A Scoping Review of Pharmacogenomic Educational Interventions to Improve Knowledge and Confidence

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1. Introduction

Pharmacogenomics refers to genetic variation within an individual’s genome which can result in proteins with altered function, affecting drug pharmacokinetics (absorption, distribution, metabolism, and elimination) and/or pharmacodynamics. Through pharmacogenomic testing, an understanding of an individual’s pharmacogenomic profile can facilitate individualized medicine by informing decisions on medication selection and dose. For example, the dose of fluoropyrimidines should be reduced by 50% in people with DPYD*2A, which encodes for reduced functioning dihydropyrimidine dehydrogenase (involved in fluoropyrimidine metabolism) to avoid severe toxicity. This tailored approach ensures that patients are exposed to safe and efficacious drug therapy, aiming to improve patient quality of life and longevity.

While pharmacogenomic-guided medication management has clinical utility for various therapeutic areas, including cardiology, psychiatry, and oncology, implementation into practice remains uncommon. Clinical implementation of pharmacogenomics requires a multidisciplinary approach that involves prescribers and non-prescribers. Pharmacists play a key role in pharmacogenomic implementation given their extensive knowledge of drug interactions, allowing them to account for phenoconversion. A key barrier to the use of pharmacogenomic testing by health care professionals in Australia and overseas is a lack of health care professional knowledge, understanding and skill-based training in this rapidly evolving field. Consequently, health care professionals lack understanding of when and how to integrate pharmacogenomics into medication decisions. In response, many university curricula, particularly within schools of

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pharmacy, have integrated new (or improved existing) educational interventions to build student capacities in pharmacogenomics.13

Many pedagogical (eg, case-based scenarios, simulations, flipped classrooms), and experiential (eg, student self-pharmacogenomic testing) teaching methods are used to enhance and retain pharmacogenomic knowledge.14 A review by Venugopal and colleagues15 used curriculum mapping of Australian pharmacy schools to highlight pharmacogenomic education prevalence and the associated learning activities, revealing that most Australian pharmacy degree programs have included pharmacogenomics in their curricula. A recent review16 determined the effectiveness of educational interventions to improve pharmacogenomic knowledge and practice in medical, physician assistant, pharmacy and nursing health care professionals and students. All of the pharmacogenomic educational interventions improved knowledge and/or confidence measures. However, the best approach to integrate pharmacogenomic education in university curricula to facilitate the knowledge and skill acquisition relevant for clinical practice, remains unknown. Therefore, this systematic scoping review aims to comprehensively explore the educational approaches used worldwide to develop clinically relevant knowledge and confidence of pharmacogenomics in medical, pharmacy and nursing students.

2. Methods

2.1. Protocol

A systematic scoping review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews.16 No protocol registration was conducted.

2.2. Eligibility Criteria

Studies were included if they described and assessed the impact (eg, changes in knowledge, or confidence) of an educational intervention used to teach pharmacogenomics in the medicine, physician assistant, pharmacy or nursing university curriculum. Only studies written in the English language that were published within the last 10 years were included. Commentaries, conference abstracts, and studies with a sample size of less than 10 students were excluded.

2.3. Search Strategy

Ovid MEDLINE, Embase Classic, Scopus, and EBSCOhost CINAHL databases were searched (limited to 1 January 2013 to 24 March 2023). The search strategy was devised with an expert librarian, and included the following subject headings: “students, pharmacy,” “students, nursing,” “students, medical,” “education, pharmacy,” “education, nursing,” “education, medical,” and “pharmacogenetics.” This was accompanied by the following terms: “student”, “pharmac”, “student”, “nurs”, “student”, “medic”, “pharmac curricul”, “nurs curricul”, “medic curricul”, and “pharmacogenomic”. This strategy was adapted using database-specific search strategies. Citation searching of a key systematic review17 was conducted to identify additional studies.

2.4. Selection of Sources

The search results were imported into Covidence17 where duplicate studies were removed. Two independent reviewers screened the titles and abstracts. For each study that passed the initial screening, the full text was screened by the independent reviewers to determine eligibility.

2.5. Data Extraction

Two reviewers independently extracted data using a standardized form developed by the study investigators. The data extracted included: study demographics (eg, year of intervention), intervention design (eg, compulsory), intervention delivery (eg, online), and intervention evaluation (eg, pre and post intervention survey). Any conflicts during screening and data extraction were resolved by referral to a third independent reviewer until a consensus was reached.

2.6. Data Synthesis

In the results tables, studies were listed in ascending order according to the year of intervention. Knowledge of pharmacogenomics prior to the educational intervention was recorded if studies used indicative terms such as ‘prior’ or ‘assumed.’ If the duration of the intervention was not reported, the duration was estimated based on the length of the semester (when applicable). If this was also not reported, then credit hours were reported (else, “not reported”). Student knowledge, confidence in report interpretation, confidence in communication with patients and other health care professionals, and competence in acquired skills were assessed. Knowledge of pharmacogenomics was typically assessed objectively (eg, examination questions) and reported as the percentage of correct answers, before and after the intervention. To enable comparison across studies, the absolute difference in knowledge before and after the educational intervention was calculated (ie, by subtracting the postintervention percentage of correct answers from the preintervention percentage). Some studies provided the percentage of correct answers of individual knowledge questions, so the average of these percentages was calculated. For studies that did not describe knowledge as the percentage of correct answers, raw results were reported but excluded from comparisons. The P-values were reported from studies when documented.

The assessment of self-reported confidence was variable. Some studies used nonvalidated surveys that asked students to rate their confidence in the application of knowledge, such as “I am confident I can answer questions from patients on pharmacogenomics”. For each study, 2 investigators independently identified the questions that best related to the 3 predetermined confidence areas.3,18–40 Any conflicts were resolved by referral to a third independent reviewer until a consensus was reached. Most studies reported confidence using a 5-point Likert scale, while others used scales out of 3 or 4. For studies reporting confidence using a 5-point Likert scale, the “strongly agree” and “agree” categories were combined, as were “strongly disagree” and “disagree.”

To enable comparisons across studies, the absolute difference in confidence (percentage of strongly agree and agree) responses before and after the educational intervention was calculated (ie, same approach as knowledge calculations). For one study, the percentage of ‘agree’ and ‘strongly agree’ responses were combined to calculate the average percentage of positive responses. For 2 studies, the positive responses were calculated through the reciprocal of the reported negative response. For studies that used an alternative scale (eg, 4-point Likert scale), raw results were reported but excluded from comparisons. The P-values were reported from studies when documented. For studies that evaluated the competence of skill acquisition, the raw results were reported.

3. Results

3.1. Study Selection

A total of 1205 studies were identified from database searches, and 8 studies were identified from citation searching of a key systematic review15 (Fig. 1). Following duplicate removal, 654 studies were screened based on the title and abstract. A total of 127 studies qualified for a full-text review. After full-text review, 24 studies were eligible for data extraction. Most of the studies (56%, 58 of 103) were excluded because the educational intervention focused on genomic medicine, and not pharmacogenomics.
Fig. 1. PRISMA Flow Diagram for Study inclusion.
3.2. Study Characteristics

All studies were conducted in North America (United States and Canada), except for one conducted in South America (Peru) (Table 1). Washington State University (8%, 2 of 24) and Manchester University (8%, 2/24) contributed more than one study that spanned multiple years (between 2015 and 2017, and 2015 and 2018, respectively). The mean number of students per study was 143 (range 15–318). This average excludes one cross-institutional study (43 sites). All but one study conducted in North America (United States and Canada), except for one conducted in South America (Peru)

3.4. Impact of Education on Knowledge Acquisition in Pharmacogenomics

Due to the heterogeneity in the measurement of knowledge, only 12 studies (50%, 12 of 24) that evaluated the impact of educational interventions on student knowledge through the percentage of correct answers in surveys, were compared. For these studies, knowledge results improved on average by 23% (range 6% – 65%) with the educational intervention (Fig. 2A). Knowledge improved by 20% (range 6% – 65%) in the studies that used self-pharmacogenomic data (own or aggregated form) (75%, 9 of 12) compared to an improvement of 16% (range 13% – 19%) for studies using mock pharmacogenomic data (17%, 2 of 12). In the one study that used the pharmacogenomic data of a faculty member, knowledge improved by 37% in the postcourse knowledge questions. For the study which implemented the simulation activity, knowledge improved by 13% (from 64% to 77%). In the study that evaluated peer-led study groups, knowledge improvement was similar among students who attended the study group (87%) compared to those learning independently (86%). In one study that compared an intervention group (exposed to self-pharmacogenomic testing, a flipped classroom approach and case-based scenarios) with a control group (exposed to didactic lectures and quizzes), knowledge improvement was higher in the intervention group (22%) compared to the control group (9%). Another study that compared knowledge outcomes between a genotyped and nongenotyped group, knowledge improvement was higher in the genotyped group (31%) compared with the nongenotyped group (1%). Of the 2 studies which reported on knowledge retention, knowledge decreased by 4% 4 years post-intervention, while the other study found that 77% to 100% of students answered all knowledge questions correctly 6 months after the intervention.

3.5. Impact of Education on Confidence in Skill Acquisition in Pharmacogenomics

Most (71%, 17 of 24) of the studies evaluated the student self-reported confidence on at least one of the 3 key skills-based domains: pharmacogenomic report interpretation, communication of pharmacogenomic-related information to patients, and to other health care professionals.

3.6. Interpretation of Pharmacogenomic Data

Seven studies (41%, 7 of 17) evaluated the percent change in confidence of students to interpret pharmacogenomic data. Overall, confidence improved on average by 30% (range – 12% to 69%) (Fig. 2B). Students using their own or aggregated pharmacogenomic test data, observed an improvement in confidence by 35% (range –12% to 69%), whereas a 37% improvement in confidence (range 22% – 47%) was reported for studies using mock pharmacogenomic data. In one study that compared the confidence in report interpretation between a genotyped and nongenotyped group, improvement in confidence was higher in the nongenotyped group (38%) compared with the genotyped group (22%). One study that utilized interprofessional learning found that confidence in report interpretation decreased by 12% in pharmacy students and did not change in medical students.

3.7. Communication of Pharmacogenomic Information to Patients

Seven of the studies (41%, 7 of 17) evaluated the percent change in confidence of students in communicating pharmacogenomic information to patients (Fig. 2C). Confidence improved on average by 41% (range 24% – 74%). For students using their own or aggregated pharmacogenomic data, confidence improved by 50% (range 29% – 74%) compared to an improvement of 34% (range 24% – 47%) for students using mock pharmacogenomic data. In one
<table>
<thead>
<tr>
<th>Study</th>
<th>Year of intervention</th>
<th>Country</th>
<th>Size of student cohort (N)</th>
<th>Compulsory</th>
<th>Prior PGx knowledge assumed</th>
<th>Duration of education</th>
<th>Mode of delivery</th>
<th>Teaching activities</th>
<th>Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salari and colleagues, 2013</td>
<td>2010</td>
<td>United States</td>
<td>46c</td>
<td>No</td>
<td>No</td>
<td>8 weeks</td>
<td>In person</td>
<td>Yes, using own PGx test results (cost NR) or mock data</td>
<td>N/A</td>
</tr>
<tr>
<td>Nickola and colleagues, 2013</td>
<td>2010-2013</td>
<td>United States</td>
<td>310b</td>
<td>Yes</td>
<td>No</td>
<td>Semester long (3 or 2 credit hours)</td>
<td>In person</td>
<td>Yes, using student aggregate PGx test results (cost NR)</td>
<td>N/A</td>
</tr>
<tr>
<td>Lee and colleagues, 2015</td>
<td>2010-2012</td>
<td>United States and Canada (43 schools of pharmacy)</td>
<td>2674b</td>
<td>Dependent on school</td>
<td>No</td>
<td>Dependent on school</td>
<td>In person</td>
<td>Shared PharmGenEd curriculum</td>
<td>NR</td>
</tr>
<tr>
<td>Bova and colleagues, 2014</td>
<td>2013</td>
<td>United States</td>
<td>51b</td>
<td>No</td>
<td>No</td>
<td>Semester long (15 weeks)</td>
<td>Online</td>
<td>Yes, using one faculty members PGx test results (cost $207/test)</td>
<td>N/A</td>
</tr>
<tr>
<td>Weitzel and colleagues, 2016</td>
<td>2014</td>
<td>United States</td>
<td>34b</td>
<td>No</td>
<td>NR</td>
<td>16 hrs over 8 weeks</td>
<td>Online</td>
<td>Yes, using own PGx test results (at no cost) or mock data</td>
<td>Blog format – read a weekly blog by coordinators and peer responses</td>
</tr>
<tr>
<td>Surofchy and colleagues, 2017</td>
<td>2014</td>
<td>United States</td>
<td>122b</td>
<td>Yes</td>
<td>NR</td>
<td>Semester long (10 weeks)</td>
<td>In person</td>
<td>Yes, using own PGx test results (cost covered, $50/test) and mock data</td>
<td>N/A</td>
</tr>
<tr>
<td>Medina and colleagues, 2022</td>
<td>2014</td>
<td>Peru</td>
<td>160c</td>
<td>No</td>
<td>NR</td>
<td>10 hrs</td>
<td>Online</td>
<td>Yes</td>
<td>Information and Communication Technologies and Problem-Based Learning</td>
</tr>
<tr>
<td>Adams and colleagues, 2016</td>
<td>2014</td>
<td>United States</td>
<td>122b</td>
<td>Yes</td>
<td>NR</td>
<td>NR</td>
<td>In person</td>
<td>Yes, using own PGx test results (at no cost) or mock data</td>
<td>N/A</td>
</tr>
<tr>
<td>Marcink and colleagues, 2018</td>
<td>2014</td>
<td>United States</td>
<td>197b</td>
<td>Yes</td>
<td>No</td>
<td>Semester long (2 credit hours)</td>
<td>In person</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>O'Brien and colleagues, 2016</td>
<td>2014, 2015</td>
<td>United States</td>
<td>125d</td>
<td>Yes</td>
<td>No</td>
<td>1.5 hrs</td>
<td>In person</td>
<td>Yes, using student aggregate PGx test results (cost NR)</td>
<td>Workshop</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Study</th>
<th>Year of intervention</th>
<th>Country</th>
<th>Size of student cohort (N)</th>
<th>Compulsory</th>
<th>Prior PGx knowledge assumed</th>
<th>Duration of education</th>
<th>Mode of delivery</th>
<th>Teaching activities</th>
<th>Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arwood and colleagues, 2021</td>
<td>2014-2016</td>
<td>United States</td>
<td>285(^b)</td>
<td>Yes</td>
<td>NR</td>
<td>Control: 10 weeks</td>
<td>Hybrid</td>
<td>Yes Intervention: Yes, using own PGx test results (cost covered) or mock data Control: No</td>
<td>Flipped classroom, discussion boards, journaling</td>
</tr>
<tr>
<td>Remsberg and colleagues, 2017</td>
<td>2015</td>
<td>United States</td>
<td>133(^b)</td>
<td>Yes</td>
<td>Yes</td>
<td>Semester long (2 hrs per week)</td>
<td>In person</td>
<td>Yes Yes, using own PGx test results or aggregate data (cost NR)</td>
<td>N/A</td>
</tr>
<tr>
<td>Patel and colleagues, 2018</td>
<td>2015</td>
<td>United States</td>
<td>113(^b)</td>
<td>Yes</td>
<td>Yes</td>
<td>3 hrs</td>
<td>Online</td>
<td>Yes Yes, using mock data only. No personal PGx test results used (at reduced cost)</td>
<td>IGx simulation involving patient case review; report interpretation, SBAR note, counseling Weekly group session and laboratory</td>
</tr>
<tr>
<td>Frick and colleagues, 2018</td>
<td>2015, 2016</td>
<td>United States</td>
<td>222(^b)</td>
<td>Yes</td>
<td>No</td>
<td>75 hrs</td>
<td>In person</td>
<td>Yes Yes, using mock data only. No personal PGx test results used (at reduced cost)</td>
<td>NR</td>
</tr>
<tr>
<td>Kisor and colleagues, 2019</td>
<td>2015-2018</td>
<td>United States</td>
<td>6(^b)</td>
<td>No</td>
<td>NR</td>
<td>NR</td>
<td>Online</td>
<td>Yes Online PGx certification program Interprofessional education laboratory Team activities: paper, verbal presentation, genetic counseling, class debate</td>
<td>Chapter quizzes, Mid-term exam, Final exam</td>
</tr>
<tr>
<td>Galinsky and colleagues, 2016</td>
<td>2016</td>
<td>United States</td>
<td>71(^a,b), 25(^a,d)</td>
<td>Yes</td>
<td>No</td>
<td>1 hr long session</td>
<td>In person</td>
<td>Yes Yes, using mock data only. No personal PGx test results used (at reduced cost)</td>
<td>NR</td>
</tr>
<tr>
<td>Gálvez-Peralta and colleagues, 2018</td>
<td>2016</td>
<td>United States</td>
<td>76(^a)</td>
<td>Yes</td>
<td>NR</td>
<td>Semester long: 1 hr team activity/quiz per week + 3 lecture sessions per week</td>
<td>In person</td>
<td>Yes Yes, using mock data only. No personal PGx test results used (at reduced cost)</td>
<td>NR</td>
</tr>
<tr>
<td>Powers and colleagues, 2019</td>
<td>2016</td>
<td>United States</td>
<td>130(^b)</td>
<td>Yes</td>
<td>NR</td>
<td>Semester long: 2 hr sessions 3 times per week 14 weekly 1 hr sessions during semester</td>
<td>In person</td>
<td>Yes Yes, using mock data only. No personal PGx test results used (at reduced cost)</td>
<td>Laboratory</td>
</tr>
<tr>
<td>Zhang and colleagues, 2020</td>
<td>2016, 2017</td>
<td>United States</td>
<td>284(^b)</td>
<td>No</td>
<td>Yes</td>
<td>NR</td>
<td>Online</td>
<td>Yes Yes, using mock data only. No personal PGx test results used (at reduced cost)</td>
<td>Peer-led study groups</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Study</th>
<th>Year of intervention</th>
<th>Country</th>
<th>Size of student cohort (N)</th>
<th>Compulsory Prior PGx knowledge assumed</th>
<th>Duration of education</th>
<th>Mode of delivery</th>
<th>Teaching activities</th>
<th>Assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calinski and colleagues, 2021</td>
<td>2016, 2017</td>
<td>United States</td>
<td>97b, 67c</td>
<td>Yes: medical students No: pharmacy students</td>
<td>3 hrs</td>
<td>In person</td>
<td>No Yes, using mock and aggregate data (at no cost)</td>
<td>Interprofessional education Prescriptions writing assessed by independent reviewers.</td>
</tr>
<tr>
<td>Grace and colleagues, 2021</td>
<td>2017-2020</td>
<td>United States</td>
<td>318b</td>
<td>Yes NR</td>
<td>3 credit hour course</td>
<td>In person</td>
<td>Yes Yes, using own PGx test results (at no cost) or mock data</td>
<td>N/A</td>
</tr>
<tr>
<td>Assem and colleagues, 2020</td>
<td>2019</td>
<td>United States</td>
<td>15b</td>
<td>No</td>
<td>Semester long (1 credit hour course)</td>
<td>In person</td>
<td>Yes Yes, using mock and aggregate data (cost NR)</td>
<td>Laboratory</td>
</tr>
<tr>
<td>Quesnelle and colleagues, 2018</td>
<td>2020</td>
<td>United States</td>
<td>45b</td>
<td>Yes NR</td>
<td>NR</td>
<td>In person</td>
<td>Yes Yes, using own PGx test results (cost NR) or mock data</td>
<td>Laboratory</td>
</tr>
</tbody>
</table>

Studies are listed based on the intervention year.
N/A, not applicable; NR, not reported; PA, physician assistant (licensed medical professional); PGx, pharmacogenomics; SBAR, situation background assessment recommendation.

aNumber of pre and post survey responders reported, total N not reported.
bPharmacy students.
cMedical students.
dPA students.
Table 2
Impact of the Pharmacogenomic Education on the Knowledge, Confidence, Perspectives and Opinions and Competence of Students.

<table>
<thead>
<tr>
<th>Study</th>
<th>Study design</th>
<th>Survey response rate</th>
<th>Change in measurable outcomes&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Impact of self-PGx testing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Knowledge</td>
<td>Confidence</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Report interpretation</td>
<td>Communication</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Patient</td>
<td>HCPs</td>
</tr>
<tr>
<td>Salari and colleagues, 2013&lt;sup&gt;10&lt;/sup&gt;</td>
<td>Pre/post surveys, individual interviews</td>
<td>74%</td>
<td>Genotyped: 31% (pre: 38%, post: 69%)</td>
<td>Genotyped: 22% (pre: 79%, post: 100%, P = .005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Nongenotyped: 1% (pre: 46%, post: 47%), P = .002</td>
<td>Nongenotyped: 38% (pre: 50%, post: 88%, P = .02)</td>
</tr>
<tr>
<td>Nickola and colleagues, 2013&lt;sup&gt;19&lt;/sup&gt;</td>
<td>Pre/post surveys</td>
<td>NR</td>
<td>9% (across four years, pre: 52%, post: 61%, P &lt; .0001)</td>
<td>NR</td>
</tr>
<tr>
<td>Lee and colleagues, 2015&lt;sup&gt;20&lt;/sup&gt;</td>
<td>Pre/post surveys</td>
<td>95%</td>
<td>NR</td>
<td>47% (pre: 17%, post: 64%, P &lt; .001) in educating patients about PGx</td>
</tr>
<tr>
<td>Bova and colleagues, 2014&lt;sup&gt;21&lt;/sup&gt;</td>
<td>Pre/post surveys</td>
<td>96%</td>
<td>37% (pre: 37%, post: 74%)</td>
<td>NR</td>
</tr>
<tr>
<td>Weitzel and colleagues, 2016&lt;sup&gt;22&lt;/sup&gt;</td>
<td>Pre/post surveys</td>
<td>100%</td>
<td>35% (pre: 45%, post: 80%, P &lt; .01)</td>
<td>53% (pre: 38%, post: 91%, P &lt; .01) in answering questions from patients</td>
</tr>
<tr>
<td>Surofchy and colleagues, 2017&lt;sup&gt;23&lt;/sup&gt;</td>
<td>Pre/post surveys</td>
<td>80%</td>
<td>Self-reported knowledge, Genotyped: 1&lt;sup&gt;b&lt;/sup&gt; (pre: 31.0, post: 4.02) Nongenotyped: 1&lt;sup&gt;a&lt;/sup&gt; (pre: 31.4, post: 4.18) P = .77</td>
<td>NR</td>
</tr>
<tr>
<td>Medina and colleagues, 2022&lt;sup&gt;24&lt;/sup&gt;</td>
<td>Post-training vs 4-year post-training</td>
<td>84%</td>
<td>Excellent: – 4% (post: 67% of students, 4-years post: 63%) Very good: 0% (post: 22%, 4-years post: 22%) Good: 4% (post: 8%, 4-years post: 12%)</td>
<td>NR</td>
</tr>
</tbody>
</table>

<sup>a</sup> Impact of self-PGx testing.

<sup>b</sup> Self-reported knowledge.
<table>
<thead>
<tr>
<th>Study</th>
<th>Study design</th>
<th>Survey response rate</th>
<th>Change in measurable outcomes</th>
<th>Impact of self-PGx testing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8% (pre: 83%, post: 91%, <em>P</em> &lt; .001)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Genotyped: 0.8% (pre: 2.7, post: 3.5, <em>P</em> &lt; .001)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-genotyped: 0.6% (pre: 2.6, post: 3.2, <em>P</em> = .05)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1% (pre: 1.4, post: 2.4, <em>P</em> &lt; .0001)</td>
<td></td>
</tr>
<tr>
<td>Adams and colleagues, 2016</td>
<td>Pre/post surveys</td>
<td>90%</td>
<td>NR</td>
<td>76% (2013) vs 84% (2014) in general PGx knowledge quiz</td>
</tr>
<tr>
<td>Marcinak and colleagues, 2018</td>
<td>Pre/post surveys</td>
<td>2014: 84%, 2015: 89%, 2016: 79%</td>
<td>NR</td>
<td>60% felt they had better understanding of PGx than those who did not undergo self-PGx testing</td>
</tr>
<tr>
<td>O’brien and colleagues, 2016</td>
<td>Pre/post surveys, focus groups</td>
<td>100%</td>
<td>6% (pre: 58%, post: 64%)</td>
<td></td>
</tr>
<tr>
<td>Arwood and colleagues, 2021</td>
<td>Pre/post surveys</td>
<td>Intervention: 77%, Control: 12%</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Remsberg and colleagues, 2017</td>
<td>Pre/post surveys</td>
<td>70%</td>
<td>NR</td>
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<tr>
<td>Patel and colleagues, 2018</td>
<td>Pre/post surveys</td>
<td>94%</td>
<td>1% (pre: 64%, post: 77%)</td>
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<td></td>
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<td></td>
<td>41% (pre: 52%, post: 93%, <em>P</em> &lt; .01)</td>
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Table 2 (continued)
<table>
<thead>
<tr>
<th>Study</th>
<th>Study design</th>
<th>Survey response rate</th>
<th>Change in measurable outcomes</th>
<th>Impact of self-PGx testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frick and colleagues, 2018</td>
<td>Pre/post surveys</td>
<td>31%</td>
<td>Knowledge: 22% (pre: 29%, post: 51%, P = .0045)</td>
<td>39% (pre: 51%, post: 90%, (P = .0072)) more valued PGx important in future career afterwards</td>
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<tr>
<td></td>
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<td>Confidence: 26% (pre: 52%, post: 78%, (P = .0074)) in explaining rationale of PGx to patients</td>
<td>71% reported better understanding of PGx due to self-PGx testing Genotyped had greater confidence in report interpretation (29%, pre: 29%, post: 58%) than nongenotyped (13%, pre: 29%, post 42%)</td>
</tr>
<tr>
<td>Kisor and colleagues, 2019</td>
<td>Pre/post surveys</td>
<td>100%</td>
<td>Knowledge: 1.2 (pre: 3.3, post: 4.5)</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Confidence: 24% (pre: 95%, post: 71%) in ethical patient counseling of PGx results</td>
<td>NR</td>
</tr>
<tr>
<td>Calinski and colleagues, 2016</td>
<td>Pre/post surveys</td>
<td>NR</td>
<td>Communication: Pharmacy: 1(^b) (pre: 2, post: 3, (P &lt; .01)) PA: 2(^b) (pre: 1, post: 3, (P &lt; .01))</td>
<td>NR</td>
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<td>N/A</td>
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<tr>
<td>Gálvez-Peralta and colleagues, 2018</td>
<td>Pre/post surveys, and 6-month post retention survey</td>
<td>96%</td>
<td>Knowledge: NR</td>
<td>77% (pre: 14%, post: 91%, (P &lt; .001)) in discussing PGx with another HCP or patient</td>
</tr>
<tr>
<td></td>
<td>Pre/post lecture survey, post lab survey</td>
<td>93%</td>
<td>Confidence: 91% answered quiz and final exam questions correctly</td>
<td>77% — 100% answered all questions from the retention survey correctly</td>
</tr>
<tr>
<td>Powers and colleagues, 2019</td>
<td></td>
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<td>Communication: Pharmacy: 2(^b) (pre: 1, post: 3, (P &lt; .01)) PA: 4(^b) (pre: 0, post: 4, (P &lt; .01)) in explaining PGx data to other members of an IP team</td>
<td>N/A</td>
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<td>N/A</td>
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<tr>
<td>Zhang and colleagues, 2020</td>
<td>Bi-weekly course assessments evaluated through competency-based assessment grading model</td>
<td>2016: 48% 2017: 20%</td>
<td>Knowledge: NR</td>
<td>PLSG session attenders reported they were more confident in their exams (73% 2016, 72% 2017)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Communication: 2016: attenders 86% vs nonattenders 85%, (P = .38) 2017: attenders 88% vs nonattenders 86%, (P = .03)</td>
<td>N/A</td>
</tr>
<tr>
<td>Calinski and colleagues, 2021</td>
<td>Pre/post survey</td>
<td>NR</td>
<td>Communication: NR</td>
<td>NR</td>
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<table>
<thead>
<tr>
<th>Study</th>
<th>Study design</th>
<th>Survey response rate</th>
<th>Change in measurable outcomes&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Impact of self-PGx testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grace and colleagues, 2021</td>
<td>Pre/post survey, retrospective survey based on time of presurvey</td>
<td>73%</td>
<td>19% (pre: 40%, post: 59%, ( P &lt; .001 ))</td>
<td>Knowledge: 17% vs 20%, ( P = .41 ) improvement in no self-PGx test group vs self-PGx test group</td>
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<td></td>
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<td>Confidence: 5% (retrospective pre: 42%, post: 47%, ( P &lt; .001 )) improvement in attitudes toward PGx</td>
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<td></td>
<td>Other: 5% (retrospective pre: 42%, post: 47%, ( P &lt; .001 )) improvement in comfort of PGx skills and patient education</td>
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<td>Report interpretation: NR</td>
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<td>Communication: NR</td>
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<td>HCPs: NR</td>
</tr>
<tr>
<td>Guy and colleagues, 2023</td>
<td>Pre/post surveys, focus group</td>
<td>100%</td>
<td>9% (pre: 54%, post: 63%, ( P = .03 ))</td>
<td>Knowledge: 79% vs 82% previous year vs study cohort of overall grades</td>
</tr>
<tr>
<td>Assem and colleagues, 2021</td>
<td>Pre/post surveys, cohort exam and quiz data comparison</td>
<td>100%</td>
<td>65% (pre: 32%, post: 97%, ( P &lt; .001 ))</td>
<td>Confidence: 76% (pre: 22%, post: 98%, ( P &lt; .001 )) in confidence discussing results with other HCPs</td>
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<td>Other: 79% vs 82% previous year vs study cohort of overall grades</td>
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<td>Performance: 53% vs 61%, ( P = .036 ) in those who had mock data vs own PGx self-test data</td>
</tr>
<tr>
<td>Quesnelle and colleagues, 2018</td>
<td>Pre/post surveys</td>
<td>Medical students: 90%</td>
<td>Pharmacy: 0.3&lt;sup&gt;d&lt;/sup&gt; (ΔC, pre: 3.2, post: 3.5)</td>
<td>Recommendation: NR</td>
</tr>
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<td>Pharmacy students: 85%</td>
<td>Medical: 0.5&lt;sup&gt;d&lt;/sup&gt; (ΔC, pre: 2.1, post: 2.6)</td>
<td>Prescriptions or dosages for certain drugs based on pharmacogenomic data: Pharmacy: 0.3 (pre: 3.1, post: 3.4)</td>
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<td>Medical: 0.7 (pre: 1.9, post: 2.6)</td>
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Abbreviations: HCP, health care professional; IP, interprofessional; N/A, not applicable; NR, not reported; PA, physician assistant; PGx, pharmacogenomics; PLSG, peer-led study group; Qs, questions; SA/A, strongly agree or agree.

<sup>a</sup>Change in pre and post, if applicable.
<sup>b</sup>Categorical scale out of 5 (Likert scale).
<sup>c</sup>Categorical scale out of 3.
<sup>d</sup>Categorical scale out of 4.
study, the improvement in self-reported confidence in patient education on pharmacogenomics in students that underwent self-pharmacogenomic testing when compared with those who did not, was similar (36% vs 35%, respectively).

3.8. Communication of Pharmacogenomic Information to Other Healthcare Professionals

Three studies (18%, 3/17) assessed the impact of their pharmacogenomic education intervention on self-reported confidence of students to communicate pharmacogenomic information to other health care professionals (Fig. 2D). In the 2 studies that used own or aggregated pharmacogenomic data, self-reported confidence improved by 64% (range 47%–76%). One study found a 5% improvement in communication of pharmacogenomic information to other health care professionals in students that used mock pharmacogenomic data. Likert scaling improvements in communication with other health care professionals were greater in the study that implemented interprofessional learning between pharmacy and physician assistant students when compared with a study that presented students with the opportunity to conduct self-pharmacogenomic testing (3 vs 1, respectively).

3.9. Assessment of Competence of Skill Acquisition

The clinical competence of skills developed by students following the educational intervention was reported on by 4 studies (17%, 4 of 24). However, only 2 of these studies qualitatively assessed student competency through simulated patient counseling sessions, where students were marked against a rubric under formal assessment conditions. For these 2 studies, the average competence scores of students in counseling patients on pharmacogenomics were 97% (range 75%–100%).

3.10. Qualitative Results From Focus Groups and Interviews

Two studies obtained data from focus groups to assess the effectiveness of their educational intervention. In a study that incorporated active-learning techniques such as a leadership game, simulated business plan and laboratory exercises, students reported appreciation for the interactive delivery of content. Students reported that they engaged with coursework because they could apply pharmacogenomic content in a fun and relaxed approach. The second study which offered voluntary self-pharmacogenomic CYP2D6 testing revealed participating in testing allowed students to feel a personal connection to their learning, which enhanced their understanding and knowledge retention. A study that utilized a series of questions in exchange for 5–10% of the course grade found a greater appreciation for the importance of pharmacogenomics in the health care setting was gained. Based on student feedback, another study mentioned future developments to their course to improve learning, such as self-pharmacogenomic testing and an interprofessional learning component.

3.11. Future Utilization of Pharmacogenomics Interventions in Practice

In addition to knowledge and confidence, 3 studies discussed student perceptions on the clinical utility of pharmacogenomics in practice. Two studies compared the pre and post intervention differences in attitudes toward the future utilization of pharmacogenomics. Before the intervention, 65% (range 51%–79%) of students considered pharmacogenomics as important to their career. This increased by 27% post-intervention, where 92% (range 90%–94%) of students considered pharmacogenomics as important for clinical practice.

4. Discussion

A lack of knowledge of health care professionals in pharmacogenomics contributes to the poor adoption of pharmacogenomic-guided medication management within clinical practice. In response to this knowledge gap, many universities are revising their curricula to include application-based pharmacogenomic education, aiming to enhance student knowledge and confidence and thereby promote implementation into clinical practice. Examples of current teaching strategies identified in this review include self-pharmacogenomic testing, case-based learning, peer-led study groups, simulations and interprofessional learning. Current pharmacogenomic education interventions improve knowledge, self-reported confidence, and clinical competence in applying the skills needed to interpret and communicate pharmacogenomics in the real world.

Interactive and experiential teaching approaches, such as self-pharmacogenomic testing combined with case-based learning, were common. The opportunity for students to use their own or aggregated pharmacogenomic data in case-based scenarios provided greater improvement in knowledge and self-reported confidence in report interpretation, communication with patients and other health care professionals, compared to using mock pharmacogenomic data. This is consistent with a review by
Burghardt and colleagues,\textsuperscript{41} which found self-pharmacogenomic testing increased student knowledge and positively influenced their attitudes and perceptions, compared to students who did not partake in self-pharmacogenomic testing. Similarly, a review by Omran and colleagues\textsuperscript{15} also encourages the integration of personal pharmacogenomic data within case studies to enhance the seamless transition of pharmacogenomics into clinical settings. In contrast, a recent nonblinded randomized control trial\textsuperscript{42} where students were randomized to either self-pharmacogenomic testing or no testing, found student knowledge, comfort, and attitudes toward pharmacogenomics were similar between the groups. However, engagement was greater in students that underwent testing compared to those that didn’t. For medical students, engagement in course material was also greater for those who underwent testing compared to those who did not.\textsuperscript{43} Collectively, these findings suggest that self-pharmacogenomic testing may enhance student knowledge, confidence and engagement beyond case-based learning alone.

To evaluate the effectiveness of pharmacogenomic education on the utilization of pharmacogenomics within clinical practice, retrospective assessment of long-term knowledge retention of health care professionals is required. Although the review by Omran and colleagues\textsuperscript{15} evaluated the effectiveness of educational interventions on practicing health care professionals, knowledge retention was not measured. Future studies evaluating long-term knowledge retention of postgraduates in clinical practice are essential to the development of a pharmacogenomic competent workforce.

Effective clinical performance in a specific task is dependent on a health care professional’s self-confidence.\textsuperscript{44} This highlights the importance of university curricula to integrate educational interventions that enhance student confidence in developing and applying pharmacogenomic skills. With this, reliable and validated measures that assess student confidence in skill application following an educational intervention are required. Our review revealed substantial heterogeneity in the evaluation of self-reported confidence of students, limiting comparison between studies. The Confidence in Managing Challenging Situations Scale\textsuperscript{45} is a standardized 5-point Likert scale used previously to determine the confidence of nursing students before and after an education intervention. A standardized scale such as this could be adopted for the assessment of student confidence after receiving pharmacogenomic education. Consistent use of such a tool in future studies will enable direct, cross-study comparisons to facilitate the identification of pedagogical approaches that enhance confidence.

Confidence was self-reported in all the evaluated studies. However, self-reported confidence may not translate to competence in skill application. Studies in this review lacked objective measures of student competence when performing pharmacogenomic counseling or education. Most studies only measured self-reported confidence as opposed to the practical implications of confidence. Therefore, it remains unknown whether existing educational interventions are effective in improving student ability to apply pharmacogenomics. Future studies should consider using an Objective Structured Clinical Examination (OSCE) approach, which is a better reflection of competence than self-reported confidence for measuring the ability of students to apply pharmacogenomics in practice. An effective educational tool must be supplemented with a competency-based approach to steward an experiential learning of clinical pharmacogenomics. Activities implemented in pharmacogenomic curricula should meet existing professional competency standards.\textsuperscript{46} As collated by Cicali and colleagues,\textsuperscript{47} the competency statements for pharmacy education related to pharmacogenomics were grouped into core content areas of clinical application, clinical implementation, education, foundational knowledge, informatics and resources, guidelines, and literature.

Pharmacogenomic education interventions are tailored to pharmacy students. This reflects clinical practice, where most pharmacogenomic services are pharmacist-led.\textsuperscript{48} However, the integration of pharmacogenomic-guided medication management requires interprofessional collaboration between health care professionals, including physicians, pharmacists, nurses, and genetic counselors.\textsuperscript{49} Therefore, to support the adoption of this multidisciplinary approach within clinical practice, all stakeholders require adequate understanding of how pharmacogenomics can inform medication management. Consequently, pharmacogenomic education is also required in the curriculum of medical and nursing students. The 3 studies which included an interprofessional learning opportunity demonstrated improved knowledge and communication.\textsuperscript{27,36,40} The opportunity to learn collaboratively with other disciplines in the study involving pharmacy and physician assistant students\textsuperscript{32} improved the student confidence to communicate with other health care professionals to a greater extent than students who were only exposed to self-pharmacogenomic testing.\textsuperscript{27} This is consistent with studies evaluating interprofessional learning between pharmacy and medical students.\textsuperscript{50} Inclusion of interprofessional pharmacogenomic education opportunities involving medical, pharmacy and nursing students are essential to prepare graduates for the real-life pharmacogenomic collaboration. Simulation-based learning through interprofessional learning and OSCEs develops student knowledge, skills, and attitudes in preparation for the collaboration required in practice.\textsuperscript{50}

To support student knowledge, skills and confidence in implementing pharmacogenomics, our review revealed several educational strategies to optimize pharmacogenomics curriculum. Pharmacogenomics education can be delivered through experiential activities that consolidate their understanding on core pharmacogenomic concepts and enable them to practice their skills (Fig. 3). For example, integrating pharmacogenomic indications within relevant body systems, spiraled across curricula, will help students navigate simulated pharmacogenomic case learning.

Fig. 3. The DNA Strands of Pharmacogenomic Education. The Two Strands of Theory and Practice; Held Together and Structured by the Building Blocks of Pharmacogenomic Teaching Activities. PGx, Pharmacogenomics; IPE, Inter Professional Education; WIL, Work Integrated Learning; HCP, Health Care Professional; SNPs, Single Nucleotide Polymorphisms.
throughout their degree. Subsequently, in practice, students should be able to identify cases where pharmacogenomics is important, and counsel patients on the consequences of pharmacogenomic testing. Students will benefit from a combination of the activities outlined to improve knowledge and confidence. Finally, pharmacogenomic programs should expose students to simulation-based examinations such as OSCEs to improve and evaluate student clinical performance, ensuring the ‘theory’ and ‘practise’ strands of pharmacogenomic education are properly joined by the interactive educational activity.

A strength of this review was that our comprehensive search strategy included various health care professional disciplines rather than focusing on one health care professional. Despite this, all studies in the nursing discipline were excluded because the educational content was specific to genomic medicine, not pharmacogenomics. This study directly compared the absolute percentage difference of knowledge and/or confidence outcomes, despite heterogeneity in the methods used across the studies. As such, the comparisons made are subject to biases and confounding. Additionally, the assessment of self-reported confidence was restricted to 3 themes, limiting the evaluation of other confidence domains. Further, our study did not assess the study quality (eg, risk of bias). Consequently, studies with a high risk of bias may have been included, possibly influencing our interpretation. However, the inclusion of all studies enabled the assessment of nontraditional teaching approaches, which may have otherwise been excluded.

5. Conclusion

Pedagogical approaches that use interactive case-based learning and simulation are essential to improving knowledge of and confidence in skill acquisition in pharmacogenomics in health care professional students. The multidisciplinary nature of pharmacogenomics calls for additional efforts to implement pharmacogenomic education in medical, pharmacy, and nursing curricula. An ideal pharmacogenomics curriculum is one that introduces pharmacogenomics early in the degree and is iteratively revisited as the degree progresses with greater complexity. To ensure that pharmacogenomic skill acquisition translates to competence, such curriculum should also make use of experiential learning (eg, OSCEs and interprofessional learning). Such strategies will help develop knowledgeable, skilled, and competent health care professionals as graduates in pharmacogenomics.

Author Contributions

Ruby Soueid: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. Toni Michael: Conceptualization, Validation, Formal analysis, Investigation, Writing – review & editing. Rose Cairns: Conceptualization, Supervision. Kellie Charles: Conceptualization, Validation, Formal analysis, Writing – review & editing, Visualization, Supervision. Sophie Stocker: Conceptualization, Validation, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

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

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