excluded that may have contained pharmacogenomic-related content which was not explicitly listed in their electronic profiles. Course administrators were not contacted for more information about learning objectives, assessments and learning activities due to limitations in the scope of the study. Due to the lack of reporting of pharmacogenomics specific content in course profiles, the authors expanded the search parameters to include genomics and genetics courses, with the assumption that these courses had the potential to cover pharmacogenetic concepts. There may be some PGx outcomes and assessment techniques which were not captured in our analysis: for example, terms relating to precision medicine, molecular biology, pharmacokinetics, or pharmacodynamics were not included in our screening analysis. Further, NHGRI's pharmacogenomic competencies were much more specific than the broadly stated learning objectives, which may lead to discrepancies in

the mapping activities. NHGRI's competencies were also updated in July 2021, after the analysis had been completed. However, the learning objectives, activities and assessments were screened by two authors (\*\*\*) and (\*\*\*), who have cumulative experience in pharmacy, the Australian healthcare system and academia, to minimise the potential for bias. The analysed course profiles did not contain enough information to be able to determine whether particular assessments were directly related to PGx objectives. Therefore, these results should be interpreted with caution. Two authors (\*\* and \*\*\*) categorised the learning objectives for the knowledge dimension of Bloom's Taxonomy, and (\*\*\*) further confirmed the categorisation for the 'metacognitive knowledge' domain.

Finally, the NHGRI pharmacogenomic competencies were updated in July 2021 by the American Association of Colleges of Pharmacy Pharmacogenomics Special Interest Group (AACP SIG) to reflect the more contemporary needs of pharmacy practice.<sup>23</sup> It is possible that some of the learning objectives fulfill the revised 30 competency statements but were not considered in this study. However, a brief screening of the changes did not find additional competencies of relevance which would majorly affect the findings of this study.

## 6. Conclusion

The majority of accredited registrable pharmacy degree programs in Australia contain pharmacogenomic- or genetics-related content in their course profiles. However while some programs have integrated sufficient foundational PGx education, few have addressed the need to train students in the application of pharmacogenomics. It is evident that gaps in training still exist. In order to realise the full potential of pharmacogenomics, there is a need for pharmacy programs to anticipate and incorporate more skill-based training into their curricula to better prepare pharmacists for future practice.

### Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### CRediT authorship contribution statement

**Maija-Liisa Venugopal:** Investigation, Formal analysis, Writing – original draft, Project administration. **Faith R. Yong:** Writing – review & editing. **Natalia Krzyzaniak:** Writing – review & editing. **Adam La Caze:** Conceptualization, Methodology, Supervision. **Christopher Freeman:** Conceptualization, Methodology, Supervision.

### Declaration of Competing Interest

None.

## Appendix 1

## PGx courses, related learning objectives and categorisation

Institution	Standalone PGx Course	Learning Objectives	Bloom's Taxonomy (Cognitive domain, Knowledge domain)	Category	NHGRI PGx competencies
Charles Darwin University	PHA214 – Biotechnology and pharmacogenomics (A1)	1. Use molecular modelling in the structure prediction and evaluation of molecules.	Apply, Conceptual Knowledge	Enabling Science	B2
		2. Demonstrate an understanding of the role of human drug metabolising enzymes.	Understand, Factual Knowledge	Enabling Science	P1
		3. Demonstrate an appreciation of the molecular and chemical basis of drug toxicity and multidrug resistance.	Understand, Factual Knowledge	Enabling Science	–
		4. Demonstrate an understanding of the technique associated with genetic manipulations and their ethical consideration.	Understand, Factual Knowledge	Translational Science	–
		5. Demonstrate a knowledge of the processes involved in the commercialisation and application of biotech products.	Understand, Factual Knowledge	Translational Science	–
		6. Demonstrate an appreciation of recent advances in molecular biology and genetics and their effects on drugs.	Understand, Factual Knowledge	Enabling Science	P1
James Cook University	PC2204 – Pharmacology and Pharmacogenomics for Pharmacists (E1)	1. Describe the mechanisms by which cells communicate with one another within the human body;	Understand, Factual Knowledge	Enabling Science	B1
		2. Describe key pharmacodynamic principles including cell/receptor interactions, agonism, antagonism and dose response;	Understand, Factual Knowledge	Enabling Science	–
		3. Describe key pharmacokinetic principles including absorption, distribution, metabolism and excretion;	Understand, Factual Knowledge	Enabling Science	–
		4. Apply key pharmacodynamics and pharmacokinetic principles to clinical situations and conduct relevant calculations;	Apply, Procedural Knowledge	Translational Science	–
		5. Demonstrate an understanding of the influence of genetics in pharmacy practice and how inter- patient variation alters an individual's response to pharmacological treatment.	Understand, Conceptual Knowledge	Translational Science	P1
University of Newcastle	PHAR4201 – Pharmacogenomics and Personalized Health Care (J1)	1. Demonstrate fundamental knowledge of the molecular basis of responses to drugs and other therapeutics.	Understand, Factual Knowledge	Enabling Science	G1
		2. Explain the new field of precision medicine and how recent technological advances in areas such as genomics, pharmacogenomics and bioinformatics are revolutionising modern health care.	Understand, Factual Knowledge	Enabling Science	–
		3. Discuss how modern pharmacogenomics differs from traditional pharmacogenetics and why this is important for clinical utility.	Create, Factual Knowledge	Enabling Science	–
		4. Provide balanced, critical evaluations of the benefits and limitations of important current and emerging technologies in these fields, including modern genotyping technologies such as polymerase chain reaction (PCR), microarrays and next-generation sequencing.	Evaluate, Procedural Knowledge	Translational Science	E1
		5. Explain how genomics and other individual factors such as environment or lifestyle can influence drug pharmacokinetics and pharmacodynamics.	Understand, Conceptual Knowledge	Enabling Science	B2, P1
		6. Apply evidence-based, systematic approaches to understanding and implementing pharmacogenomics and personalized health care.	Apply, Procedural Knowledge	Translational Science	–
		7. Discuss the advanced concepts of multifactorial drug-gene interactions and maternal-fetal pharmacogenomics.	Create, Conceptual Knowledge	Enabling Science	–
		8. Perform balanced, evidence-based assessments of controversial issues and new information and concepts in these and other emerging fields.	Evaluate, Procedural Knowledge	Translational Science	–
		9. Describe potential impacts of personalized healthcare for consumers, health professionals, industry, government and society and demonstrate responsible professional attitudes in relation to ethical, legal and social issues (ELSI) in personalized health care.	Understand, Procedural Knowledge	Translational Science	E1
		10. Discuss probable future trends in applications of these fields in clinical practice.	Create, Conceptual Knowledge	Enabling Science	–
University of Technology Sydney (Masters)	96,076 – Genomics in Healthcare (elective) (V1)	1. Understand the key biological concepts in genomics and genetics and key elements and role of DNA and recall significant events in the history of the genomic evolution and how it impacts on contemporary healthcare.	Understand, Factual Knowledge	Enabling Science	G1
		2. Differentiate and discuss key biological concepts in genomics/genetics to deep dive into the evidence for genomics applications in healthcare.	Create, Conceptual Knowledge	Translational Science	G1
		3. Utilize effective communication skills to implement genomics evidence for individuals and families, across diverse health care settings and populations in management plans, programs and policy advice.	Create, Procedural Knowledge	Clinical implementation	E3
		4. Appraise the range of genetic testing options in patient or community-based scenarios to assess implementation and utility strategies for either individual care or public health programs.	Evaluate, Procedural Knowledge	Clinical implementation	E3
		5. Interpret and debate genomic specific ethical and legal issues within the context of a variety of patient and community- based scenarios including health inequalities in indigenous Australians.	Evaluate, Procedural knowledge	Clinical implementation	E1
		6. Synthesize the evidence regarding the effects of pharmacogenomics on quality use of medicines and on the health of the individual patient, consumer, or population.	Create, Procedural knowledge	Clinical implementation	–

## Appendix 2

Aim/description/syllabus	Learning objectives/outcomes	Learning activities	Activity description (if any)	Assessments	Assessment description (if any)	Other information	Researcher notes
<p>This unit aims to introduce the basis of molecular biology so that students understand the concepts and techniques used to manipulate DNA for industry and research. Students will develop an understanding of DNA structure and function, the human genome, genetic engineering and gene therapy. Plus gain an appreciation of the ethical and safety regulations. This unit also highlights the importance of pharmacogenomics through our increased knowledge of the human genome and new molecular techniques. Students will learn how an individual's genetic make-up can influence their response to drugs, in terms of drug metabolising enzymes, transporters, receptors and adverse effects. They will also understand how these molecular techniques are used in drug development to produce improved and personalized medications.</p>	<p>1. Use molecular modelling in the structure prediction and evaluation of molecules.</p> <p>2. Demonstrate an understanding of the role of human drug metabolising enzymes.</p> <p>3. Demonstrate an appreciation of the molecular and chemical basis of drug toxicity and multidrug resistance.</p> <p>4. Demonstrate an understanding of the technique associated with genetic manipulations and their ethical consideration.</p> <p>5. Demonstrate a knowledge of the processes involved in the commercialisation and application of biotech products.</p> <p>6. Demonstrate an appreciation of recent advances in molecular biology and genetics and their effects on drugs.</p>	<p>This subject contains a 4 day Compulsory Residential School.</p> <p>Laboratory sessions in this subject allow practical experience in the identification and growth of micro-organisms and the prevention and control of microbial growth in a variety of contexts.</p>	<p>The laboratory sessions allow students to gain experience in aseptic technique. Transmission of micro-organisms and environmental sources of microbial contamination are also stressed. Laboratory sessions provide essential support for the theoretical knowledge provided in the lecture notes/study guide and are integral to introductory microbiology in all situations.</p>	<p>Poster presentation (15 min)</p> <p>Practical worksheets (10 × 150 words)</p> <p>Quizzes (2 × 20 min)</p> <p>Exam (2 h)</p>	<p>Related learning outcomes 2,3,4,5,6</p> <p>Related learning outcomes 1,4</p> <p>Related learning outcomes 2,3,4,6</p> <p>Related learning outcomes 1,2,3,4,5,6</p>		
<p>This subject will examine the broad field of genetics. It will cover standard Mendelian genetics, our modern understanding of molecular genetics, and the central dogma (DNA is transcribed to mRNA which is translated to protein). Modern disciplines of applied molecular technology (including proteomics and genomics), the genetic basis of molecular diseases, epigenetics and the genetics of cancer will also be examined.</p>	<p>• be able to distinguish between the processes of mitosis and meiosis and their implications in terms of the inheritance of genetic material;</p> <p>• be able to describe Mendelian inheritance</p>	<p>This subject contains a 4 day Compulsory Residential School.</p> <p>Laboratory sessions in this subject allow practical experience in the identification</p>	<p>The laboratory sessions allow students to gain experience in aseptic technique. Transmission of micro-organisms and environmental sources of microbial contamination are also stressed. Laboratory sessions provide essential support for the theoretical knowledge provided in the lecture notes/study guide and are integral to introductory microbiology in all situations.</p>	<p>Poster presentation (15 min)</p> <p>Practical worksheets</p>	<p>Related learning outcomes 2,3,4,5,6</p> <p>Related learning</p>		
<p><b>This subject will cover the following topics:</b></p>							

(continued on next page)

## Appendix 2 (continued)

Aim/description/syllabus	Learning objectives/outcomes	Learning activities	Activity description (if any)	Assessments	Assessment description (if any)	Other information	Researcher notes
	patterns	and growth of micro-organisms and the prevention and control of microbial growth in a variety of contexts.		(10 × 150 words)	outcomes 1,4		
• Chromosomes and cellular reproduction	• be able to describe and differentiate between different modes of inheritance	–		Quizzes (2 × 20 min)	Related learning outcomes 2,3,4,6		
• Basic principles of heredity	• be able to describe how genetic information is stored in chromosomes and how chromosomes can be mutated	–		Exam (2 h)	Related learning outcomes 1,2,3,4,5,6		
• Sex determination and sex linked characteristics	• be able to describe the structure of DNA	–					
• Extensions and modifications of basic principles	• be able to describe and apply the flow of genetic information from DNA through to expression as cellular constituents and structure	–					
• Pedigree analysis, applications, genetic testing and ethics	• be able to describe basic DNA mechanisms of replication, translation and transcription	–					
• Linkage, recombination and eukaryotic gene mapping	• be able to outline how mutations result from alterations in DNA structure	–					
• Chromosome variation	• be able to describe standard molecular technologies and the newer technologies of proteomics and genomics	–					
• DNA: The chemical nature of the gene	• be able to describe the role of epigenetics in human inheritance	–					
• Chromosome structure and DNA replication	• be able to describe how genetics plays a role in human disease	–					
• Transcription	• be able to describe how mutations play a role in several human genetic diseases (with a focus on cancer)	–					
• RNA molecules and RNA processing	–	–					
• The genetic code and translation	–	–					
• Gene mutations and DNA repair	–	–					
• Molecular genetic analysis and genomics/proteomics	–	–					
• Epigenetics and cancer genetics	–	–					



## References

- Wake DT, Ilbawi N, Dunnenberger HM, Hulick PJ. Pharmacogenomics: prescribing precisely. *Med Clin North Am* 2019;103:977–990.
- T PA, M SS, Jose A, Chandran L, Zachariah SM. Pharmacogenomics: the right drug to the right person. *J Clin Med Res* 2009;1:191–194.
- Relling MV, Klein TE, Gammal RS, Whirl-Carrillo M, Hoffman JM, Caudle KE. The clinical pharmacogenetics implementation consortium: 10 years later. *Clin Pharmacol Ther* 2020;107:171–175.
- Relling MV, Evans WE. Pharmacogenomics in the clinic. *Nature* 2015;526:343–350.
- Kisor D. *The DNA of Pharmacy Education: CAPE Outcomes and Pharmacogenomics*. AACPE Outcomes. 2016.
- Elewa H, Awaisu A. Pharmacogenomics in pharmacy practice: current perspectives. *Integr Pharm Res Pract* 2019;8:97–104.
- Hicks JK, Aquilante CL, Dunnenberger HM, et al. Precision pharmacotherapy: integrating pharmacogenomics into clinical pharmacy practice. *J Am Coll Clin Pharm* 2019;2:303–313.
- ASHP statement on the pharmacist's role in clinical pharmacogenomics. *Am J Health Syst Pharm* 2015;72:579–581.
- McMahon T, Tucci J. The perceptions of pharmacists in Victoria, Australia on pharmacogenetics and its implications. *Pharm Pract (Granada)* 2011;9:141–147.
- Coriolan S, Arikawe N, Moscati A, et al. Pharmacy students' attitudes and perceptions toward pharmacogenomics education. *Am J Health Syst Pharm* 2019;76:836–845.
- Council AP. *Accreditation Standards for Pharmacy Programs in Australia and New Zealand Canberra*. Australia: Australian Pharmacy Council Ltd. 2020:32.
- Roederer MW, Kuo GM, Kisor DF, et al. Pharmacogenomics competencies in pharmacy practice: a blueprint for change. *J Am Pharm Assoc* 2003;2017(57):120–125.
- Komenda M, Vítá M, Vaitis C, et al. Curriculum mapping with academic analytics in medical and healthcare education. *PLoS One* 2015;10, e0143748.
- Rawle F, Bowen T, Murck B, Hong R. Curriculum mapping across the disciplines: differences, approaches, and strategies. *Collect Essays Learn Teach* 2017;10:75–88.
- Meekin SA, Klein JE, Fleischman AR, Fins JJ. Development of a palliative education assessment tool for medical student education. *Acad Med* 2000;75:986–992.
- Wood EB, Meekin SA, Fins JJ, Fleischman AR. Enhancing palliative care education in medical school curricula: implementation of the palliative education assessment tool. *Acad Med* 2002;77:285–291.
- Plaza CM, Draugalis JR, Slack MK, Skrepnek GH, Sauer KA. Curriculum mapping in program assessment and evaluation. *Am J Pharm Educ* 2007;71:20.
- Lam BH, Tsui KT. Curriculum mapping as deliberation – examining the alignment of subject learning outcomes and course curricula. *Stud High Educ* 2016;41:1371–1388.
- Zelenitsky S, Vercaigne L, Davies NM, Davis C, Renaud R, Kristjanson C. Using curriculum mapping to engage faculty members in the analysis of a pharmacy program. *Am J Pharm Educ* 2014;78:139.
- Lammerding-Koeppel M, Giesler M, Gornostayeva M, et al. Monitoring and analysis of the change process in curriculum mapping compared to the National Competency-based Learning Objective Catalogue for undergraduate medical education (NKLK) at four medical faculties. Part I: conducive resources and structures. *GMS J Med Educ* 2017;34:Doc7-Doc7.
- Robley W, Whittle S, Murdoch-Eaton D. Mapping generic skills curricula: outcomes and discussion. *J Furth High Educ* 2005;29:321–330.
- Australian Pharmacy Council. *Australian Accredited Pharmacy Degree Programs*. 2021.
- Gammal RS, Lee YM, Petry NJ, et al. Pharmacists leading the way to precision medicine: updates to the Core pharmacist competencies in genomics. *Am J Pharm Educ* 2021;86:34.
- Adams NE. Bloom's taxonomy of cognitive learning objectives. *J Med Libr Assoc* 2015;103:152–153.
- Krathwohl DR. A revision of Bloom's taxonomy: an overview. *Theory Pract* 2002;41:212–218.
- Bloom's Taxonomy of Measurable Verbs.
- TUoS. *PHAR5715: Metabolism and Pharmacokinetics. Current students: Units / Phar5715*, 2021. 2021.
- Weinshilboum RM, Wang L. Pharmacogenomics: precision medicine and drug response. *Mayo Clin Proc* 2017;92:1711–1722.
- Masapanta-Carrión S, Velázquez-Iturbide JÁ. A systematic review of the use of Bloom's taxonomy in computer science education. 49th ACM Technical Symposium on Computer Science Education. Baltimore, USA: Association for Computing Machinery (ACM); 2018. p. 441–446.
- Booker M. *A Roof without Walls: Benjamin Bloom's Taxonomy and the Misdirection of American Education*. Academic Questions (Springer Nature). 2007:20.
- Calhoun JG, Davidson PL, Sinioris ME, Vincent ET, Griffith JR. Toward an understanding of competency identification and assessment in health care management. *Qual Manag Healthcare* 2002;11:14–38.
- Verenna A-MA, Noble KA, Pearson HE, Miller SM. Role of comprehension on performance at higher levels of Bloom's taxonomy: findings from assessments of healthcare professional students. *Anat Sci Educ* 2018;11:433–444.
- Bümen NT. Effects of the original versus revised Bloom's taxonomy on lesson planning skills: a Turkish study among pre-service teachers. *Int Rev Educ* 2007;53:439–455.
- Medina MS, Castleberry AN, Persky AM. Strategies for improving learner metacognition in health professional education. *Am J Pharm Educ* 2017;81:78.
- Mahdavi M. An overview: metacognition in education. *Int J Multidiscipl Curr Res* 2014;2:529–535.
- Murphy JE, Green JS, Adams LA, Squire RB, Kuo GM, McKay A. Pharmacogenomics in the curricula of colleges and schools of pharmacy in the United States. *Am J Pharm Educ* 2010;74:7.
- Arafah A, Rehman MU, Syed W, Babelghaith SD, Alwhaibi A, Al Arifi MN. Knowledge, attitude and perception of pharmacy students towards pharmacogenomics and genetics: an observational study from King Saud University. *Genes* 2022;13:269.
- Matti N, Khoo S, Wiese M, King C, Suppiah V. Teaching of pharmacogenomics in Australian pharmacy schools. *Public Health Genomics* 2015;18:47–48.
- PSoAL. 2016 National competency standards framework for pharmacists in Australia. National Competency Standards Framework for Pharmacists in Australia. Canberra, Australia: Pharmaceutical Society of Australia; 2016. p. 112.
- Weitzel KW, Aquilante CL, Johnson S, Kisor DF, Empey PE. Educational strategies to enable expansion of pharmacogenomics-based care. *Am J Health Syst Pharm* 2016;73:1986–1998.
- Suppiah V, Lim CX, Hotham E. Community pharmacists and their role in pharmacogenomics testing: an Australian perspective drawing on international evidence. *Aust J Prim Health* 2018;24:441–447.