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RESEARCH ARTICLE

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Pharmacogenomic curriculum in Australian medical schools: a content analysis study

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ABSTRACT

Aims: To ascertain and describe pharmacogenomic concepts included in the intended curriculum of accredited Australian medical schools.

Methods: Content analysis of curriculum learning objectives of Australian medical schools was conducted, focusing on keywords and phrases pertaining to pharmacogenomic education. Learning objectives related to pharmacogenomics were categorized using (1) undergraduate medical genomic competencies per the Association of Professors in Human and Medical Genetics (2) Bloom's Taxonomy for cognitive and knowledge dimensions and (3) knowledge translation (enabling science, translation science and clinical implementation).

Results: The curricula of 19 accredited medical schools in Australia were analyzed. Two-thirds (68%) contained genomic/pharmacogenomic education. Eight schools had content relating to undergraduate medical genomic competencies. Of those which had pharmacogenomic-related learning objectives, the majority (65%) were categorized in Bloom's Taxonomy's lower levels (Remember and Understand) and 15% were deemed to be at the level of 'Clinical Implementation.'

Conclusion: The majority of Australian medical schools have incorporated pharmacogenomics in their current curriculum; however, learning objectives addressing application and clinical implementation are required. Doctors have a unique role to play in implementing pharmacogenomics into clinical practice. Comprehensiveness of course curricula across all learning domains would support uptake of pharmacogenomics into routine practice.

PLAIN LANGUAGE SUMMARY

What is this article about?

Pharmacogenomics uses genetic information to individualize drug treatment and its use in medicine is rapidly expanding. This article reviews pharmacogenomic education provided in Australian medical schools to understand how prepared medical graduates are to use pharmacogenomic concepts in daily practice.

What were the results?

The majority of Australian medical schools offer education regarding the science of pharmacogenomics; however, there is limited education on applying this information in the clinical setting to support patients and a multidisciplinary approach to care.

What do the results mean?

Australian medical schools should consider enhancing core pharmacogenomic clinical skills to utilize pharmacogenomics to its full potential.

ARTICLE HISTORY

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KEYWORDS

Pharmacogenomics; precision medicine; undergraduate; medicine; education; content analysis; medical curricula

1. Introduction

Targeting treatments at an individual's genotype and phenotype is often referred to as 'precision medicine.' Pharmacogenomics (PGx), a genre of precision medicine, is the use of genetic information (genomics) to individualize drug treatment to maximize efficacy and safety [1]. Discovery and validation of individual PGx variation remains a challenge for drug development, disease management, and predictability of patient outcomes [2]. National investment into schemes to integrate genomics in clinical practice includes the Australian Government-funded $500.1 M Genomics Health Futures Mission [3], whilst Australian Genomics cites funding of up to $155 M from government and philanthropic sources [4].

Screening for pharmacogenetic variability and subsequent individualized therapeutics have the potential to revolutionize clinical practice, as up to 90% of patients carry at least

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Article highlights

Aims
- Objective: To ascertain and describe pharmacogenomic concepts included in the intended curriculum of accredited Australian medical schools.

Methods
- Content Analysis: Focused on curriculum learning objectives using keywords related to pharmacogenomics.
- Categorisation: Learning objectives categorized using undergraduate medical genomics competencies, Bloom's Taxonomy, and knowledge translation.

Results
- Curriculum Analysis: 68% of the curricula included genomic/pharmacogenomic education.
- Competency Representation: Eight schools had content related to undergraduate medical genomics competencies.
- Learning Levels: Majority of pharmacogenomic–related learning objectives were at lower levels of Bloom's Taxonomy (Remember and Understand).

Conclusion
- Current State: Most Australian medical schools have incorporated pharmacogenomics, but application and clinical implementation are underrepresented.
- Future Needs: Enhanced focus on clinical implementation and application of pharmacogenomics in medical curricula is required.

one genetic variability related to medicine efficacy and safety [5]. The field of PGx is rapidly advancing and future prescribers need to be educated to integrate pharmacogenomic concepts into daily practice [6–8]. Research has shown that medical professionals feel underprepared for integrating PGx into their clinical practice due to insufficient training [9]. In a US survey, few physicians (10%) reported feeling confident applying PGx concepts in clinical practice and rarely order PGx tests [10,11]. Integrating PGx test into clinical practice is complex [12]. This complexity is driven by multiple PGx tests for a wide variety of medications, and ethical considerations with respect to communication of results. A multidisciplinary approach is recommended for integration of PGx into clinical practice including pharmacists, nurses, genetic counselors, and other allied health professionals, due to complementary competencies in healthcare [10,13]. Future clinical practice will include PGx as a crucial tool for providing patient-centered care through the personalization of medication treatments [14].

Currently, consumers can access PGx testing either via a referral from a medical professional or through Direct To Consumer (DTC) point-of-care genetic testing [11]. DTC genetic testing has risen in popularity due to patient-perceived confidentiality and control of the process and avoidance of doctors' surgeries [15]. These genetic tests are held in high esteem by the mainstream media and are perceived as highly accurate [15]. However, there is variability in the quality and accuracy of DTC tests including false positives and negatives [15,16]. Consumers have reported anxiety and distress when there is a lack of medical guidance to assist with interpreting PGx results [17], demonstrating the need for medical expertise.

Postgraduate medical education has provided general practitioners (GPs) and specialist medical professionals with some understanding and readiness data about PGx service use [18–23]. Multiple genomics alliances and institutions, involving multiple universities and across several Australian states, have addressed standardized terminology, diagnostics, post-graduate education, and ethical considerations with respect to PGx [4,18,19,23–28].

Pharmacogenomic education varies across medical schools in Australia, North America, and Europe. In Australia, efforts are underway to integrate pharmacogenomics into medical curricula, with national guidelines developed by the Royal College of Pathologists of Australasia [29]. However, awareness among practitioners remains low. In North America, particularly the United States, pharmacogenomics is more established in medical and pharmacy school curricula, supported by guidelines from the Clinical Pharmacogenetics Implementation Consortium. Surveys have shown significant improvements in education since 2005 [30]. In Europe, a survey of 248 medical schools revealed that 87% include pharmacogenomics in their curricula, often as part of pharmacology courses [30]. The European Society of Pharmacogenomics and Personalized Therapy plays a key role in standardizing education across the continent [30]. Overall, while there are regional differences, all three regions are making strides to ensure future healthcare professionals are equipped with pharmacogenomic knowledge for clinical practice.

However, Australian undergraduate medical PGx curriculum is less established. Whilst PGx medical school core curriculum competencies in the US and Europe have been published [31,32], there have been no Australian studies on PGx content in undergraduate medical curricula.

2. Aim

To ascertain the extent of Pharmacogenomics curricula taught in Australian medical schools.

3. Methods

This study used content analysis to explore the learning objectives related to PGx in medical school curricula (i.e., intended curriculum) [33]. The methodology follows that of recently published research exploring PGx curriculum in Australian pharmacy schools [34].

Publicly available medical school curricula were collated, and relevant data were extracted, and content analyzed for relevance to pharmacogenomic-related curriculum activities (Table 1). The universities were selected based on the Australian Medical Council's accredited list. Any programs that were not conducted here in Australia, or did not have publicly available course profiles were not included in the analysis.

The intended curriculum of the medical schools was examined [35], with the understanding that the 'ideal intended' curriculum should provide learners the opportunity to be immersed in and participate in workplaces as a 'social practice,' and provide assisted structural support for progression in their socialization and learning to be a medical professional [36].

Table 1. Content analysis steps (1).

Content analysis steps	Applied to this study
1. Define the research questions to be addressed by content analysis	What pharmacogenomic and medical genomic content are apparent in the intended curricula, and how will this affect their practice as medical professionals?
2. Define the population from which units of text are to be sampled	Formal documentation of medical undergraduate curricula in Australia.
3. Define the sample to be included	Publicly available Australian medical school courses accredited by the Australian Medical Council: 19 schools with detail on aims, learning objectives/outcomes and assessments.
4. Define the context of the generation	JT retrieved the aims, learning objectives/outcomes and assessment details for each course from university websites.
5. Define the units of analysis	Learning aims, objectives, and outcomes. Assessment details were included.
6. Decide the codes to be used in the analysis	Pharmacology terms, pharmacogenetics, and undergraduate medical genetic competencies.
7. Construct the categories for analysis	Revised Bloom's Taxonomy (cognitive and knowledge dimensions); APHMG undergraduate medical competencies; Enabling Science/Translation Science/Clinical Implementation categories.
8. Conduct the coding and categorization of the data	JT and FY conducted the categorization of the data using an Excel spreadsheet independently, and meetings were held to come to a consensus.
9. Conduct the data analysis	JT and FY held sessions for discussing the themes and categories. Steps 6–9 were an iterative process.
10. Summarising	JT wrote a draft and summarized elements of the analysis. FY visualized the data and completed the analysis and discussion.
11. Making speculative inferences	Findings were compared with literature on the medical profession's pharmacogenetics implementation in Australia and abroad.

Medical genomic learning objectives were also included as these provide foundational knowledge for PGx.

4. Data source and identification

Publicly available current (2022) electronic course profiles from accredited Australian medical schools were downloaded [37]. If the 2022 course profile was not available, the previous year's profile was used. Any course that was not publicly available was not included. If the course was offered at multiple locations, only one profile from the main campus location was selected. Subjects that were not part of the core curriculum (i.e., electives) were not analyzed, as not all graduates would partake in these subjects and therefore would not form the basis of their clinical practices.

Course curricula were searched using the following of key phrases: 'pharmacogenomics,' 'pharmacogenetics,' 'genetics,' 'genes,' and 'bioinformatics.' Each source data was further explored for key terms closely related to the above phrases, including terms like 'pharmacokinetics' and 'pharmacodynamics' and application of these principles.

The undergraduate medical genetics curriculum by the Association of Professors in Human and Medical Genetics (APHMG) was also used to identify relevant content. At the time of the study, the APHMG curriculum content had been recently reviewed by international genetic education expert committees including the European Society of Human Genetics, National Coalition for Health Professional Education in Genetics (NCHPEG) and the Genetics/Genomics Competency Centre for Education [32,38,39].

5. Data extraction

All identified course content was initially screened by one author (JT) for relevance to the study objectives, in an iterative deductive process. The screening was purposively over-inclusive due to the broad nature of learning objective descriptions, since they may not be fully representative of the educational content actually taught (i.e., if key words were not apparent but hinted at genomics or pharmacology topics, they were included). Collated data were reviewed by two other researchers for validation and cross-checking.

Learning objectives that did not mention genetics, pharmacogenetics or pharmacology topics were excluded from the analysis. Broad learning objectives repeated in different subjects more than twice during one course were excluded. Extracted data and exclusions were then independently screened by two authors (NK and FY). Conflicts were discussed within the research team to reach consensus.

6. Data analysis

The identified learning objectives were mapped to analyze the extent of PGx education provided to medical students, and discussed among the research team until consensus was reached.

(1) Learning objectives were categorized according to the 2013 APHMG medical school core curriculum in genetics (Appendix 1).
(2) Extracted data were evaluated using the revised Bloom's Taxonomy's Cognitive and Knowledge Dimensions (Figure 1). These categories include the cognitive levels of Remember, Understand, Apply, Analyse, Evaluate, and Create, and the knowledge levels of Factual, Conceptual, Procedural, and Metacognitive Knowledge [40]. These categories signify increasing depth of learning. The research team interpreted the learning objectives according to competencies required for medical practice: for example, the learning objective "Critically review the significance and scope of bioinformatics in biology and biotechnology;" was categorized by Bloom's Taxonomy as "Evaluate" due to the critical analysis required to apply such information in practice, and "Procedural knowledge" as this task would be necessary to perform as a medical professional involved in personalized medicine.
(3) A previously developed scale of translation knowledge ("enabling science," "translational science," "clinical implementation") [34] was used to further categorize learning objectives, in order to understand the utility of

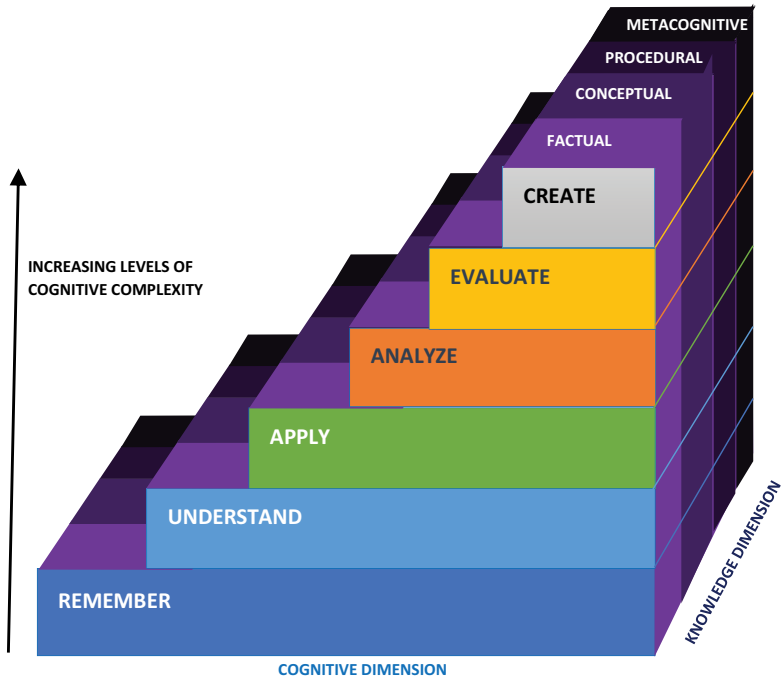


Figure 1. Visualisation of the revised bloom's taxonomy hierarchy, adapted from krathwohl 2002 and used with permission from Venugopal et al. 2022[34].

this learning content for PGx implementation into practice. 'Enabling science' would comprise the understanding of basic scientific concepts; 'Translational science' would relate to these concepts being associated or applied to healthcare in general; and 'Clinical implementation' describes the implementation of PGx practices, methods, and treatment into clinical practice.

Findings were summarized to determine what PGx concepts were intended to be taught to undergraduate medical students in Australia.

7. Results

Eighteen university websites were searched for medical curriculum details. Nineteen medical school programs were identified from 13 medical schools in Queensland, ACT, Victoria, NSW, South Australia, and Tasmania (one university had both undergraduate and post-graduate course websites).

Of the included 19 programs, 13 (64%) had related learning objectives (Table 2). The number of relevant subjects per school ranged from 1 to 5. This included broad concepts about DNA, genetic variation in disease, and bioinformatics. Eight out of 13 (61.5%) medical school curricula contained learning objectives (LOs) related to APHMG competencies (range 3 to 62) (Table 2)

The most represented APHMG competency domain curricula were Medical Knowledge: Gene Knowledge/Genome regulation (IA), and Medical Knowledge: Genetic Variation (IB). APHMG competencies not represented related to specific communication of genetic information (as distinct from other medical information) to patients, families, and carers, or collaboration with genetic professionals (Figure 2).

Of the PGx-related learning outcomes, there was a spread in the Bloom's Taxonomy cognitive dimensions, where the majority of the objectives were classified in 'Understand' (62%) and 'Apply' (18%) (Figure 3).

The categorization of learning objectives into the knowledge translation categories is represented below in Figure 4, with the

Table 2. Summary of Australian medical degrees with publicly available genetics- or pharmacogenomics-related content in learning objectives.

University	Coursework Subjects (No., Titles)	Total APHMG competencies represented
Australian National (ANU)	2. MEDI8030, MEDI8040	3
Bond	3. BMED11–207, BMED12–120, BMED13–214	31
Deakin	1. No title given	5
Flinders	5. BIOL1102, BIOL2772, BIOL3761, CHEM1202, MMED2934	42
James Cook	2. MD1020, MD3011	62
Macquarie	3. MEDI8100, MEDI8202, MEDI8301	0
Monash	4. MED1200, MED2100, MED3100, MED5105	0
Melbourne	1. MEDS90020	0
Newcastle/ University of New England	2. MEDI1101A, MEDI6201A	0
Queensland	3. MEDI7311, MEDI7313, MEDI7314	49
Sydney	2. MDMP5511, MDMP6511	0
Tasmania	3. CAM101, CAM201, CAM304	27
Wollongong	3. BIOL103, BIOL213, CHEM325	17

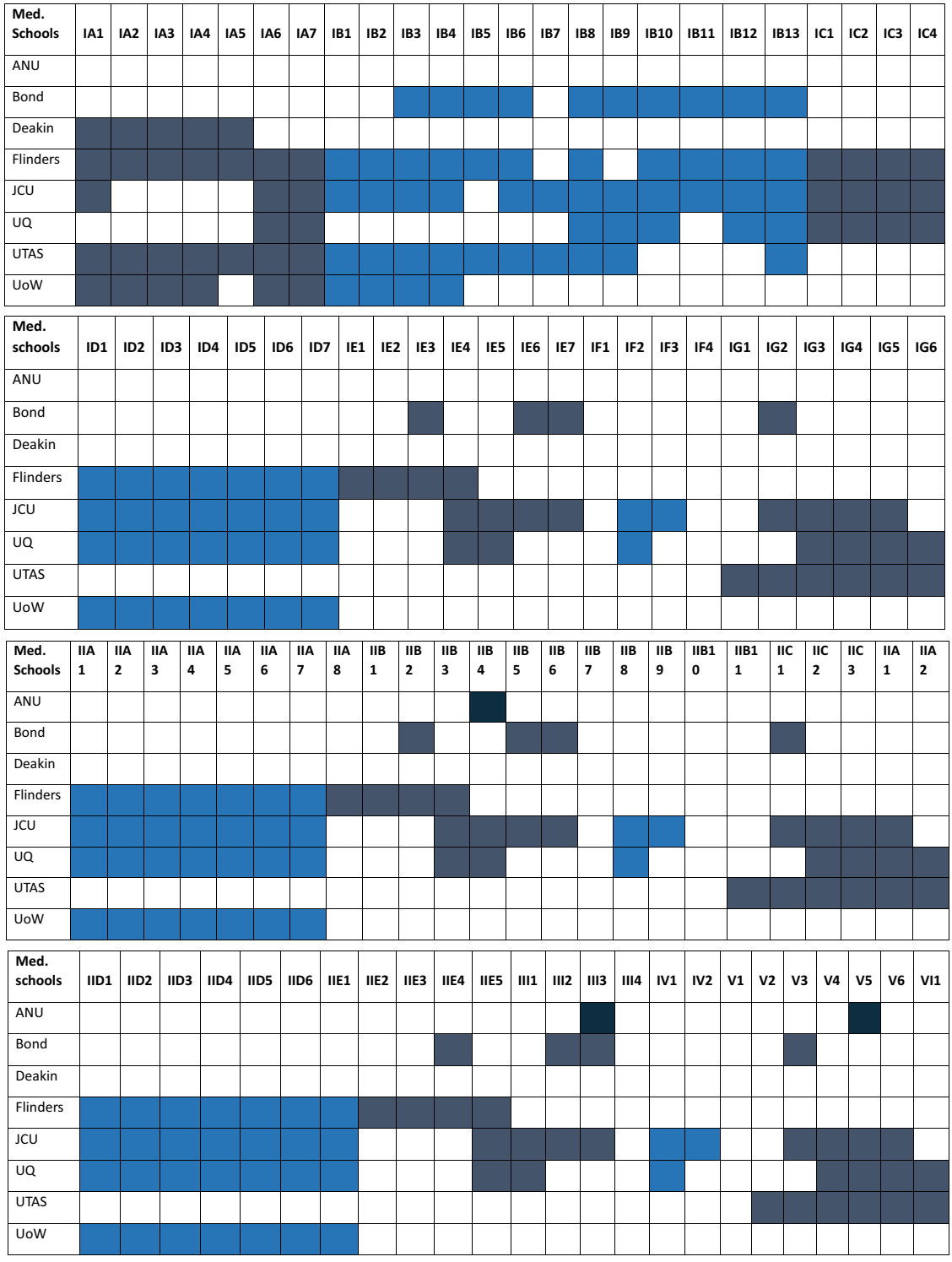


Figure 2. APHMG competencies represented in medical school learning outcomes.

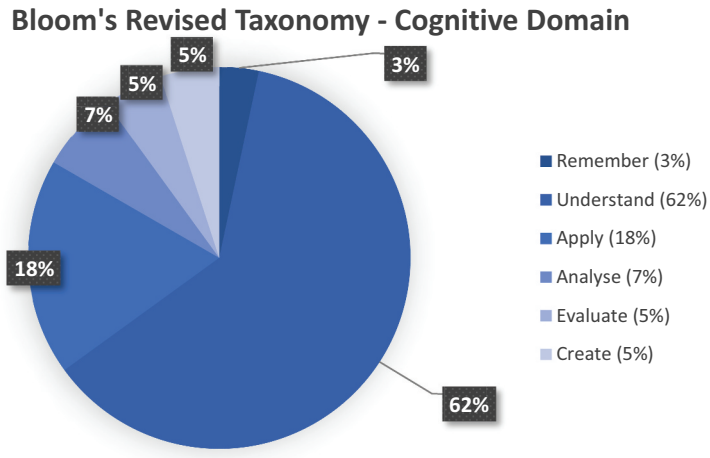
majority (by a small margin) falling under 'Translational Science' (46.7%, $n = 28$).

8. Discussion

This study shows that whilst the majority of Australian medical curricula includes genomic- and pharmacogenomic-related content, a large proportion of learning objectives are not met. No curricula covered all learning objectives with patient communication and multidisciplinary approaches poorly represented. Knowledge to support clinical implementation of PGx was also poorly represented.

Below, we discuss the implications of the categorized learning objectives, the changes required for increasing medical genetics learning, methodology confounders, and the importance of learning metacognitive knowledge in relation to pharmacogenomics competencies.

a. Cognitive Domains and Knowledge (in green) Domains.



b. Knowledge Domains.

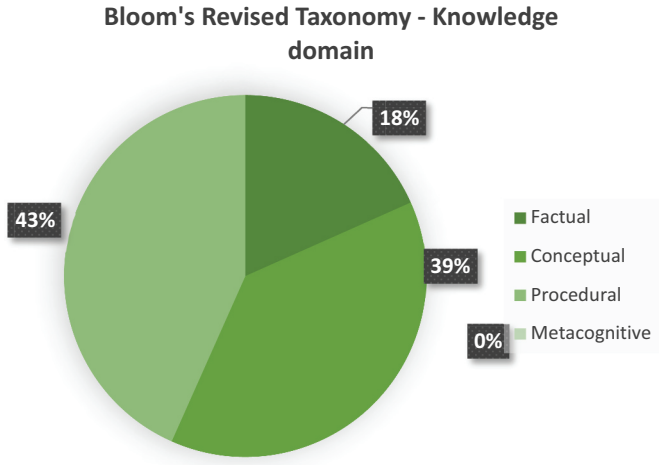


Figure 3. Categorisation of included genomic- and pharmacogenomic-related learning objectives in Bloom's revised Taxonomy.

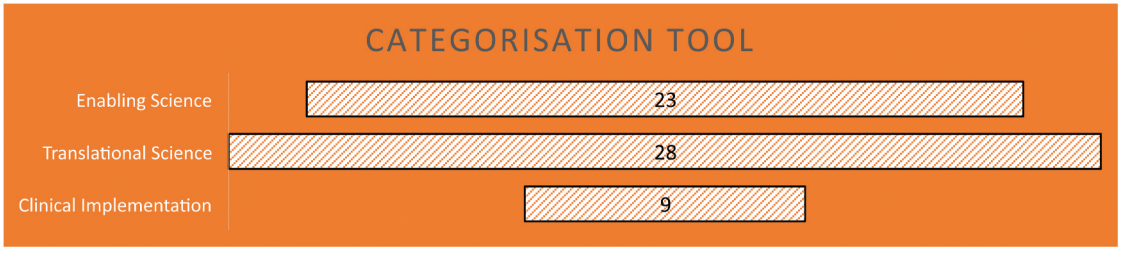


Figure 4. Self-developed scale categorization of genomic- and pharmacogenomic-related learning objectives.

Where PGx learning objectives were included in the intended curriculum, they often focused on lower-order learning objectives with few directly addressing the application of PGx concepts in clinical practice. Given this is a rapidly progressing area of clinical practice, further inclusion of genetic- and pharmacogenomic competencies for the future medical workforce would aid implementation of the rapidly emerging technology of personalized medicine [41,42]. Genomic medicine is a multidisciplinary process [42] wherein medical professionals are leaders for healthcare systems [43,44], and should therefore be further trained in advance when possible. Utility of PGx competencies should be used together with professional behavior guidelines from the AAMC Medical School Objectives Project in Genetics Education [32,38,39], since use of PGx requires sensitivity and a high standard of patient confidentiality.

To further enhance pharmacogenomics inclusion in medical curricula, core medical competencies in evaluating research evidence to make individualized clinical decisions should be further integrated. Introducing students to a range of meaningful research experiences, research skills and relevant communities of learning [45,46] could provide future medical professionals and medical practices necessary contextual information to evaluate genomic medicine research and implement findings into practice. Such communities of learning and workplace training opportunities are currently being constructed by Australian Genomics [18,20,27,47]. Critical evaluation of such research studies requires a procedural understanding of both the research process and topic involved. Basic understanding of the science behind genomic medicine is vital. Thus, use of the comprehensive APHMG medical genetics competencies in medical curricula may begin to address medical professionals' understanding of personalized medicine.

Recognition of the importance of personalized medicine to individual patient care by Australian regulatory bodies of medicine, such as the Australian Medical Council and the Medical Board of Australia, may be necessary to integrate PGx into medical competency standards. Whilst some postgraduate medical courses require a basic science undergraduate degree which may have some of these competencies within their course curricula, this factor should not be relied upon to ensure core medical learning. The support of the Australian Medical Council and other similar bodies, which determine end goals for medical training (i.e., Outcome-Based Education (OBE) [48]), may thus be pivotal in ensuring PGx content is integrated into tertiary-level medical training.

There has been a rise in the adoption of direct-to-consumer (DTC) PGx testing which poses a challenge for healthcare providers, including medical professionals. The medical curriculum may include modules that teach students how to critically evaluate and select appropriate PGx tests. This involves understanding the validity, reliability, and clinical utility of various tests, weather accessed via DTC or through pathology providers. Additionally, incorporating case studies can help illustrate the decision-making process for selecting tests based on patient history, genetic predispositions, and specific medications. To deal with the limitations of DTC testing, the curriculum should apply the development of critical appraisal skills to PGx testing, enabling students to assess the quality and limitations of these tests, including potential biases and the accuracy of results.

Most medical frameworks of learning are analytical and start with a set of abstract domains or a profile of what a graduate should look like, usually defined by a set of qualities which are then further unpacked [48]. The strength of this strategy is that it provides a comprehensive description of what is required of the student. This feature is not present in many of the integrated curriculums included in this study since they necessarily cover many topics. Integrated curriculum approaches ensure more streamlined learning for the student since they learn material in context (rather than separated in subjects according to basic science/clinical science categories; these categories are superfluous to medical students) [41,49,50]. Therefore, the presence of pharmacogenomic- and genomic-related learning objectives were more important than number count, and the data was treated in a more qualitative fashion. The challenge of integrated curricula seem to be the decreased detail in course descriptions, rendering it more difficult to understand what was intended to be taught. A large proportion of the curricula included in this study were found to be integrated medical courses through the course descriptions or educational literature, including ANU [41], UNSW [51], USyd [50], and UoW [49].

We acknowledge learning objectives and outcomes merely serve as an intention to teach content, whilst student definitions of knowledge and the gain thereof are meant to occur through learning activities (i.e., pedagogy); assessments should then examine student competency [52]. The knowledge dimension of Bloom's Taxonomy divides knowledge into four subcategories, providing further depth of understanding [40]; the *metacognitive* dimension was not represented in this research. Whilst there was evidence of provision for higher order thinking around the healthcare system and patient care, competencies for genetic information and collaboration are important, and should be addressed separately. The multidisciplinary mode required for genetic treatment will require acquired metacognitive knowledge for the medical professional, and further training in this area is required. Adams [53] also points out that health professional educators continuously wish to develop skills at the higher end of the Bloom's Taxonomy hierarchy, but that studies show that learning objectives are more commonly at the lower end of the pyramid. Our research supports this statement. Problem-based learning, which was well represented in the medical school curricula, seeks to support this higher-order thinking, since it is more akin to workplace learning. There are also further dimensions to medical professional competence such as psychomotor dimensions, e.g., tying sutures, and effective communication skills, e.g., empathy, that are paramount to being a successful health professional [53]. It may be these approaches need to be applied to genetic- and pharmacogenetic-related content as well. Medical educators could benefit from Australian Genomics' publication on various models and theories in genomic education [54].

9. Limitations

First, the information available from each university on their publicly accessible electronic course profiles varied between schools. No university was contacted for more information about their learning objectives, activities, and assessment; it is possible programs contained further pharmacogenomic-related content not listed in their course profile. For example, a 2009 description of ANU medical school integrated curriculum had a stated importance of teaching genomics and 'pharmacogenetic' content [41] that was not reflected within our exploration of their 2022 curriculum, despite iterative passes at the collated and extracted data. The aim and approach used in this study meant that the prior learning of the medical students (such as in previous undergraduate degrees) was not accounted for and may provide variation in the competency of students in PGx upon graduation.

Similarly, most medical school course profiles ($n = 14$, 26.3%) did not relate learning objectives to specific learning activities or assessments; some did not report learning activities at all. Most assessments (e.g., written exams, OSCEs) examined whole-of-subject content without specifying the learning objectives/outcomes they were assessing. Thus, analysis of the learning activities and assessment of genomic- and pharmacogenomic-related content was not possible, particularly as this type of information may not be readily accessible in the public domain. See Appendix 1 for a list of the included learning objectives/outcomes, learning activities and assessments, and the categorization of the learning objectives/outcomes.

It should be acknowledged that standardized digital methodology has been made for curriculum mapping, which has been found to have some utility in curriculum design. Komenda, Víta [55] developed a medical curriculum mapping web-based programme that offers a summary of medical programs to aid in analyzing relevant learning objectives and activities [55] for gap analyses, and may support critical decision making when addressing quality improvement in medical education [55].

10. Conclusions

Pharmacogenomics are likely to play a major role in individualized prescribing to optimize the safety and efficacy of medicines. However, there are significant gaps in Australian medical school training regarding pharmacogenomic knowledge. There is currently little indication in the intended curriculum that Australian medical schools systematically teach genomics-related knowledge and skills. To utilize pharmacogenomics to its full potential, there is an increasing need for medical professionals, as critical members of health care teams, to have adequate relevant education and training.

Author contributions

CF: Conceptualization, Experimental design, Writing – editing, Supervision
CN: Educational conceptualization, Writing – Editing,
FY: Experimental design, Data Analysis, Writing – editing, Supervision
JT: Data Collection, Data Analysis, Writing – first draft
NK: Data checking, Supervision

Disclosure statement

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

Ethical conduct of research

Ethics approval was not required for this study: all data collected was publicly available online information, and no patients or participants were involved.

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Data sharing

All data collected for this research are publicly available. Appendix 2 includes all data collated for this research.

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