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Enhancing Clinical Adoption of Pharmacogenomics: Impact of Targeted Training on Healthcare Professionals' Self-Efficacy and Competency

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ABSTRACT

Despite its potential, the integration of pharmacogenomics (PGx) testing into clinical practice remains limited, largely due to gaps in education and training. This study investigates healthcare professionals' (HCPs) knowledge, attitudes, and confidence in applying PGx, using surveys conducted before and after a structured training program. The training program was organized into five modules addressing three main learning goals. Participants completed surveys both prior to and following the training to assess changes in their self-perceived ability and readiness to implement PGx in clinical settings. Among 102 respondents, most acknowledged the value of PGx testing, yet many reported low confidence and skill in utilizing PGx data. Post-training results demonstrated a significant improvement in self-efficacy and competency, indicating that brief, focused educational interventions can enhance preparedness and may encourage broader adoption of PGx in healthcare practice.

Keywords: Pharmacogenomics, Clinical education, Healthcare professionals, Training program, Implementation

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Introduction

Pharmacogenomics (PGx) studies how genetic differences among individuals influence their responses to medications, including both therapeutic effects and adverse reactions [1]. While research has made significant progress in mapping drug-gene interactions, the application of PGx in routine clinical practice remains limited [2]. For example, a study in Singapore revealed that nearly one-third of adverse drug reactions involved drugs with known PGx associations, highlighting the potential of testing to improve patient safety [3]. Despite its promise, PGx is underutilized in clinical care, especially across Asian healthcare settings, largely due to insufficient training among healthcare professionals [4-7].

Although PGx topics are increasingly incorporated into undergraduate and postgraduate curricula in medicine and pharmacy [2, 8-12], practicing clinicians often have limited opportunities to gain this knowledge [13, 14]. Many report low confidence in ordering PGx tests or interpreting results, which hampers the adoption of personalized therapy [4, 13-15]. In a survey of psychiatrists in Singapore, less than half felt competent to request PGx testing [14]. Enhancing PGx education for clinicians could therefore bridge this gap and promote the integration of personalized medicine into patient care [13].

Educational interventions have demonstrated effectiveness in improving clinicians' knowledge and attitudes toward PGx. Even short training sessions, such as 45-minute lectures, can positively influence perspectives and increase willingness to adopt PGx testing [6, 16]. To maintain the relevance and impact of training, PGx courses should be regularly updated [17, 18].

Currently, several organizations provide online PGx education, including the American Society of Health-System Pharmacists (ASHP), American College of Clinical Pharmacy (ACCP), Mayo Clinic, and the Test2Learn program. ASHP's accredited course emphasizes establishing a PGx program, focusing on logistical and

administrative processes [19]. ACCP offers a blended online and workshop-based program with case-based instruction but limits enrollment frequency, reducing accessibility outside the U.S. [20]. Mayo Clinic provides a comprehensive, disease-focused 16-hour online curriculum covering concepts, applications, case studies, and implementation; however, it is time-intensive, U.S.-centric, and costly for international participants [21]. Test2Learn focuses on the immediate application of PGx knowledge to patient reports but provides limited theoretical background [9].

Given these limitations, there is a need for concise, clinically oriented PGx training that equips healthcare professionals with actionable knowledge in a short timeframe, without the administrative focus of existing programs.

Previous research has documented growing clinical adoption of pharmacogenomics (PGx) testing by healthcare professionals (HCPs) to optimize prescription outcomes in North America. For instance, Mayo Clinic has reported that PGx integration has expanded its use within community clinics [21, 22]. A systematic review also highlighted that one of the main barriers to PGx implementation is the rapidly evolving knowledge landscape, which traditional educational methods may struggle to keep pace with. However, most of these studies focus on practices in the United States and Europe, leaving the adoption of PGx in Asian healthcare systems relatively unexplored.

This study aimed to evaluate the current level of PGx awareness and understanding among HCPs in Asia. To achieve this, we delivered training materials through a combination of offline and online courses. The objectives of the training program were threefold: (1) to understand the clinical applications of PGx, (2) to engage confidently with patients regarding PGx testing, and (3) to interpret, evaluate, and implement PGx-informed recommendations. Participants' perceptions of PGx's clinical relevance, its practical utility, and their own self-efficacy in integrating PGx into practice were assessed.

Materials and Methods

Ethical approval

The study received ethical clearance from the respective institutional review boards (IRB No. 038/KEPK/III/2018 for Indonesia; 2017/007 for Singapore). All participants provided written informed consent, and participation was voluntary.

Study recruitment

Healthcare professionals from Singapore and Indonesia—including physicians, nurses, medical and pharmacy students, and other healthcare-related personnel—were invited to participate in the training modules at no cost. Recruitment was conducted via email notifications and word-of-mouth, emphasizing voluntary enrollment.

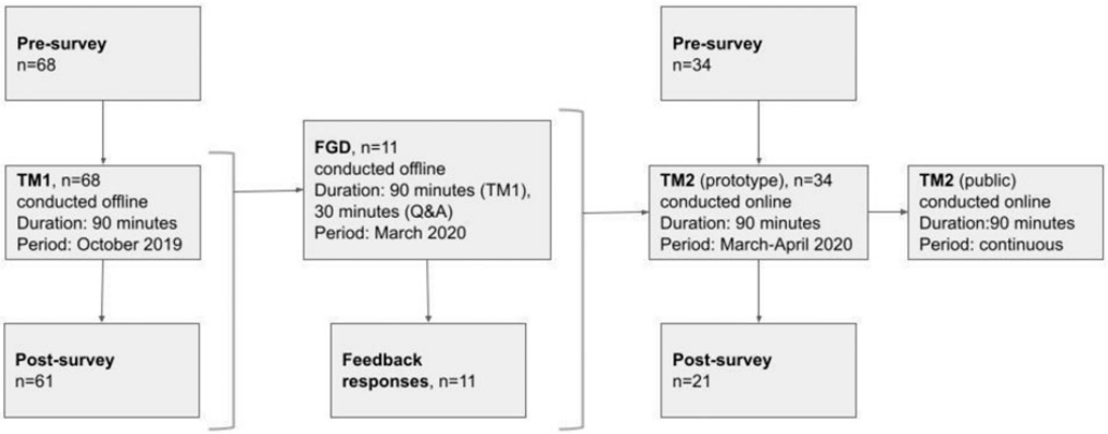
Offline training module 1 (TM 1)

The initial module was developed using a "5W1H" framework, covering the "what, when, why, where, who, and how" of PGx to provide a structured introduction to key concepts. The module began by defining PGx terminology and core genetic principles ("what"). Participants were guided on where to access relevant PGx information and how to navigate resources such as PharmGKB, CPIC, and DPWG. A patient case study was used to reinforce the remaining elements: "when" testing should be applied, "why" PGx is important, "how" to interpret test results, and "who" can benefit from PGx-informed therapy **(Figure 1a)**.

TM1 (prototype) → based on 5W1H

What	Definition of PGx, fundamentals and key concepts
When	Case study (when can PGx be implemented)
Why	Case study (showing why PGx is important)
Where	Information on where healthcare providers can find information related to PGx
Who	Case study (showing which patients can benefit from PGx)
How	Information on how healthcare providers can interpret information related to PGx

(a)



(b)

Module Sections	Learning Objectives	Topics in TM1	Topics in TM2
Introduction: Why do Pharmacogenomics Testing?	- To explain about the current situation on ADR and its likelihood - To inculcate the need of reducing ADR - To elaborate on the measures that has been taken to reduce ADR and its varying degrees of success - To distinguish the different types of genotyping and its place in therapy - To identify the situations that calls for pre-emptive genotyping and reactive genotyping	1. Importance of PGx testing 2. Factors that inhibit PGx implementation 3. Benefits of PGx testing 4. Types of genotyping (pre-emptive vs reactive)	
Fundamentals of Pharmacogenomics I	- To explain what is pharmacogenomics, and various genetic lingos, i.e. SNPs, allele, genotype, haplotype, phenotype, diplotype, and star alleles - To inform where one can find information about pharmacogene variations in PharmVar	1. Definitions commonly used in PGx field (e.g. pharmacogenomics, alleles, haplotypes, etc.) 2. The science of how PGx works	
Fundamentals of Pharmacogenomics II	- To inform about resources and to look for reliable informations related to pharmacogenomics	1. Pharmacogenomics resources (e.g. PharmGKP, CPIC, etc.)	
Important Pharmacogenes and How to Interpret Them	- To explain how pharmacogenes are affecting drug response in certain medications - To increase capability in engaging patients in discussion about pharmacogenomic testing - To increase capability in interpreting and evaluating pharmacogenomic recommendations	1. Brief description about five genes that affect ten commonly prescribed drugs.	1. CYP2D6, CYP2C19, and TCAs 2. Allopurinol and HLA-B*58:01 3. Codeine and CYP2D6 4. Clopidogrel and CYP2C19
Implementation of Pharmacogenomics	- To increase capability in implementing pharmacogenomic recommendations	1. Study case of PGx feasibility study conducted at Raffles Medical Group	1. Workflow of ordering PGx testing, interpreting results, and actions to take by physicians

(c)

Figure 1. Development of Training Materials

(a)The initial training materials and objectives were structured using the "5W1H" approach (what, when, why, where, who, and how). (b) TM1 was developed based on these 5W1H questions and delivered as an in-person training session. Following TM1, a focus group discussion (FGD) was conducted offline with participants to gather feedback. The insights from the FGD were then used to design a more comprehensive online training module, TM2. (c) Overview of learning objectives and topics covered in TM1 and TM2.

TM1 implementation

TM1 targeted hospital physicians and was delivered as a 90-minute classroom session at Raffles General Hospital, Singapore, and Rumah Sakit Cipto Mangunkusumo, Indonesia. Before the session, participants completed a 10-minute pre-training survey to assess their baseline perceptions, self-efficacy, and competency in applying pharmacogenomics in clinical practice. After the session, a 30-minute post-training survey using the same metrics was administered. Attendance was mandatory, except under unavoidable circumstances. Participation in the surveys was voluntary and not considered part of the formal training.

Focus group discussion

Participants were invited via email to join an optional in-person FGD. The session began with a review of TM1, followed by a 30-minute open discussion, which was audio-recorded. The FGD explored participants' self-perceived competency and confidence in implementing PGx, assessed across knowledge, comprehension, and application using patient case scenarios. Questions mirrored the sequence of TM1 content and were open-ended to encourage detailed feedback. Participants also provided suggestions for improving content and delivery. The feedback collected informed the development of TM2, which incorporated the requested refinements and enhancements **(Figure 1b)**.

Online training module 2 (TM2)

Building on feedback obtained from the TM1 focus group discussion (FGD), a second training module (TM2) was developed to provide a deeper understanding of pharmacogenomics (PGx), with particular emphasis on clinically relevant drug-gene interactions and the scientific principles underlying these interactions. TM2 aimed to address the knowledge gaps and suggestions raised by participants in TM1, thereby creating a more comprehensive and applicable learning experience.

TM2 was delivered as a 90-minute online course through a secure e-learning platform. Enrollment was open for one month following the course launch (March–April 2020), and data were collected from participants who voluntarily registered. To ensure consistency with the evaluation framework of TM1, pre- and post-training surveys were administered using a five-point Likert-type scale. The surveys assessed participants' perceptions of PGx utility and clinical relevance, self-efficacy in applying PGx in practice, and competency in interpreting and implementing PGx recommendations **(Figures 1b and 1c)**. Completion of the training was mandatory to obtain a certificate; however, participation in the surveys was optional.

Data collection

Survey data were used to characterize participant demographics, clinical experience, and baseline familiarity with PGx. To evaluate whether the training influenced anticipated clinical behavior, post-training surveys included questions regarding participants' experience with and anticipated use of PGx testing. An open-ended section was also included to capture feedback on course content and delivery, allowing further refinement of TM2 and guiding the development of future PGx educational initiatives.

Survey domains

The surveys were structured into three main domains:

1. **Perceptions:** To evaluate changes in understanding the clinical relevance (P1) and utility (P2) of PGx, participants were asked questions related to how PGx could be incorporated into their routine clinical practice. This domain addressed the first training objective, focusing on participants' attitudes toward PGx application.
2. **Self-Efficacy:** This domain assessed participants' confidence in using PGx data to guide drug therapy decisions (SE1) and in engaging patients in discussions about PGx testing (SE2). These measures corresponded to the second and third training objectives, reflecting the participants' perceived ability to implement PGx in a clinical setting.
3. **Knowledge:** To assess objective comprehension, participants were presented with case-based scenarios designed to evaluate knowledge, understanding, and application of clinical PGx recommendations. Assessment items were adapted from the American Society of Health-System Pharmacists (ASHP) pharmacogenomics professional certification course and further customized by licensed pharmacists who had completed the ASHP certification. Questions were mapped to the first three levels of Bloom's

taxonomy: knowledge (recall), comprehension (understanding), and application (practical implementation), and included illustrative patient cases to simulate real-world clinical decision-making.

Data analysis

Ordinal data from perception and self-efficacy responses were summarized using median and interquartile range (IQR). Likert-scale items were consolidated into three categories: "agree," "neutral," and "disagree." Pre- and post-training responses were compared using the Wilcoxon rank-sum test to determine statistically significant changes. Knowledge questions were scored as correct or incorrect, with unanswered items treated as incorrect. Percentages of correct responses overall, as well as by individual question, were compared between pre- and post-training surveys using chi-square tests. All statistical analyses were performed using R Version 3.5.2, with a p-value of less than 0.05 considered statistically significant.

Results and Discussion

Structure of training module 1

The content of TM1 focused on practical applications of pharmacogenomics (PGx) in clinical practice. Training outcomes were aligned with the competency framework established by the Pharmacogenetics/Pharmacogenomics Special Interest Group of the American Association of Colleges of Pharmacy [23]. The module was designed to achieve three primary objectives: (1) understanding the applications of PGx in clinical settings, (2) effectively engaging patients in discussions regarding PGx testing, and (3) interpreting, evaluating, and applying PGx recommendations in practice **(Figure 1c)**. Among participants of TM1, 68 completed the pre-training survey and 61 completed the post-training survey **(Figure 1b)**.

Demographics of training module 1 participants

Participants in TM1 were predominantly physicians (93.4%), with the majority practicing in Family Medicine (68.9%), while 18.9% did not specify their specialty. The remaining 6.6% were distributed across surgical, cardiology, and other specialties **(Table 1)**. Over half of the respondents (55.9%) had more than five years of clinical experience. Prior exposure to PGx education was limited, with only 27.9% reporting previous training or self-directed learning, including resources such as online materials, journal articles, drug labeling, lectures, seminars, or university coursework. Notably, no other healthcare professionals, such as nurses or pharmacists, participated in TM1, as this module specifically targeted practicing physicians in hospital settings.

Table 1. Participant characteristics in offline TM1 training.

Characteristics	Pre-Intervention (Offline; n = 68)	Post-Intervention (TM1; n = 61)
Age, mean (range)	42.1 (24–73)	43.1 (24–73)
	Gender	
Male	33 (48.5%)	32 (52.5%)
Female	28 (41.2%)	21 (34.4%)
	Position	
Doctor	63 (92.6%)	57 (93.4%)
Pharmacist	4 (5.9%)	3 (4.9%)
Nurse	0 (0.0%)	0 (0.0%)
Medical student	0 (0.0%)	0 (0.0%)
Pharmacy student	0 (0.0%)	0 (0.0%)
Other	1 (1.5%)	1 (1.6%)
	Specialty	
Family medicine	44 (64.7%)	42 (68.9%)
Surgery	1 (1.5%)	2 (3.3%)
Emergency medicine	1 (1.5%)	0 (0.0%)
Other specialties	8 (11.9%)	3 (4.8%)
Not applicable	1 (1.5%)	1 (1.6%)
No response	13 (18.9%)	13 (21.4%)

Years of practice experience		
1–5 years	18 (26.5%)	15 (24.6%)
6–10 years	11 (16.2%)	10 (16.4%)
11–20 years	12 (17.6%)	10 (16.4%)
21–30 years	11 (16.2%)	9 (14.8%)
31–40 years	3 (4.4%)	4 (6.6%)
41–50 years	1 (1.5%)	1 (1.6%)
No response	12 (17.6%)	12 (19.6%)
Prior PGx education experience	19 (27.9%)	–

Pre- and post-training Assessment of perception, self-efficacy, and knowledge in training module 1

Perceived relevance and utility of pharmacogenomics in clinical practice

Participants' perceptions of PGx testing were evaluated using a 5-point Likert-type scale both before and after TM1 **(Table 2)**. Prior to the training, 52.4% of respondents agreed or strongly agreed that PGx testing is clinically relevant and useful, reflecting generally favorable baseline perceptions **(Figure 2)**. Following completion of the TM1 session, this proportion increased to 84.8%, indicating a substantial enhancement in perceived clinical relevance and utility. Median perception scores improved from 3 to 4 **(Table 2)** ($p < 0.05$), demonstrating a statistically significant positive shift in participants' views. Additionally, 77% of respondents reported a heightened anticipation of applying PGx testing in their clinical practice after the training.

Table 2

Survey Domain	Item	Pre-Intervention (Offline; n = 68)	Post-Intervention (TM1; n = 61)	p-value
Perceptions (P1): Relevance of pharmacogenomics (PGx) to clinical practice	P1-1 PGx is applicable to my clinical practice / I am motivated to integrate PGx into practice	Median: 3, IQR: 2	Median: 4, IQR: 0	< 0.05
	P1-2 A patient's genetic profile may influence drug response	Median: 4, IQR: 1	Median: 4, IQR: 1	< 0.05
Perceptions (P2): Clinical utility of PGx	P2-1 Overall, the benefits of PGx testing outweigh potential risks	Median: 3, IQR: 1	Median: 4, IQR: 1	< 0.05
	P2-2 PGx testing helps identify suitable medications	Median: 4, IQR: 1	Median: 4, IQR: 1	< 0.05
	P2-3 PGx testing guides appropriate medication dosing	Median: 3, IQR: 1	Median: 4, IQR: 1	< 0.05
	P2-4 PGx testing reduces adverse drug reactions	Median: 4, IQR: 1	Median: 4, IQR: 1	< 0.05
	P2-5 PGx testing improves treatment efficacy	Median: 4, IQR: 1	Median: 4, IQR: 1	< 0.05
	P2-6 PGx testing may reduce treatment costs	Median: 3, IQR: 1	Median: 4, IQR: 2	< 0.05
Self-efficacy (SE1): Confidence in using PGx information to guide therapy	SE1-1 Identifying clinical situations or patients for PGx testing	Median: 3, IQR: 1	Median: 4, IQR: 1	< 0.05
	SE1-2 Interpreting PGx test results	Median: 2, IQR: 1	Median: 4, IQR: 1	< 0.05
	SE1-3 Making treatment recommendations based on PGx results	Median: 2, IQR: 1	Median: 4, IQR: 1	< 0.05

	SE1-4 Identifying reliable PGx resources (e.g., guidelines) for clinical use	Median: 2, IQR: 1	Median: 4, IQR: 1	< 0.05
Self-efficacy (SE2): Confidence in discussing PGx testing with patients	SE2-1 Explaining the rationale of PGx testing	Median: 3, IQR: 1	Median: 4, IQR: 1	< 0.05
	SE2-2 Discussing risks and benefits of PGx testing with patients	Median: 2, IQR: 1	Median: 4, IQR: 1	< 0.05

[a] Score is ranged using five-point Likert scale from (1) strongly disagree to (5) strongly agree.
[b] IQR is calculated as the difference in scores falling in the first and third quartile.
[c] Wilcoxon test was used to analyze changes in pre- and post-training responses. Significant p-values (<0.05) are bolded.

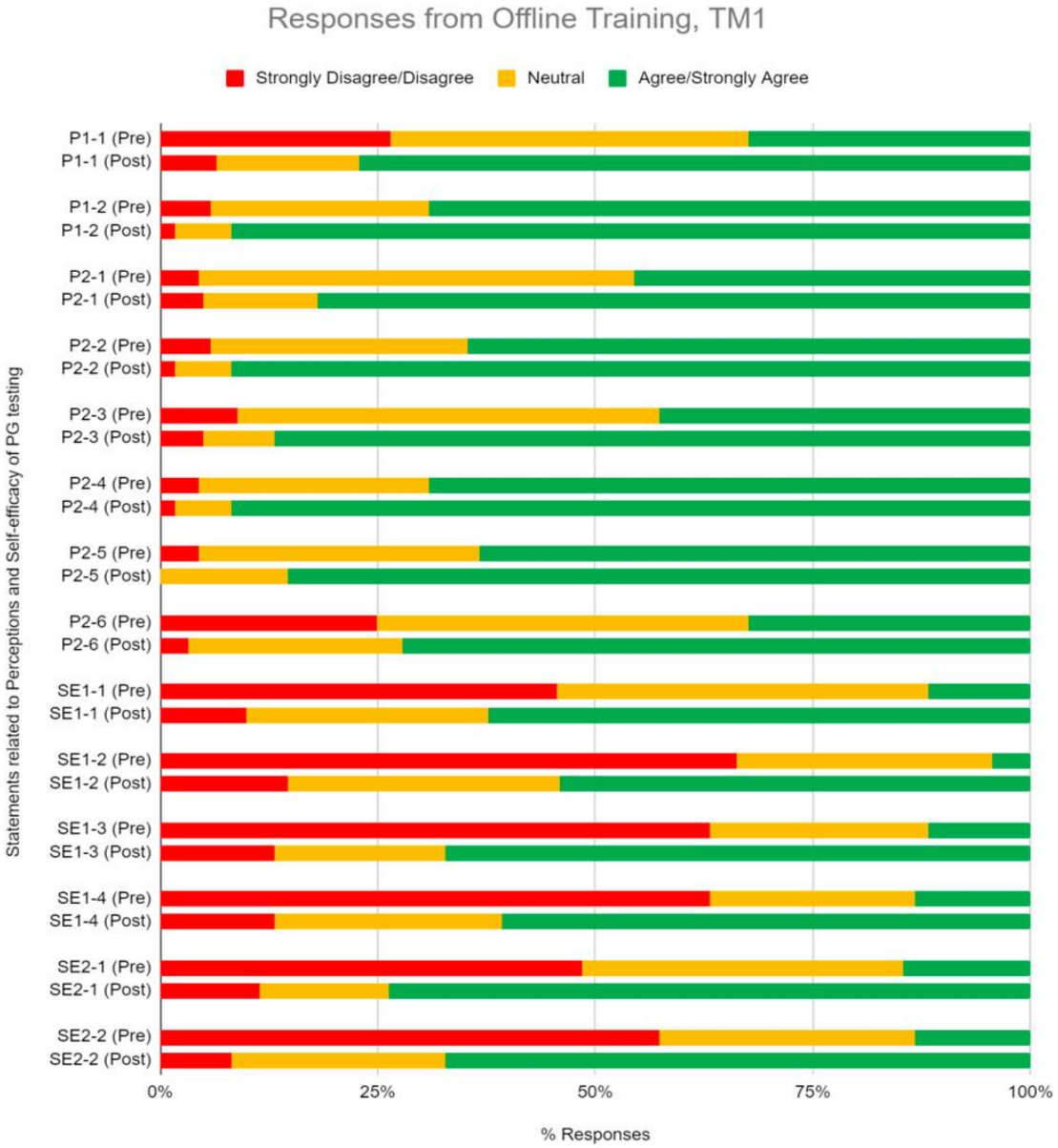


Figure 2.

Perceived competence in implementing pharmacogenomics in clinical practice

Self-efficacy regarding the application of PGx in clinical decision-making and patient communication was assessed using targeted questions **(Table 2)**. Pre-training responses indicated that participants initially reported limited confidence in utilizing PGx data to guide drug therapy decisions and to engage in discussions with patients about PGx testing. After completing TM1, perceived self-efficacy increased by 51.5% **(Figure 2)**, with median

scores rising from 2 to 4 **(Table 2)** ($p < 0.05$), reflecting a significant enhancement in participants' confidence to implement PGx in clinical settings.

Knowledge and proficiency in applying pharmacogenomics

Knowledge acquisition was evaluated across two domains: foundational PGx theory and practical clinical application. Pre- and post-training assessments measured participants' improvement in understanding and applying PGx concepts **(Table 3)**. Overall, respondents demonstrated a 15.1% increase in correct responses for proficiency-based questions following TM1 **(Figure 3, Table 3)** (Chi-square test, $p < 0.05$). Significant gains were observed in one theoretical PGx knowledge question and in practical application-level questions, indicating that TM1 effectively improved both conceptual understanding and the ability to apply PGx principles in clinical practice.

Table 3. Correct responses to questions about knowledge on PGx comparing pre- and post- offline training for TM1.

Survey Domain	Item	Correct Answer	Pre-Intervention (Offline; n, %)	Post-Intervention (TM1; n, %)	p-value
Knowledge (K1): Theoretical pharmacogenomics	K1-1 Consequence of a PGx polymorphism (Comprehension)	Increased risk of drug toxicity in affected individuals	40, 59%	43, 65%	0.4507 a
	K1-2 Meaning of poor metabolizer phenotype (Knowledge)	Reduced enzyme activity	17, 25%	18, 27%	0.7646 a
	K1-3 CYP2D6 phenotype for a patient with activity score 1.5 (Knowledge)	Normal metabolizer	6, 38%	10, 63%	0.1573 a
	K1-4 Incorrect statement regarding pre-emptive vs. reactive genotyping (Knowledge)	Reactive genotyping is more cost-effective than pre-emptive genotyping	14, 27%	28, 56%	< 0.05 a
	K1-5 Implication of ultra-rapid metabolizer phenotype for CYP2C19 (Knowledge)	Increased enzyme activity	–	–	–
Knowledge (K2): Practical clinical implementation of PGx	K2-1 Likelihood of Ms. Lee developing Stevens-Johnson Syndrome (Comprehension)	FALSE	–	–	–
	K2-2 Ms. Lee's CYP2D6 enzyme activity score (Comprehension)	2	–	–	–
	K2-3 Appropriate adjustment for Ms. Lee's amitriptyline therapy per CPIC guidelines (Application)	Consider an alternative drug not metabolized by CYP2C19	–	–	–
	K2-4 PGx rationale for modifying tamoxifen therapy in breast cancer patient without prior genetic testing (Application)	CYP2D6 poor metabolizer leading to reduced drug efficacy	11, 69%	10, 63%	0.7097 a
	K2-5 Appropriate approach for clopidogrel therapy in CYP2C19 poor metabolizers (Application)	Consider alternative antiplatelet therapy if no contraindications	15, 29%	31, 62%	< 0.05 a

[a] Chi-square test was used to compare the percentage of correct responses between pre- and post- training surveys. Significant p-values (<0.05) are bolded.

[b] Fisher's test was used if criteria for Chi-square (expected value size > 5) is not met.

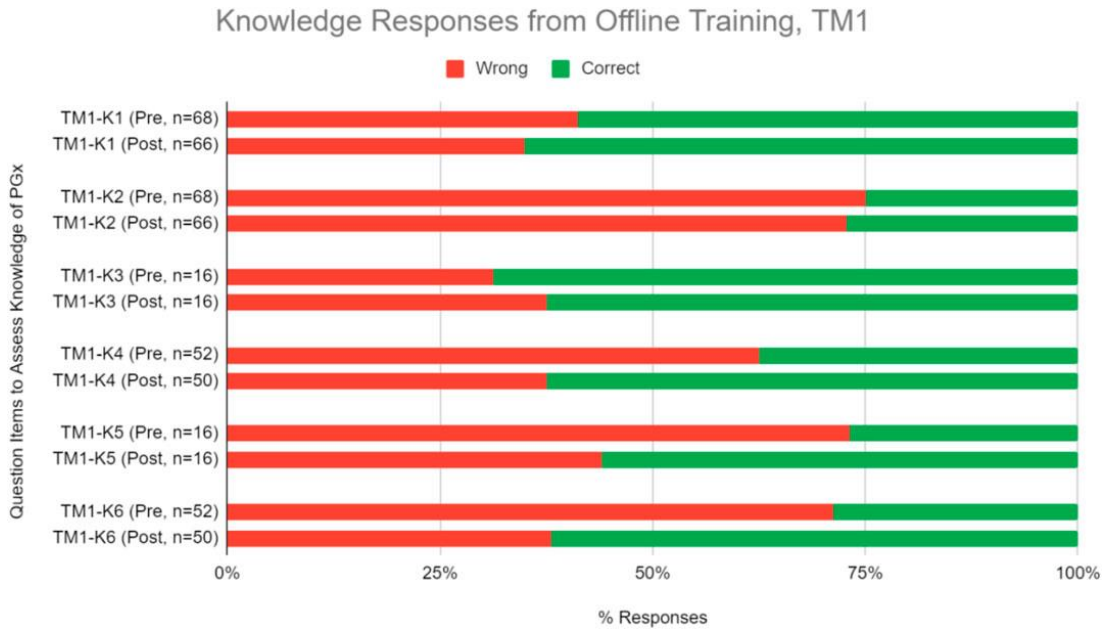


Figure 3. Percent of correct or wrong responses to knowledge questions obtained during pre-and post-PGx offline training TM1.

Focus group discussion (FGD) feedback and analysis

Analysis of responses from the FGD revealed several recurring suggestions for improving TM1. The most frequently mentioned request, noted seven times, was the inclusion of patient case studies to enhance practical understanding. Two participants suggested making the training available online to allow for repeated viewing and review of the content. Other notable recommendations included incorporating more visual aids (three mentions), providing demonstrations on how to navigate PGx resources (two mentions), adding a list of relevant drugs, and increasing interactivity within the course (two mentions). Some additional comments were made, but these were considered less relevant for immediate improvements **(Figure 4)**.

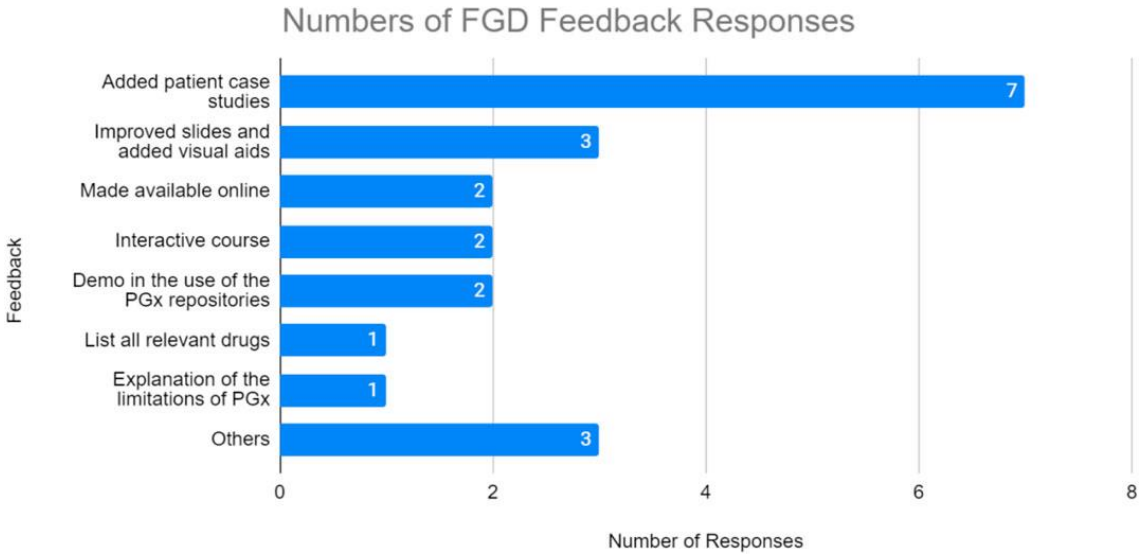


Figure 4. Number of responses from focus group discussion feedback. TM1 participants highly suggested more case studies to be added on the training material.

TM2 development and design

Building on insights from the TM1 focus group, TM2 was developed as a fully online program to incorporate the most frequently requested enhancements. The virtual delivery enabled participants to access content at their convenience, supporting both time flexibility and broader reach, while allowing the course to be scaled to a larger

audience **(Figures 1b and 1c)**. The online format also allowed integration of additional interactive elements, case studies, and practical examples of drug-gene interactions highlighted as areas of interest during TM1 feedback.

Participant characteristics in TM2

TM2 attracted a wider and more varied cohort of healthcare professionals, reflecting the accessibility of the online format **(Table 4)**. The participants included physicians (61.8%), pharmacy students (20.6%), medical students (8.8%), nurses (5.9%), and pharmacists (2.9%). Only two specialties—Family Medicine and Emergency Medicine—were represented, and the majority of respondents reported under five years of clinical experience. Similar to TM1, most participants had limited prior exposure to formal pharmacogenomics education, suggesting that the online module reached both early-career clinicians and students seeking foundational knowledge in PGx.

Table 4. Participant characteristics in online TM2 training.

Characteristics	Pre-Intervention (Online; n = 34)	Post-Intervention (TM2; n = 21)
Age, mean (range)	30.41 (23–50)	29.69 (23–46)
Gender		
Male	19 (55.9%)	10 (47.6%)
Female	15 (44.1%)	11 (52.4%)
Position		
Doctor	21 (61.8%)	8 (38.1%)
Pharmacist	1 (2.9%)	1 (4.8%)
Nurse	2 (5.9%)	2 (9.5%)
Medical student	3 (8.8%)	3 (14.3%)
Pharmacy student	7 (20.6%)	7 (33.3%)
Other	0 (0.0%)	0 (0.0%)
Specialty		
Family medicine	21 (61.8%)	8 (38.1%)
Emergency medicine	2 (5.9%)	2 (9.5%)
Other (surgery, cardiology, etc.)	0 (0.0%)	0 (0.0%)
Not applicable	11 (32.4%)	11 (52.4%)
Years of practice experience		
1–5 years	10 (29.4%)	6 (28.6%)
6–10 years	4 (11.8%)	2 (9.5%)
11–20 years	7 (20.6%)	3 (14.3%)
21–30 years	3 (8.8%)	0 (0.0%)
>30 years	0 (0.0%)	0

Changes in perception, self-efficacy, and knowledge following TM2

Clinical relevance and utility of pharmacogenomics testing

Consistent with findings from TM1, participants in TM2 demonstrated strong recognition of the clinical value of PGx testing. Prior to the online training, 62.5% of respondents agreed or strongly agreed that PGx is relevant and useful in clinical practice. This proportion increased to 88.1% following completion of TM2 **(Figure 5, Table 5)**. The median perception score remained at 4, reflecting a statistically significant enhancement in participants' views on the applicability of PGx testing in patient care ($p < 0.05$). Notably, 85.7% of participants expressed confidence in the practical utility of PGx after engaging with the TM2 content.

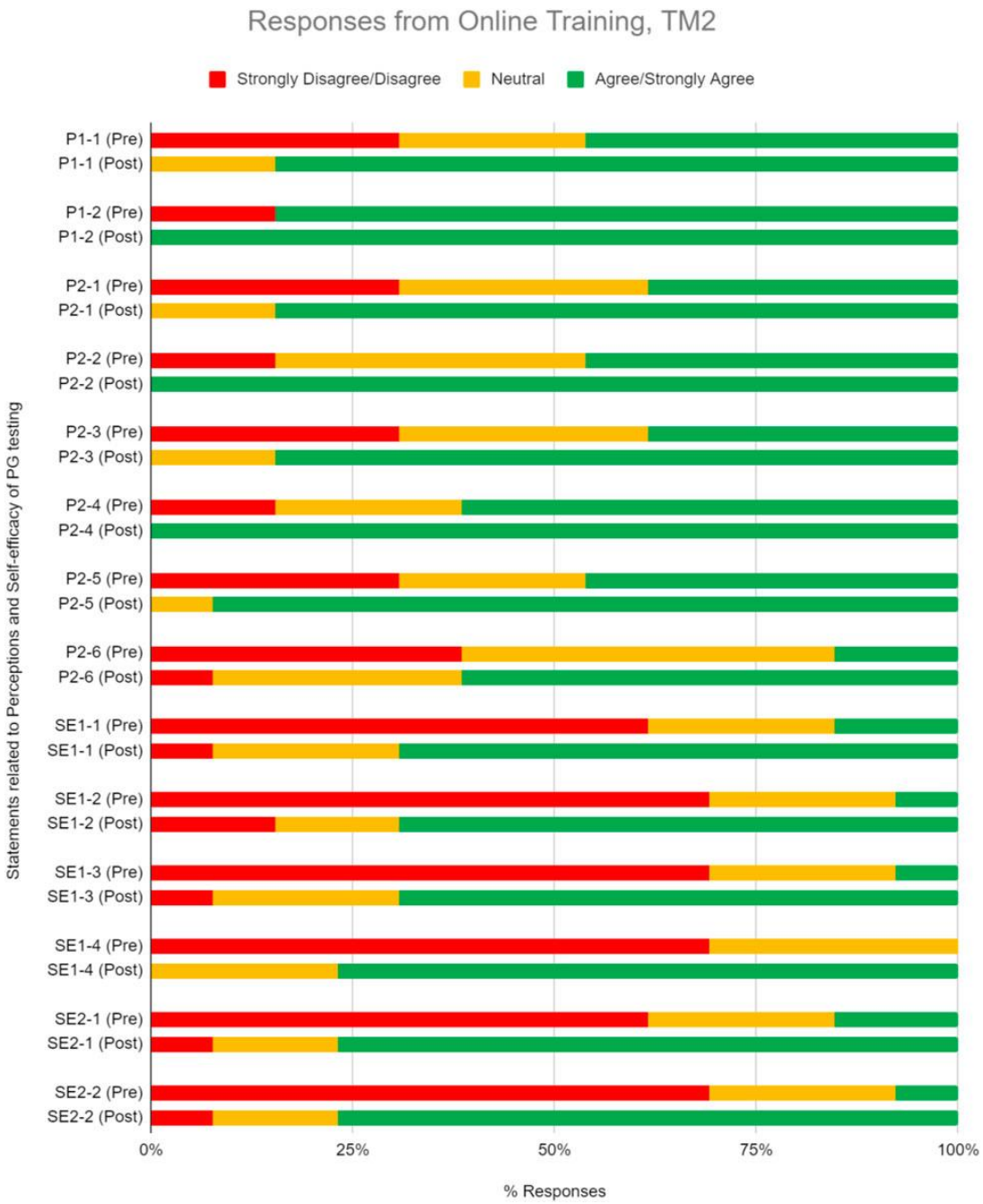


Figure 5. Percent of respondents relative to 5-point Likert-type scale labels pre- and post-PGx training conducted online for TM2 in perception (P) and self efficacy (SE) sections. Three questions in P section (P1-2, P2-2, and P2-4) received 100% of respondents answering agree/strongly agree in the post-training questionnaire. TM2 pre-training survey knowledge evaluation, $n = 34$; TM2 post-training survey knowledge evaluation, $n = 21$.

Table 5. Pre- and post-online TM2 training results related to perceptions and self-efficacy of addressing PGx testing.

Survey Domain	Item	Pre-Intervention (n = 34)	Post-Intervention (n = 21)	p-value
Perceptions (P1): Relevance of pharmacogenomics	P1-1 PGx is applicable to my clinical work / I am motivated to integrate PGx into practice	Median: 4	IQR: 1	Median: 4

(PGx) to clinical practice	P1-2 A patient's genetic profile may influence drug response	Median: 4	IQR: 0	Median: 4
Perceptions (P2): Clinical utility of PGx	P2-1 Overall, the advantages of PGx testing outweigh potential risks	Median: 4	IQR: 1	Median: 4
	P2-2 PGx testing assists in selecting appropriate medications	Median: 4	IQR: 1	Median: 4
	P2-3 PGx testing aids in determining appropriate drug dosing	Median: 4	IQR: 1	Median: 4
	P2-4 PGx testing helps minimize adverse drug reactions	Median: 4	IQR: 0	Median: 5
	P2-5 PGx testing enhances treatment effectiveness	Median: 4	IQR: 1	Median: 5
	P2-6 PGx testing can reduce treatment costs	Median: 3	IQR: 1	Median: 4
Self-efficacy (SE1): Confidence in utilizing PGx information for therapeutic decisions	SE1-1 Identifying clinical situations or patients appropriate for PGx testing	Median: 3	IQR: 2	Median: 4
	SE1-2 Interpreting PGx test outcomes	Median: 3	IQR: 1	Median: 4
	SE1-3 Formulating treatment recommendations based on PGx results	Median: 3	IQR: 1	Median: 4
	SE1-4 Identifying reliable PGx resources (e.g., guidelines) for clinical use	Median: 3	IQR: 2	Median: 4
Self-efficacy (SE2): Confidence in communicating with patients about PGx	SE2-1 Explaining the rationale of PGx testing to patients	Median: 3	IQR: 2	Median: 4
	SE2-2 Discussing the risks and benefits of PGx testing with patients	Median: 3	IQR: 2	Median: 4

[a] Score is ranged using five-point Likert scale from (1) strongly disagree to (5) strongly agree.
[b] IQR is calculated as the difference in scores falling in the firstAnd thirdquartile.
[c] Wilcoxon test was used to analyze changes in pre- and post-training responses. Significant p-values (<0.05) are bolded.

Perceived competence in implementing pharmacogenomics in clinical practice

Completion of TM2 led to a notable improvement in participants' confidence in applying PGx in clinical settings. Respondents reported a 44.6% increase in perceived ability, with the median self-efficacy score rising significantly from 3 to 4 **(Figure 5, Table 5)** ($p < 0.05$).

Knowledge acquisition and application of pharmacogenomics

TM2 also enhanced participants' knowledge and practical proficiency in pharmacogenomics. The average correct response rate for proficiency-based questions increased by 28.0% following the online training **(Figure 6, Table 6)** ($p < 0.05$). For theoretical PGx concepts, at least one knowledge-level question showed a significant score improvement. Similarly, for clinical application, questions targeting comprehension-level skills demonstrated measurable gains, indicating better understanding and readiness to apply PGx in practice **(Figure 6, Table 6)**.

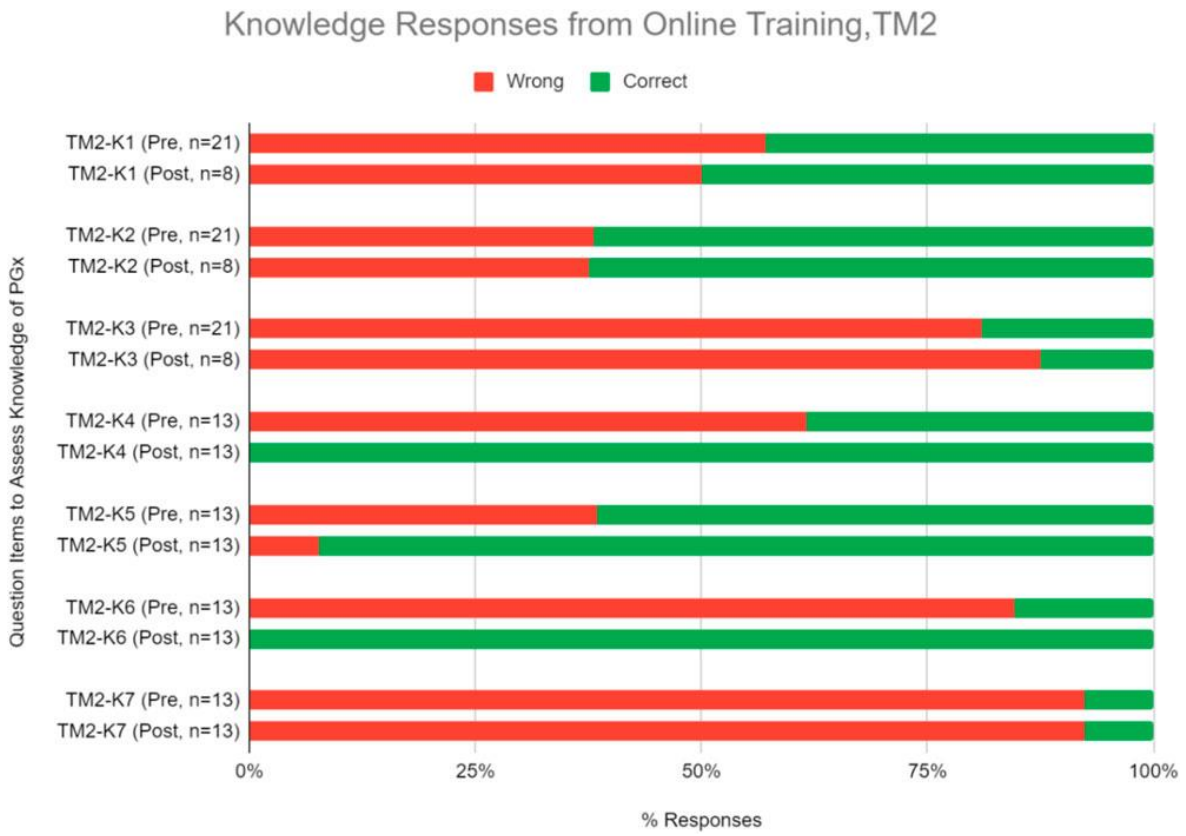


Figure 6. Percent of correct or wrong responses to knowledge questions obtained during pre-and post-PGx online training TM2. Two questions in the knowledge section (TM2-K4 and TM2-K6) received 100% of respondents answering correctly in the post-training assessment.

Table 6. Correct responses to questions about knowledge on PGx comparing pre- and post-online training for TM2.

Survey Domain	Item	Correct Answer	Pre-Intervention (Online; n, %)	Post-Intervention (TM2; n, %)	p-value
Knowledge (K1): Theoretical pharmacogenomics	K1-1 Consequence of a PGx polymorphism (Comprehension)	Higher risk of drug toxicity in affected individuals	9, 43%	4, 50%	1 b
	K1-2 Meaning of poor metabolizer phenotype (Knowledge)	Reduced enzyme activity	13, 62%	5, 63%	1 b
	K1-3 CYP2D6 phenotype for a patient with activity score 1.5 (Knowledge)	Normal metabolizer	–	–	–
	K1-4 Incorrect statement regarding pre-emptive vs. reactive genotyping (Knowledge)	Reactive genotyping is more cost-effective than pre-emptive genotyping	4, 19%	1, 13%	1 b
	K1-5 Implication of ultra-rapid metabolizer phenotype for CYP2C19 (Knowledge)	Increased enzyme activity	5, 38%	13, 100%	<0.05 b

Knowledge (K2): Practical clinical application of PGx	K2-1 Likelihood of Ms. Lee developing Stevens-Johnson Syndrome (Comprehension)	FALSE	8, 62%	12, 92%	0.1602 b
	K2-2 Ms. Lee's CYP2D6 enzyme activity score (Comprehension)	2	2, 15%	13, 100%	<0.05 a
	K2-3 Appropriate adjustment for Ms. Lee's amitriptyline therapy per CPIC guidelines (Application)	Consider an alternative drug not metabolized by CYP2C19	1, 8%	1, 8%	1 b
	K2-4 PGx rationale for modifying tamoxifen therapy in breast cancer patient without prior genetic testing (Application)	CYP2D6 poor metabolizer leading to insufficient drug effect	–	–	–
	K2-5 Recommended approach for clopidogrel therapy in CYP2C19 poor metabolizers (Application)	Consider alternative antiplatelet therapy if no contraindications	–	–	–

[a] Chi-square test was used to compare the percentage of correct responses between pre- and post-training surveys. Significant p-values (<0.05) are bolded.
[b] Fisher's test was used if criteria for Chi-square (expected value size >5) is not met.

This study examined the impact of pharmacogenomics (PGx) implementation training, initially piloted through in-person Continuing Education (CE) seminars and later expanded into an online module. The primary goal was to educate participants on foundational PGx concepts and their clinical applications. Our findings indicate that participants held positive views on the relevance and utility of PGx in clinical practice. Furthermore, training delivered in a case-based format effectively enhanced participants' self-efficacy, enabling them to apply PGx information in patient care and engage in PGx-related discussions.

Comparison between TM1 and TM2

The participant composition differed notably between the two training modules. TM1 attracted mostly practicing physicians, whereas TM2 drew a higher proportion of students. This discrepancy may be attributed to TM2's online format, which allowed students to engage conveniently and acquire additional skills. TM1 had a larger number of participants, likely because attendance was required as part of the Continuing Medical Education (CME) program. In contrast, the flexibility of TM2's online delivery permitted participants to pause or exit the course at their discretion, contributing to lower completion rates. Reduced external motivation in online training could also account for this difference.

TM1 appeared more appealing to active clinical practitioners, who could easily attend scheduled sessions during working hours. The limitation of in-person delivery is that those unavailable at the scheduled time missed the learning opportunity. TM2, being online, offered flexibility in scheduling and location, allowing participants to access content at their convenience and replay segments for better comprehension. This adaptability likely improved knowledge retention and may enhance the effectiveness of PGx implementation.

Pre- and post-training outcomes for TM1 and TM2

Comparing pre- and post-training results, TM1 participants showed increases of 32.4%, 52.7%, and 14.9% in perception, self-efficacy, and knowledge, respectively **(Figure 7a)**. TM2 participants demonstrated even higher gains, with 41.3%, 64.1%, and 44.3% improvements in the same metrics **(Figure 7b)**. These findings suggest that online delivery through TM2 may be more effective in enhancing participants' understanding, confidence, and ability to implement PGx in clinical practice.

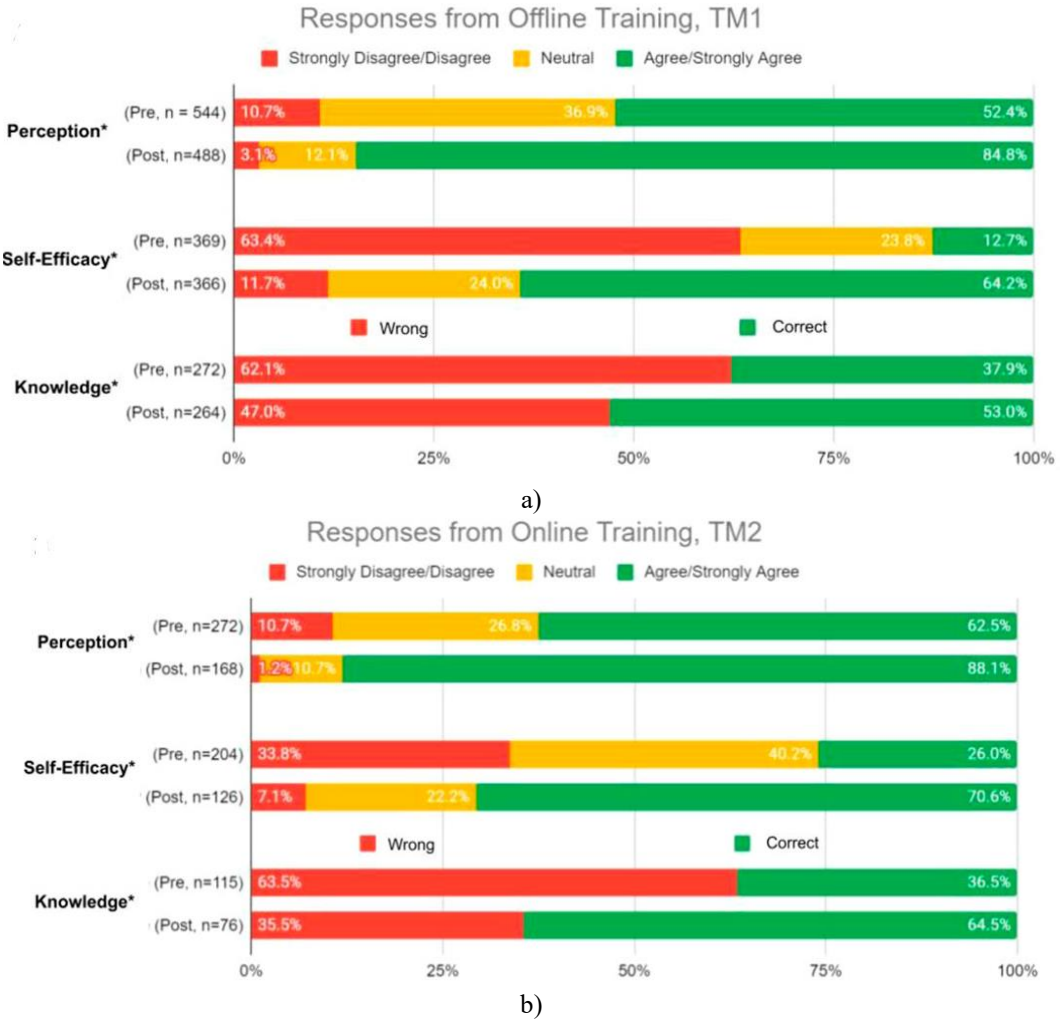


Figure 7. Overall percentage of respondents based on the 5-point Likert-type scale pre- and post-PGx training, conducted (a) offline for TM1, and (b) online for TM2. Survey domains included: Perceptions of PGx relevance and clinical utility, Self-Efficacy measured as confidence in using PGx information to guide treatment decisions and engage in patient discussions, and Knowledge questions based on PGx case studies. Sample size, n, indicates the total number of responses collected for each survey domain before and after training. *Significant differences ($p < 0.05$) were observed between pre- and post-training responses.

Certain perception and knowledge questions in TM2 achieved a 100% agreement or correct response rate in the post-test. Specifically, three perception items reached full agreement, highlighting participants' strong belief in the influence of genetic profiles on drug response and the value of PGx for selecting appropriate medications and reducing adverse drug events **(Figure 5, Table 5)**. Additionally, 50% of the post-test knowledge questions in TM2, which were based on case studies of PGx application, were answered correctly by all participants **(Figure 6, Table 6)**. These outcomes indicate that online training may be particularly effective in enhancing healthcare professionals' understanding and clinical application of PGx.

Comparison of pre- and post-training knowledge responses demonstrated improvements for both TM1 and TM2. Following offline TM1 training, participants exhibited only modest gains in knowledge, similar to previous findings from PGx educational programs targeting pharmacists **(Figure 7a)** [24]. In contrast, TM2 online training led to substantial increases in correct responses **(Figure 7b)**. Limited retention of information in TM1 may be attributed to the complexity of PGx concepts or the condensed format of the in-person session, which may overwhelm learners [9, 24]. TM2 addressed these challenges by offering online content that promotes active learning, enabling participants to review materials at their own pace and reinforcing learning through quizzes [25]. Moreover, presenting complex PGx concepts alongside case-based scenarios allowed for deeper comprehension, which participants confirmed as helpful for understanding key principles.

Comparison with existing online PGx courses

The TM2 online module effectively addressed limitations identified in other online PGx courses provided by ASHP, ACCP, Mayo Clinic, and NACDS. Whereas these programs typically require 16 hours or more and cost between USD $400–$1,099, TM2 was designed to be completed in roughly 90 minutes at a significantly lower cost of USD $14.85. Additionally, existing courses target mainly pharmacists or physicians, while TM2 provided clinically relevant PGx education to a broader audience, including physicians, pharmacists, nurses, and students.

Limitations

Several limitations should be noted. Pre- and post-training survey responses were not linked, so changes could only be analyzed at the aggregate level rather than individually. The study population was non-randomized and comprised a convenience sample, potentially leading to selection bias toward participants with prior PGx interest. TM1 included primarily physicians with limited pharmacist participation, and TM2 had a lower overall response rate, which may limit generalizability. Differences in delivery format (offline vs. online) could have influenced outcomes. Finally, the study did not evaluate actual PGx test implementation or long-term training effects, as it was intended to provide baseline data and initial assessment of training outcomes. Future research should track participants longitudinally to assess sustained impact and integration of PGx into clinical practice.

Conclusion

Participants exhibited generally positive perceptions of PGx testing but initially lacked confidence and competency in its clinical application. Training was effective in significantly enhancing self-efficacy and knowledge. Survey results also indicated increased anticipation of PGx adoption following training. Online delivery emerged as a preferred method due to its flexibility and scalability, supporting its potential for continuous education and long-term integration of PGx into routine clinical practice.

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Conflict of Interest: Authors FA, CM, KJ, LS, and AI were employed by the company Nalagenetics Pte Ltd, Singapore. Author AC is a scientific advisor for Nalagenetics Pte Ltd, Singapore. AI and LS has financial holdings in Nalagenetics Pte Ltd, Singapore.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ethics Statement: The studies involving human participants were reviewed and approved by IRB No. 038/KEPK/III/2018 for Indonesia; 2017/007 for Singapore. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

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