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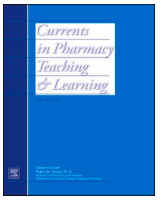

Review Article

A comparison between the delivery of genomic and pharmacogenomic education and training for pharmacy undergraduates between the UK and other international countries: A narrative review

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ABSTRACT

Genomics is perceived to impact healthcare in the United Kingdom and pharmacy professionals are believed to have a key role in the delivery of pharmacogenomic services.
Purpose: To compare the delivery of genomic education within pharmacy undergraduate training between the UK and other countries.
Method: Six electronic databases were searched including MEDLINE, EMBASE and Cochrane Library using variations of the terms pharmacogenomic, genomics and education, looking at all levels of education. No date restrictions were applied. Studies were then screened for duplicates and eligibility for inclusion.
Results: Fifty studies were included and categorised into three main themes: identifying training requirements, training methods, and curriculum design/review. Most studies ($n = 30$) were from the United States. Many international studies highlighted the need to improve pharmacy undergraduate pharmacogenomic training. The pharmacist pharmacogenomic focussed competencies available in the United States have underpinned the development of pharmacist pharmacogenomic education and many studies described a mixed-methods approach to education delivery to ensure pharmacy student pharmacogenomic competence. The curricula evaluation in the Unites States and Australia demonstrated improved pharmacogenomic content within school of pharmacy curriculums but lacks nationwide standardisation.
Conclusions: This review demonstrates global growth in pharmacy pharmacogenomic education, particularly in the US, where competencies and delivery methods have been defined and explored across institutions. The United Kingdom should develop its own competency framework to guide pharmacogenomic education for pharmacy undergraduates. This would support efforts to standardise genomic content in UK pharmacy curricula and promote the creation of standardised tools for effective training across all pharmacy schools.

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Introduction

Genomics is a study of a person's genetic information and pharmacogenomics (PGx) is one aspect of genomics when genetic variation can be used to predict how a person is likely to respond to medicines.[1] The use of pharmacogenomic testing in practice will inform prescribing decisions and is an example of personalised medicine which will potentially reduce a patient's risk of experiencing adverse drug reactions or identify patients who are unlikely to respond to certain treatments.[2] In the United Kingdom (UK), the ambition to mainstream genomics was set out across the four UK nations within the 2020 Genome UK strategy,[3] and pharmacogenetic testing is believed to have an impact on the UK healthcare system with the current availability of reactive single gene tests moving to a more comprehensive panel testing approach within the research phase of development.[4] The implementation of pharmacogenomics is also developing internationally in countries such as the United States (US) and the Netherlands.[5,6]

To support the implementation of pharmacogenomics within routine clinical practice, all countries must address many challenges, one of which is to upskill and prepare the healthcare workforce to safely and effectively deliver pharmacogenomic services. Despite differences within healthcare systems between countries, often the pharmacy profession is believed to have a leadership role in the delivery of pharmacogenomic services and have an appropriate level of genomic knowledge to acknowledge the relevance of pharmacogenomic data in practice.[7]

In a country as ethnically diverse as the UK, incorporating pharmacogenomics into pharmacy education is particularly important. Genetic variability across different ethnic groups can affect how patients respond to medications, highlighting the need for future pharmacists to understand and apply pharmacogenomic principles in a way that supports safe prescribing, and equitable and effective care.[8] Equipping pharmacy undergraduates with the knowledge to interpret and apply pharmacogenomic data in diverse populations is essential for reducing health disparities and ensuring that the benefits of personalised medicine are achieved across all communities. As such, the integration of population diversity into pharmacogenomic education has important implications not only for optimised treatment outcomes and patient safety, but also for public health outcomes in multi-ethnic societies like the UK.[8]

In the UK, numerous national strategies and plans have been developed to progress the healthcare workforce on genomics and the relevance of training healthcare professional undergraduates to deliver future services.[9–13] A National Health Service England (NHSE) pharmacy undergraduate indicative curriculum[14] has been developed to guide UK schools of pharmacy with the potential genomic content that could be included within their pharmacy undergraduate programmes with suggestions over learning resources and content. Whilst in the US, pharmacy specific competencies have been defined for pharmacogenomics,[15] but other international pharmacy specific genomic competencies have not become widely available if they are in existence. Therefore, this review explores the current developments and approaches to genomic and pharmacogenomic pharmacy education internationally in comparison to the United Kingdom (UK) where the published developments are limited, to propose potential next steps for pharmacy undergraduate genomic and pharmacogenomic education and curricula development in the UK.

The aim of this narrative review is to compare the various approaches to the delivery of genomic and pharmacogenomic education and training for pharmacy undergraduate students between the UK and other international countries within published literature.

Methods

Design

This narrative review was conducted following the principles outlined within the RAMESES publication standards for meta-narrative reviews by Wong et al.[16] It was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement.[17]

Search strategy and selection criteria

A comprehensive search of the literature was performed using a combination of controlled vocabulary and free text terms, around the concepts of pharmacogenomics and education, on the following databases from their inception to 30th April 2025: MEDLINE ALL (via OvidSP), Embase (via OvidSP), Scopus (via Elsevier), Cochrane Library (Wiley), British Education Index (EBSCO) and CINAHL (EBSCO). In addition, a basic search was performed on Google Scholar and ERIC (Institute of Education Sciences) to look for additional

literature not captured by the medical databases. See supplementary information for search strategy and terms used.

All references were then imported in Endnote and duplicate references were removed before importing into Rayyan for screening. Reference lists of relevant references were also screened to locate any additional references not captured by the database searches.

Screening and types of included studies and topics

One independent reviewer initially screened the titles and abstracts for eligibility including only primary, original studies exploring pharmacogenomics and genomics undergraduate education published in English Language with no restrictions on time or educational contexts.

Free texts were then obtained; the reviewer then assessed each record against the following criteria including only studies that had: 1) pharmacy students as participants alone or with other healthcare professionals or directly impacting pharmacy student training; 2) undergraduate education focussed study either within the delivery of the education or in identifying the needs of pharmacy students; 3) include pharmacogenomic and/or genomic focussed education delivery; 4) primary studies only. The full texts were then reviewed of relevant studies allowing the integration of quantitative, qualitative and mixed methods designed studies. This manuscript has been submitted as a narrative review rather than a systematic review. As such, it does not follow the methodological requirements of a systematic review, including independent screening by multiple reviewers. This approach aligns with the accepted standards for narrative reviews, which allow for a more flexible and descriptive synthesis of the literature.[18–20]

Data extraction and synthesis

All the necessary information for the narrative review was extracted by the reviewer from the included studies, such as author, publication year, characteristic of participants, objective, methodology, method of assessment and key findings. A thematic approach was then used to categorise the studies by coding data and develop emerging themes which were further refined, and the analysis was checked for accuracy by another independent reviewer.[21]

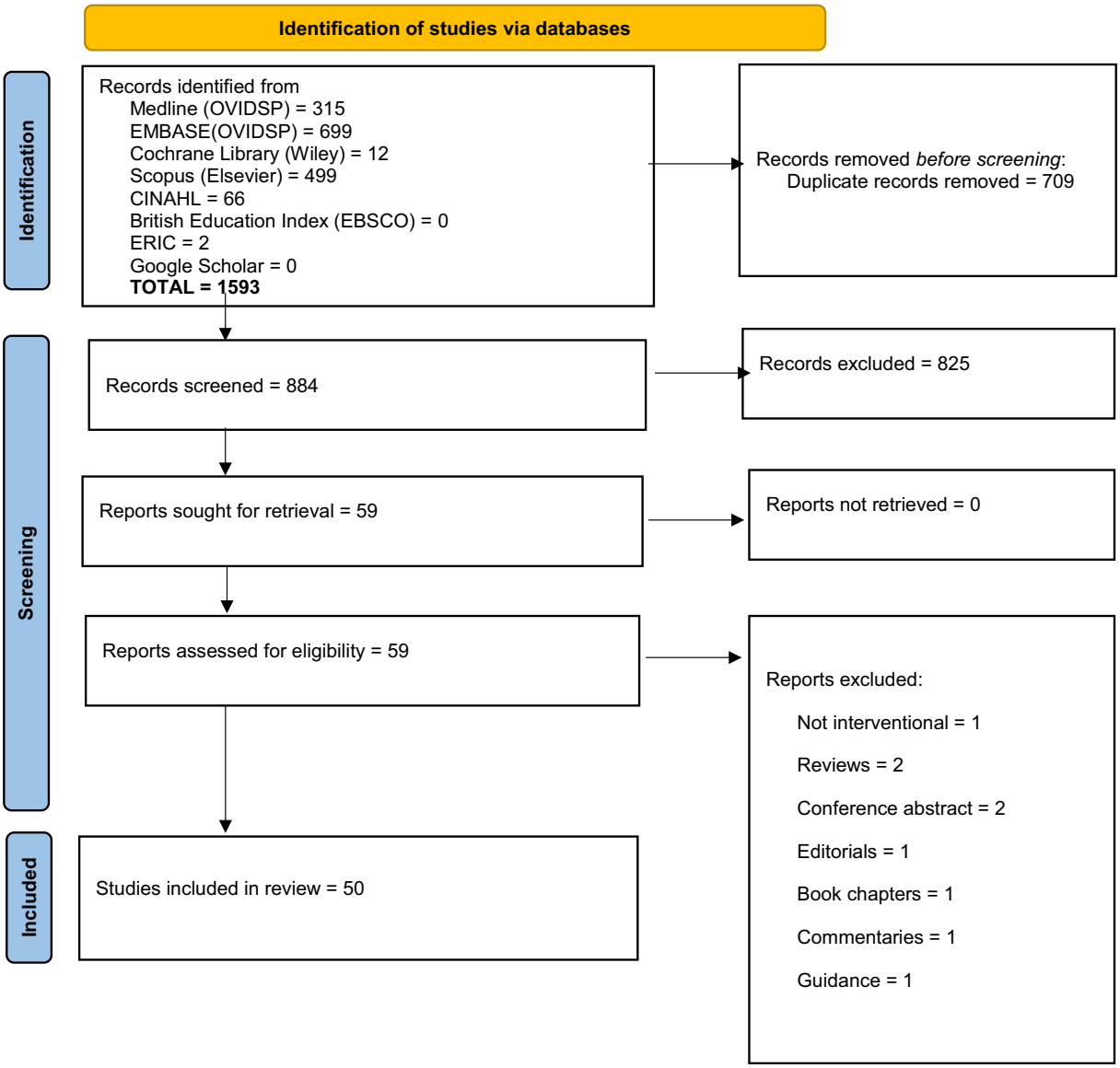
Quality of studies identified

The quality of the studies was assessed using the range of critical appraisal skills programme (CASP) review checklists and the SANRA scale was used to assess the quality of a narrative review.[20,22] There was a wide variation in the quality of studies which were screened for inclusion as some were described and delivered with a focus on minimising bias, whilst others lacked clarity around the methodology used and assessments performed to evaluate tools or obtain data.

Results

Identification and selection of studies

A PRISMA flowchart can be found in Fig. 1, used to record and report on the screening process. The search identified published articles across a variety of databases and resulted in 1593 articles being retrieved, 709 of these were identified as duplicates and were removed. The remaining articles were screened through titles and abstracts, 825 were removed due to their irrelevance to pharmacy undergraduate students training. This resulted in 59 articles being full text reviewed for eligibility. Of those, nine articles were excluded due to the exclusion reasons described in Fig. 1. Finally, a total of 50 studies were included in this narrative review.



Study characteristics

The characteristics of the fifty studies included are summarised in Appendix One. Most of the studies were conducted in the US (n = 38) followed by the UK (n = 3) and one study (n = 1) from each of the following countries: Australia, Bosnia, Indonesia, Jordan, Saudia Arabia, The Netherlands and the Ukraine.

Participant characteristics

Studies selected, included pharmacy students at all stages of undergraduate training but it was not always specified at what year of study they were currently studying. Most studies were for pharmacy students alone (n = 30), but some studies had pharmacy students and registered pharmacists (n = 5) when exploring education interventions such as interprofessional education or focussed education training. Five studies delivered training to pharmacy students alongside medical and/or nurse students (n = 5) and two studies also delivered training to pharmacy students alongside other healthcare professional students and one of those studies was specifically biomedical science participants (n = 1). Studies exploring pharmacy student curricula had schools of pharmacy (n = 6) as study participants when exploring curriculum content within and across a country, as well as one study who explored PGx curriculum across health care professional schools in the world (n = 1). Pharmacy educator participants were also included in some studies when exploring methods of delivering pharmacy undergraduate training (n = 3).

Pharmacy undergraduate study characteristics

The studies found have been categorised within Table 1 into three main themes and sub-themes with further explanation of each theme within this section. The included studies are available within Appendix One.

Theme 1: Training requirements

Nine publications from a range of international countries explored the views of pharmacy students either solely, alongside students undertaking other healthcare programmes or registered pharmacists and focussed largely on pharmacogenomic education. All nine studies used a survey method to obtain the opinion data and were published over an extended time between 2012 and 2025. One of these survey studies was undertaken in the UK in 2019 and explored pharmacy students' opinions alongside registered pharmacists and concluded that pharmacogenomic training needed to be added to undergraduate UK pharmacy curricula as well as training for postgraduate pharmacists, to ensure the pharmacy workforce is ready to support the implementation of pharmacogenomics into routine clinical practice.[23] Other international countries such as the US had three survey studies published over the last decade, but despite advancements in the implementation of pharmacogenomics in some US states over the last 20 years, the need for genomic education to be improved was still concluded within a recent US survey study by Wen et al[24] who found that pharmacy students believed they lack knowledge of the basic concepts of genomics within their training programme. However later publications explored variations within the US pharmacy schools curriculums when explored. Other international countries such as Bosnia, Saudi Arabia and the Ukraine also describe the need for pharmacy student ownership and knowledge of pharmacogenomics specifically for pharmacy undergraduates which is acknowledged by other professions. Finally, despite The Netherlands being well advanced with their pharmacogenomic specific implementation, a survey study by Bank et al[25] described the need to improve pharmacist pharmacogenomic knowledge and training.

Theme 2: Training methods

There were many different methods and approaches to the delivery of pharmacogenomic and genomic education and training for pharmacy undergraduate students but most of the content was focussed on pharmacogenomics. The different methods described and explored have been grouped within five different categories for ease of describing published studies; interprofessional experience, personal genotyping, laboratory and coursework-based learning and focussed training courses.

Interprofessional experience

Interprofessional experience is when a group of individuals from different professional backgrounds learn or receive education together. All five studies concluded that the method of grouping interprofessional students to create an interprofessional learning experience (IPE) whilst undertaking PGx and/or genomic education had a positive impact on students, but the professional background of the students varied within each study. Perwitsari et al[26] and Caliniski et al[27] both described how the use of IPE improved student confidence when discussing IPE as it enabled the hands-on use experience of using PGx in practice as described by Chamala et al.[28] Quesnelle et al[29] also described how IPE improved the attitudes and perspectives of multi-professional students when used in a practical role play setting. The Zhang et al. study[30] explored the use of pharmacy student only peer group sessions after pharmacogenomic teaching and found they added value to their learning experience but did not always improve exam scores.

Personal genotyping

Personal genotyping is when students are offered a DNA test to determine their own personal genetic information which can be used to learn about pharmacogenomics. Nine publications either solely or alongside other education interventions offered personal genotyping to pharmacy students. This approach enabled students to explore case studies using their genetic information to develop their confidence and understanding of pharmacogenomic knowledge. Many studies used different methods of evaluating optional personal genotyping within undergraduate training and found that pharmacy students who consented to providing a DNA sample believed interpreting their own results enabled them to develop a greater knowledge for the application of pharmacogenomics. However, a randomised controlled trial by Grace et al[31] concluded that the use of personal genotyping added no clear benefit to

Table 1
List of established themes and sub-themes from thematic analysis of included studies.

Main themes and sub-themes
1. Training requirements
2. Training methods
a. *Interprofessional experience*
b. *Personal genotyping*
c. *Laboratory and coursework-based learning*
d. *Focussed training courses*
3. Curriculum review and design

pharmacy student knowledge and advised that this funding should be used to fund other methods of delivering pharmacogenomic training for pharmacy students. The studies used commercial companies such as 23andme to provide the personal genotyping available to students.[32]

Laboratory and coursework-based learning

Many methods of delivering pharmacogenomic learning were described within both a traditional laboratory setting by Rao et al[33] and Farrell et al[34] or by approaches such as an active learning laboratory,[35] an AI augmented reality tool[36] or using coursework-based learning e.g. developing a PGx longitudinal poster.[37] Some of these educational interventions were also used in combination with other methods or approaches to learning such as didactic lectures prior to the laboratory sessions and all studies were based in the US. All the evaluation interventions within this theme were evaluated and most of the studies used pre and post educational intervention surveys assessing knowledge and perceptions and found these interventions improved knowledge and student perceptions of PGx, although these methods were most often explored within one academic institution only.

Focussed training courses

Nine US based published studies[38–48] described and evaluated a wide range of training courses for pharmacy students to support the delivery of pharmacogenomic learning at various stages of the undergraduate training journey. Two published studies by Kisor et al[40,41] explored the use of a mixed methods pharmacogenomic training programme for pharmacy students with a focus on the ability of this method to ensure pharmacogenomic competency requirements.[15] Five out of the nine studies used a comprehensive mixed methods approach to assessing knowledge and understanding learning as well as course delivery. One example of this was the Springer et al. study[45] which used the IDEAS assessment model, which involved 3 elements including the use of surveys, student care plans and test scores to assess knowledge.[45] In the Marcinak et al. study,[42] students were also re-assessed on their retention of knowledge in later study years. One study by Nickola et al[43] explored the use of a primer course to ensure the pharmacy students had the appropriate level of genetic knowledge on entry to the pharmacy undergraduate course which had a good effect. Delivery of these focussed training courses were using a mixed methods approach using didactic lectures, laboratory, simulations and AI developed software packages and were not all focussed solely on the delivery of pharmacy student education but also the training of other healthcare professionals.

Theme 3: Curriculum review and design

Nine studies explored undergraduate pharmacy pharmacogenomic and genomic training from different curricula aspects.[38–48] Brown et al[49] compared the curricula content of one US pharmacy school to the US pharmacogenomic pharmacy competencies,[15] whilst another four studies[50–53] evaluated the curricula content of Schools of pharmacy within one country using both survey and manual review methods between 2005 and 2019 and found that pharmacogenomic curricula content showed overall improvement over time despite still highlighting the need for further developments and topic recommendations. One study by Karas et al[54] evaluated the pharmacogenomic content of international healthcare professional schools including pharmacy schools and found that the content was mostly delivered within the pharmacology component of the course, but the training had improved since a previous evaluation in 2005. All studies were based or led by a lead author based in the US, except for the Venugopal et al[55] study which explored Australian pharmacy school undergraduate curricula. Three out of the nine studies explored curricula using a manual review method which involved accessing school of pharmacy curricula via university websites, compared to another approach using a survey method to question their own university staff in the other four studies. One of the US studies by Brown et al.,[49] explored the University of Minnesota's pharmacy school own curricula and compared it to the AACP pharmacogenomic competencies for pharmacists updated in 2022. The study concluded that pharmacogenomic and genomic content needed to be updated and coordinated within their own curricula to ensure their students were able to meet the set pharmacogenomic pharmacy competencies.

All other US studies exploring US pharmacy school curricula were published prior to 2019 and up until this point, demonstrated that there was a lack of standardisation between US pharmacy schools despite having pharmacist competencies available since 2002.[15] All of the five US focussed published studies concluded that their pharmacogenomic and genomic content was developing or improved since the previous evaluation, but more developments were needed to improve and coordinate the content within the US aligned with national competency standards developed. The Australian Venugopal et al[55] study and the Karas et al[54] international healthcare professional schools' studies both also described a need to improve pharmacogenomic and genomic content of their undergraduate curriculums, but Karas acknowledged this could be affected by the variations in the use of pharmacogenomic services in each country. Two studies by Lee et al[47,48] also explored the use of a train-the-trainer method (using a package software programme) whereby the university faculty were trained to deliver pharmacogenomic training. Faculty members found this improved their own knowledge and the delivery of pharmacogenomic education across schools of pharmacies by standardising curriculum delivery.[47,48]

Summary of review findings

Discussion

This review demonstrates the differences and similarities in pharmacy education for pharmacogenomics and genomics across the world compared to the UK and all studies included focussed on pharmacogenomic related aspects of genomics within their pharmacy

undergraduate curricula.

The comparability of findings across the included studies is influenced by several important factors. For instance, methodological differences such as study design (e.g. surveys vs curriculum audits), sampling strategies, and data collection approaches, introduce variability that limits direct comparisons. Also, cohort characteristics such as programme/ curriculum standards and learning outcomes, year of study, institutional setting, and national educational policies differ across countries, potentially affecting students' exposure to pharmacogenomic content. In addition, variations in how pharmacogenomics is integrated into curricula, whether as stand-alone modules or integrated theme, further complicate cross-country comparisons. These contextual differences must be considered when interpreting the findings, as they may partly explain the observed variability in education and training approaches.

Evaluation survey studies within the training requirement's theme explored the knowledge and perceptions of pharmacogenomics and genomics within pharmacy undergraduate education within many international countries. This highlights the worldwide need for pharmacogenomic education inclusion within undergraduate curricula but acknowledging that the needs of pharmacy students will adapt over time, aligned with the implementation of pharmacogenomic services within each respective country.[23–25,56–60]

Most of the narrative review published studies were based in the US where pharmacogenomic implementation has advanced in comparison to the UK enabling the American Association of Colleges of Pharmacy (AACP) body to define and refine pharmacist competencies for pharmacogenomics aligned with implementation development since 2002.[15] The availability of these competencies has enabled the evaluation of curricula content within individual academic institutions and to evaluate curricula content across the US to establish if standardised curricula content is being delivered to educate the graduating future pharmacist cohorts. Although not all schools of pharmacy have participated within the curricula content survey studies which may be due to each academic institution being self-sufficient or not offering pharmacogenomic content. There is therefore a need to explore the baseline UK curriculum content for pharmacogenomics and genomics and then to continually assess content and competence following content developments over time to measure success.

Although the AACP have developed the competencies for the pharmacy profession in the US,[15] the competencies for pharmacist undergraduate level have not been specifically defined but there is separation between foundational genetic concepts and clinical pharmacogenomics. It is also unclear due to a lack of published studies in other international countries if pharmacist competencies are developed and used to inform curricula content for pharmacogenomics or genomics, but competencies may not be defined for undergraduates due to the reduced use of pharmacogenomic services within these countries and the varying recognition for the role of the pharmacist within pharmacogenomic service delivery. The UK does not currently have a published competency framework for pharmacy undergraduates, but it does have a published indicative syllabus that describes potential points for inclusion and how they could be incorporated from current resources available in the UK, some of which are limited in nature.[14] Other countries who are advancing the use of pharmacogenomics in practice such as the Netherlands also describe a lack of defined published pharmacy competencies which does not align with the pharmacogenomic service model chosen within the Netherlands, as the pharmacist plays a key role in performing and delivering the pharmacogenomic testing service.[25] Some international countries may not have developed pharmacy competency and undergraduate curricula content due to the differences in healthcare service delivery as the pharmacist role and level of responsibility and recognition often varies between countries.

Moreover, some countries, such as the US, have begun to embed PGx competencies more systematically into pharmacy curricula using focussed competency framework initiatives and US institution collaboration. These models may offer valuable insights for the UK, where implementation remains fragmented or inconsistent. Regulatory and professional differences also play a role; for instance, in the UK, pharmacists will become prescribers on registration as of 2026, which may offer pharmacists a more established role in clinical decision-making, which can influence how PGx is prioritised within their training.

Within the training methods theme, various types of educational interventions such as interprofessional experiences (IPE) were explored and could mimic the structure of the MDT members to deliver PGx. The IPE approach should be utilised where appropriate to develop multi-professional appreciation for the role of the variety of healthcare professionals involved in pharmacogenomic service delivery. Personal genotyping was perceived to be of benefit within the studies overall, but not all students wanted to be tested. A randomised controlled trial by Grace et al[31] explored this and found that the pharmacogenomic data used did not have to be student specific to support learning e.g. case studies. If a personal genotyping approach to learning were used in the UK to support learning, the use of commercial companies to provide testing in the UK would be looked upon less favourably by UK NHS bodies. This may be due to potential inaccuracy of results if these companies did not have a high level of quality assurance processes in place within their laboratories or if some students were tested and some were not, creating inequity between student exposure within UK academic institutions or within student cohorts. The Royal College of GPs position statement on Direct-to-consumer testing describes these challenges for the use of direct-to-consumer testing although company testing processes are continually improving and more robust approaches to private testing packages may continue to become widely available and attractive for more routine use.[61]

Within the studies exploring training methods, a lack of standardised evaluation methods to delivering content was observed and therefore institutions have varied methods for evaluating the training methods used and therefore unable to compare these methods accurately. A spiralling effect to embedding these training methods into practice through continuous delivery and assessment rather than stand-alone methods was explored by two studies.[42,46] This approach allows the student to build upon their knowledge throughout their pharmacy training and to continue learning post graduating from their academic undergraduate organisations. Although there needs to be sufficient space within the undergraduate programme to spiral this content through, although this may be easier than incorporating lengthy stand-alone methods.

The more up-to-date approaches to delivery such as using AI or simulation approaches and pre-recorded software packages could form part of the approach to standardise training across pharmacy schools by ensuring that all students attain the same level of knowledge.[35,36,41,62] Another approach to standardising school faculty delivered training would be to utilise the train-the-trainer

approach described by Lee et al[47] which would ensure a standardised supportive approach to curriculum delivery across the UK creating less expectations on faculty staff to deliver training with no prior knowledge or support themselves. The train-the-trainer method would enable staff to work independently to deliver training as they would for other topics rather than seeking clinical expert expertise whenever a precision medicine session needed to be delivered to students.

When the evidence within this review (especially within the US) was compared to the UK developments, the evidence demonstrated a need to develop a competency framework for pharmacy undergraduates aligned with the national implementation of pharmacogenomics in the UK to ensure the course focussed on the elements of genomics and pharmacogenomics that pharmacists are expected to deliver within future pharmacy practice models. This coupled with the NHSE indicative curriculum[14] will support the coordination and benchmarking of school of pharmacy curriculum across the UK, but the competency framework needs to be continually updated alike the US model as UK pharmacogenomic testing services increase.

Several systemic and curricular factors influence the implementation of PGx education in the UK, despite growing awareness and its inclusion in the General Pharmaceutical Council's standards for the initial education and training of pharmacists since 2021. A key challenge lies in the autonomy of universities, which often operate independently in designing their curricula. This results in variability in the extent and depth of PGx content delivered to undergraduates.

Additionally, many pharmacy programmes face constraints such as limited curriculum space, a lack of expertise in pharmacogenomic education, and limited funding to adopt advanced technologies (e.g., AI tools for teaching). The UK currently does not have nationally defined PGx competencies for pharmacy graduates, leading to inconsistencies in the skills and knowledge acquired by students across institutions. A move towards standardisation, through clearly defined national competencies, would help ensure all pharmacy graduates achieve a baseline level of PGx competency on graduation.

Furthermore, implementing PGx education at scale would require broader support from national bodies such as the Pharmacy Schools Council, Statutory Educational Bodies, the NHS and the UK government. As a publicly funded healthcare system, the UK must ensure equitable access to both genomic services and the education that supports them. This includes equipping future pharmacists with foundational PGx knowledge that is clinically relevant, while recognising the difficulty of determining the optimal depth of content at the undergraduate level.

Finally, differing expectations and roles across healthcare professional groups (e.g., pharmacists vs doctors) may also influence how PGx education is prioritised and delivered. Compared to systems like the US, which are market-driven, the UK's public healthcare context presents both unique opportunities and challenges for equitable and coordinated implementation of PGx education. See Fig. 2 for recommendations for the UK regarding pharmacogenomic education delivery.

To support the integration of pharmacogenomics (PGx) into pharmacy education, educators should collaborate to develop standardised content and participate in train-the-trainer programmes to build expertise. Regulators can strengthen accreditation standards by clarifying expected PGx competencies and aligning educational requirements with national strategies such as the Genome UK strategy.[3] Curriculum designers should adopt structured approaches such as spiral learning, incorporate competency frameworks, and apply diverse teaching methods including case-based learning and AI-supported tools to embed PGx meaningfully throughout the curriculum.

Strengths and limitations

This is the first UK narrative review that focusses on pharmacy undergraduate training in pharmacogenomic and genomics in comparison to other international countries and it has no restrictions on exploring other healthcare student needs for PGx or genomics if reported. There are likely to be pedagogies and evaluations being used that are not actively published but are instead used for

Key recommendations

- To develop a competency framework for pharmacy undergraduates aligned with the national implementation of pharmacogenomics in the UK
- Interprofessional education (IPE) could be used as it offers an effective way to contextualise PGx within clinical practice by encouraging collaboration between pharmacy, medicine, nursing, and other healthcare students. This approach promotes a team-based understanding of how PGx can inform prescribing decisions, medication safety, and patient-centred care.
- Case-based discussions (CBD) could be used to translate genomic theory into practical application. Simulated clinical scenarios allow students to engage with PGx data, interpret test results, and make decisions based on genetic profiles, thus developing both critical thinking and clinical reasoning skills.
- A "train-the-trainer" model could address the current lack of expertise by equipping educators with the necessary PGx knowledge competencies and teaching tools.
- Emerging technologies, such as artificial intelligence (AI), may also support the delivery of personalised inclusive learning experiences and simulated patient interactions, enhancing student engagement and experience.
- Embedding PGx within regulatory accreditations would ensure consistency across pharmacy programmes and highlight its importance as a core competency in the education and training of future pharmacists.

Fig. 2. Recommendations for the UK regarding pharmacogenomic education delivery.

internal university quality improvement as pharmacogenomics and genomics becomes a clear requirement for pharmacy undergraduate training internationally due to rapid developments within pharmacogenomic implementation. Although unpublished studies were not included, and all relevant databases were searched. As with all types of review articles, this narrative review is inherent with the original studies limitations. A meta-analysis was not undertaken due to the heterogeneity and high risk of bias of the included studies. Therefore, improved quality studies such as those using a large sample and follow up evaluations are needed.

Conclusions

There are limited internationally relevant publications available, but the evidence suggests that all international countries recommend that pharmacy undergraduate pharmacogenomic training needs to be improved and standardised within countries aligned with national healthcare pharmacogenomic developments. In the UK, we need a competency framework for pharmacy undergraduate students related to UK practice to guide curriculum development within academic institutions for standardising pharmacogenomic education for undergraduates to ensure a defined level of competency is achieved upon graduation from each academic institution. This review focussed on pharmacy undergraduate training but there may be some benefit to exploring the genomic content of other health professional undergraduate programmes within future reviews to benchmark content.

Author contribution

S.E.H and A.G. conceived the research question and idea, and S.E.H and A.C conceived the methods in this narrative review paper. A.C. carried out the literature searches as described. Literature was screened and analysed by S.E.H. The original draft was completed by S.E.H. All stages of the work were supervised by A.G. and was consulted during the entire process of method development and data analysis. A.G. and A.C. reviewed the first draft once completed. All authors contributed to the article, revised it, and approved the submitted version. All authors have read and agreed to the published version of this manuscript.

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CRediT authorship contribution statement

Sophie Harding: Conceptualization, Methodology, Data curation, Investigation, Writing – original draft. **Anne Cleves:** Data curation, Writing – review & editing. **Amira Guirguis:** Conceptualization, Visualization, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

No potential conflict of interest was reported by the author(s).

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Appendix One. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cptl.2025.102481.

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