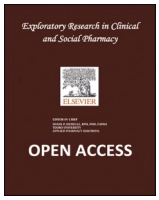
Exploratory Research in Clinical and Social Pharmacy 18 (2025) 100586

Contents lists available at ScienceDirect

Exploratory Research in Clinical and Social Pharmacy

journal homepage: www.elsevier.com/locate/rcsop



Evaluating the effect of computer-based education on pharmacist behaviour regarding point-of-care testing

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ARTICLE INFO

Keywords:
Point-of-care testing (POCT)
Pharmacists
Computer-based education (CBE)
Knowledge
Self-reported behaviour
Theory of planned behaviour

ABSTRACT

Background: Recent regulatory changes in Ontario have enabled pharmacists to perform point-of-care testing (POCT) to manage chronic diseases. With the introduction of any new service(s), educational interventions can aid acceptance and implementation. Computer-based education (CBE) improves pharmacists' knowledge, but there is little evidence of its effect on pharmacist behaviour. This study assessed the impact of CBE on pharmacist knowledge, behaviour intention, and adoption of POCT.

Methods: A three-month, web-based, randomized controlled trial was conducted between April 2024 and Sep 2024 with community pharmacists in Ontario, Canada. The intervention group was asked to complete two POCT modules using a CBE platform, while the control group was asked to review reference materials about POCTs. The primary outcome, the difference in the number of POCTs performed, was collected using monthly reports. Secondary outcomes (knowledge gain and changes in the Theory of Planned Behaviour (TPB) constructs: attitude, subjective norm, perceived behavioural control, and behaviour intention) were assessed using selfreported surveys. Generalized linear models (GLM) with negative binomial distribution were used to analyze the number of POCTs. Knowledge gain was analyzed using repeated measure ANOVA and binomial regression. TPB constructs were analyzed within groups using paired sample *t*-tests and between groups using two-sample ttests.

Results: Of the 261 pharmacists recruited, 201 completed the pre-study survey, 135 completed the one-week post-test, and 104 completed the three-month post-test. There was a significant difference in knowledge test scores between the two groups at one week ($P = .001$) and three months ($P < .00$). There was no significant difference in behavioural constructs between the two groups at three months. However, attitude increased significantly for both groups (intervention group 3.6 ± 0.6 Vs. 3.95 ± 0.5 $P < .001$; control group 3.5 ± 0.6 Vs. 3.8 ± 0.5 P < .001). There was no significant change in the number of POCTs performed after one, two, and three months for both study groups.

Conclusion: CBE improved pharmacists' knowledge of POCT but showed a limited effect on pharmacist intention or behaviour. The study highlighted that knowledge alone does not influence behaviour change. Factors such as organizational support, adequate reimbursement, and expanded practice scope (e.g., prescribing) are critical to enhance POCT implementation.

1. Introduction

Point-of-care testing (POCT) is defined as laboratory testing conducted by qualified staff close to the site of patient care, where results are made available at the same clinical visit to support clinical decision-making.[1,2] The global market for POCT is growing and is estimated to reach $65.9 billion by 2029.[3] With the current strain on the healthcare system and limited accessibility to physicians, there is a great interest in delivering POCT in different settings such as community pharmacies.[3,4] In Canada, the total health expenditure was estimated to reach $372 billion in 2024, with growing concern about the escalating costs.[5] Moreover, there were only 2.4 practising physicians per 1000 people in 2015, and it is estimated to reach 2.84 per 1000 people by 2030.[6,7]

In Ontario, regulated pharmacy professionals including part A

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https://doi.org/10.1016/j.rcsop.2025.100586
Received 18 December 2024; Received in revised form 18 February 2025; Accepted 4 March 2025
Available online 7 March 2025
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pharmacists, pharmacy interns, and pharmacy technicians, are authorized to collect blood samples, demonstrate testing machines and assist patients with self-monitoring of chronic diseases.[8] In July 2022, pharmacy professionals' scope of practice in Ontario expanded to include POCT performance for monitoring and managing medications used to treat chronic diseases.[8] The permitted POCTs include blood glucose, hemoglobin A1c, lipids, prothrombin time, and International Normalized Ratio (INR).[8] This expanded authority can enhance patient access to and convenience of POCT,[4,9] while reducing the burden on other primary health care providers and laboratories.[9,10] Furthermore, pharmacist-led POCT services can improve health outcomes for patients. A pilot study conducted in New Zealand showed that community pharmacist-led anticoagulation management services were 30 % more cost-effective than the cost of the usual care.[10] A 2020 systemic review by Albasri et al.[11] reported up to 20 % improvement in INR control in favour of pharmacist POCT compared to similar care delivered at clinics.[11] The study also showed a decrease in triglycerides (TG) and low-density lipoprotein (LDL) cholesterol levels between baseline and 2-year follow-up favouring pharmacist POCT. Similarly, community pharmacist-led anticoagulation management services in Nova Scotia improved INR control compared to historical data (time in therapeutic range (TTR) of 71.4 % Vs. 60 %).[9]

For pharmacy professionals, a change in legislation alone is not enough to improve the delivery of expanded scope services.[12–14] Innovative educational interventions are needed to support behaviour change. Computer-based education (CBE), defined as "the delivery of educational content through information and communication technologies",[15] can be a promising intervention for pharmacists. CBE is geographically flexible and can be delivered fully online, in synchronous or asynchronous formats.[16,17] CBE is also easily scalable, as educational packages and programs can be updated and tailored to users' needs and topics of interest.[18,19]

The effectiveness of CBE for experienced healthcare professionals varies widely. It has been shown that CBE is as effective as face-to-face learning and more effective than printed materials.[20–24] A 2019 systematic review by Fontaine et al.[25] reported that CBE is more effective than traditional learning in enhancing skills in healthcare professionals. On the other hand, a 2018 review by Vaona et al.[26] found that CBE has a similar effect on knowledge and skills compared to traditional learning (without access to e-learning), but has little impact on clinical behaviour or patient outcomes. Furthermore, a systematic review by Salter et al.[27] included 17 studies that assessed the effectiveness of CBE in pharmacy education. Eleven studies reported a significant increase in knowledge with CBE compared to traditional learning. Two studies reported enhanced skills. Four studies reported a change in behavioural intention. No studies assessed change in patient outcomes.

A few studies have addressed the features of CBE programs designed for experienced healthcare professionals that may enhance the achievement of learning outcomes and enable behaviour change.[17,28] A 2023 scoping review by Zhang & Thompson[29] analyzed 32 studies evaluating e-learning effectiveness for continuing professional education among healthcare professionals. The review identified common features in online learning programs to promote behaviour change, including the inclusion of relevant case studies, social interaction through discussion forums and blogs, timely feedback to learners, step-by-step instructions and self-improvement tools.[29] Social interaction proved particularly important for fully online programs, as it creates a sense of community and reduces learner isolation, thereby enhancing learners' success. Similarly, a 2024 systematic review by Aryee et al.[30] included 44 studies focused on the effectiveness of e-learning among healthcare professionals. The review did not examine design features in detail; still, Aryee et al. listed facilitators that enhanced healthcare professionals' positive experiences with e-learning programs, such as relevant content, interaction via discussion forums, and feedback for learners. In particular, discussion forums improved healthcare professionals' interactivity with e-learning programs and knowledge sharing.

1.1. Goals and objectives

In this study, we aim to improve the design of Pharmacy5in5, a fully online CBE platform designed to accelerate knowledge application and facilitate adoption of best practices by Canadian pharmacy professionals**.** The platform was created by Dr. Grindrod, a pharmacist and pharmacy professor, with support from colleagues in the fields of digital gaming, human factors, and adult education. Since launching in Ontario in January 2018, over 20,800 pharmacists, pharmacy students, and pharmacy technicians have enrolled in Pharmacy5in5, representing over 24 % of community pharmacists in Ontario. The platform publishes new modules regularly on clinical or pharmacy practice topics. The platform was designed using the COM-B (capability, opportunity, motivation, and behaviour) model,[31] the Behaviour Change Wheel (BCW),[31] and the Theoretical Domains Framework (TDF),[32] to promote elements that influence pharmacist behaviour and build confidence in applying new knowledge. Further details about the platform can be found in a separate paper.[33]

We have previously assessed Pharmacy5in5 in two randomized-controlled trials (RCTs). The first demonstrated that the platform can increase knowledge at a rate similar to paper-based educational tools.[33] A second RCT showed that incorporating a charitable reward boosted platform engagement and module completion rates.[34] The goal of the current study is to evaluate if new design features can influence behaviour change. As such, we have tailored the Pharmacy5in5 experience with the addition of a peer support feature through a discussion forum hosted on the Facebook social media platform. This was supplemented by live question-and-answer (Q&A) sessions presented by pharmacy staff experienced in POCT.

1.2. Objectives

(1) To assess the effect of the CBE on the number of point-of-care tests performed by individual pharmacists; (2) To assess the effect of CBE on pharmacists' knowledge of point-of-care testing and associated disease parameters; (3) To assess the effect of CBE on pharmacists' behaviour intention; and (4) To assess pharmacists' perceived satisfaction with CBE.

1.3. Hypothesis

We hypothesized that the CBE, Phamracy5in5, could increase the number of point-of-care tests performed by pharmacists in Ontario.

2. Methods

2.1. Study design

A three-month, web-based randomized controlled behavioural intervention was conducted to assess the effect of the CBE platform on pharmacists' self-reported behaviour, knowledge and behaviour intention of POCT. The RCT was conducted as per the CONSORT-EHEALTH checklist.[35] Pharmacists were allocated either to the intervention group, where they were asked to complete online POCT modules, or to the control group, where they were asked to read the Ontario College of Pharmacists information on POCT and other related references, as shown in Fig. 1 in the study flowchart. Ethics approval was obtained from the University of Waterloo Ethics Board (ORE# 44998).

2.2. Recruitment

Participants were recruited from users of the Pharmacy5in5.ca platform. Registered users who indicated that they are registered pharmacists in Ontario, Canada ($n = 4341$) were recruited through an

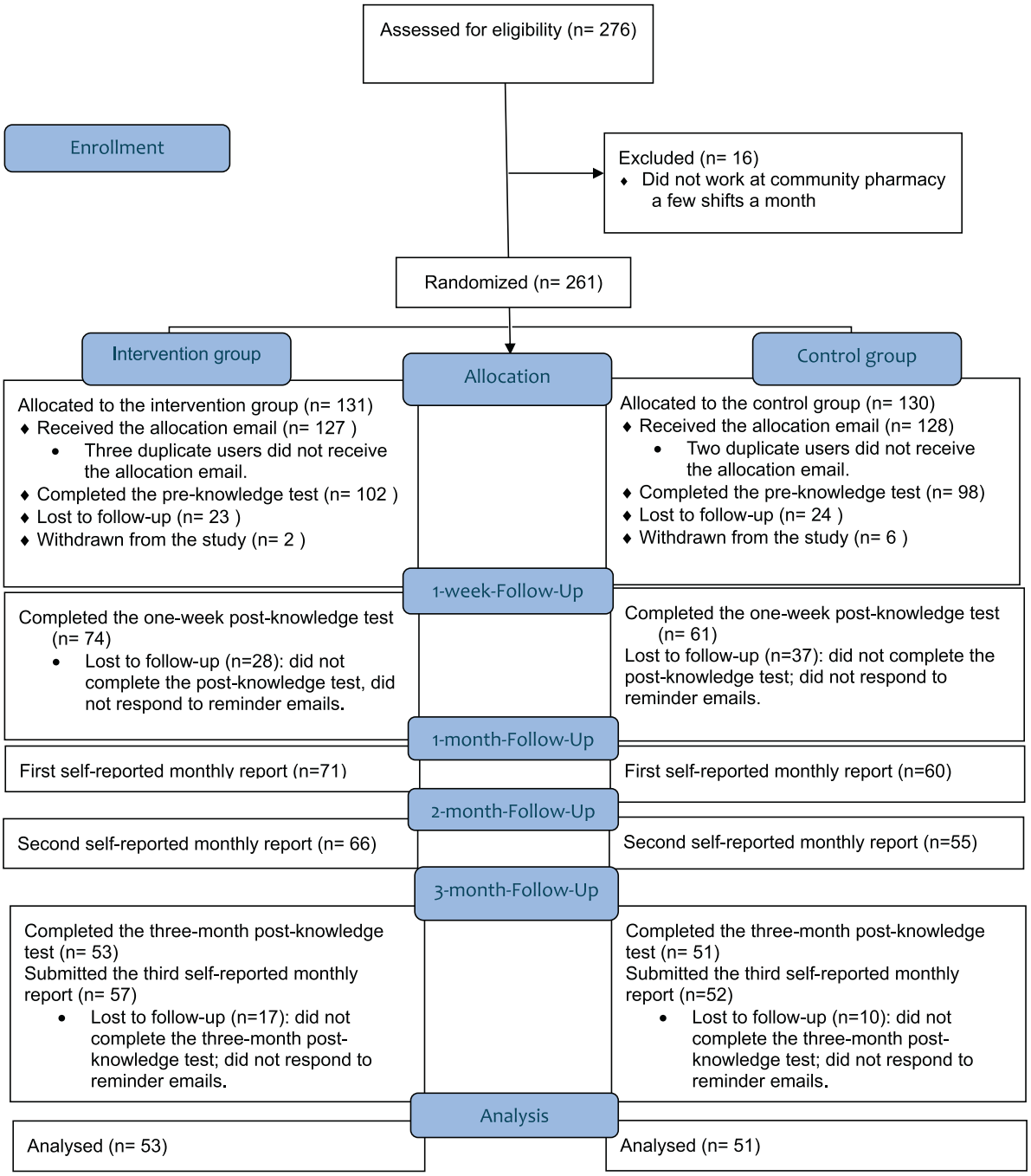

Fig. 1. Study flowchart.

email sent through our MailChimp program. We also used posters on the Pharmacy5in5 Facebook and School of Pharmacy Twitter pages to recruit users. Participants were also recruited from the pharmacist contact database provided by the Ontario Pharmacy Evidence Network (OPEN) ($n = 7298$). The email included a link to a screening survey to confirm eligibility according to inclusion and exclusion criteria. For this study, the inclusion criteria included being a registered pharmacist practising in the province of Ontario, Canada and working in a community pharmacy at least a few shifts per month. The exclusion criteria included being a pharmacy technician, a pharmacy student, a pharmacy technician student, or an unlicensed pharmacist. All platform users have already agreed to be contacted via email for research purposes during the platform registration process.

2.3. Study procedure

All potential participants were asked via email to review the information sheet and consent letter and to provide their email addresses. Next, participants were assigned to one of the study groups in a 1:1 allocation ratio using a computer-generated list of random numbers. All participants were asked to use their study ID to access and complete an initial survey composed of two sections: 1) a 24-question knowledge test; and 2) a 14-question survey based on the Theory of Planned Behaviour to assess behaviour intention, perceived behavioural control, subjective norms and attitudes. The participants were also asked to provide their demographics. The survey was delivered through the Qualtrics survey software to both groups before and after module completion, and after 3 months to test for knowledge retention. The

intervention group received a second email with a link to access the point-of-care testing modules on the Pharmacy5in5 platform, and a link to access a discussion board on a private Facebook group. The participants were given one week to complete the two online POCT modules on Pharmacy5in5.ca. Over the three-month intervention period, the intervention group participants were also asked to participate in discussion boards and were invited to ten Facebook Live events to explore how different POCTs can be implemented in Ontario pharmacies. The control group participants were instructed via a second email to review a list of references about POCT regulations and scope of practice. After one week of accessing the Pharmacy5in5.ca modules or reviewing the list of references, all participants were invited to complete a post-test knowledge test via a third email. After three months, all users were asked to complete a second survey that is composed of three sections: 1) a 24-question post-knowledge test to assess knowledge gain; 2) a 14-question survey based on the Theory of Planned Behaviour to assess changes in behaviour intention; and 3) a 20-question to assess user satisfaction with the educational content. Participants were also asked to complete a monthly report in which they recorded the number of POCTs performed at their pharmacy. Participants were offered a $15 gift card plus a complimentary 6-month subscription to the Pharmacy5in5.com website at the completion of the study.

2.4. Randomization and blinding

The statistician and the primary investigator performing data analysis were blinded for group allocation. A researcher who was independent from data analysis randomly assigned participants. The data analysis was conducted after collecting all the participants' responses.

2.5. Sample size calculation

Using G power, we estimated that 64 pharmacists were needed per group to detect a medium effect size (effect size d 0.5) with a 2-sided test, α-level 0.05, and power of 80 %. A total of 261 participants were enrolled in the study to account for a dropout rate of approximately 25 %.

2.6. Interventions

2.6.1. POCT modules development and validation

We started by conducting a pre-study survey for Ontario pharmacists, students and technicians that included questions on legislation, test administration, interpretation of tests, documentation, communication and follow-up. The pre-study quiz was used to determine the learning topics that were most poorly understood with POCT. Two modules were developed:1) Point-of-care testing (Ontario) to address legislation, documentation, and communication with POCT; and 2) Interpreting point-of-care testing to address test administration and interpretation of test results. The development process started by having an expert team of pharmacists draft five learning objectives for each module, which was informed by the pre-study quiz. The learning objectives were used to create multimedia resources including educational infographics, flashcards, and quizzes.

Next, we developed two sets of quizzes for each module to address the learning objectives, with each set consisting of one Fast-Facts immediate feedback quiz and six case-based delayed feedback quizzes. Next, a panel of experts from the Ontario College of Pharmacists reviewed all module components and provided their input and feedback for the quizzes and all multimedia resources. The modules were piloted with practising pharmacists for readability and clarity. See Fig. 2, which summarises all interventions of the study.

2.6.2. Facebook group content development

We created a private group on Facebook and asked the intervention participants to join it. The group was called "Pharmacy5in5 research group". An Excel sheet was created for discussion post topics based on the learning objectives of the Pharmacy5in5 modules; the first month addressed topics related to managing pharmacy workflow and popular POCT devices used in pharmacies in Ontario, the second month addressed regulations governing POCT in Ontario, and the last month addressed interpretation and clinical decision making based on POCT results. A total of 36 posts were created, with two to three posts added to the Facebook group every week for three months. Furthermore, the intervention participants were able to post any POCT-related questions or comments in the Facebook group. Intervention participants also had access to question-and-answer sessions (Q&A) with experts. Participants had the freedom to attend the live sessions or watch the recordings. A total of ten sessions were conducted throughout the duration of the study.

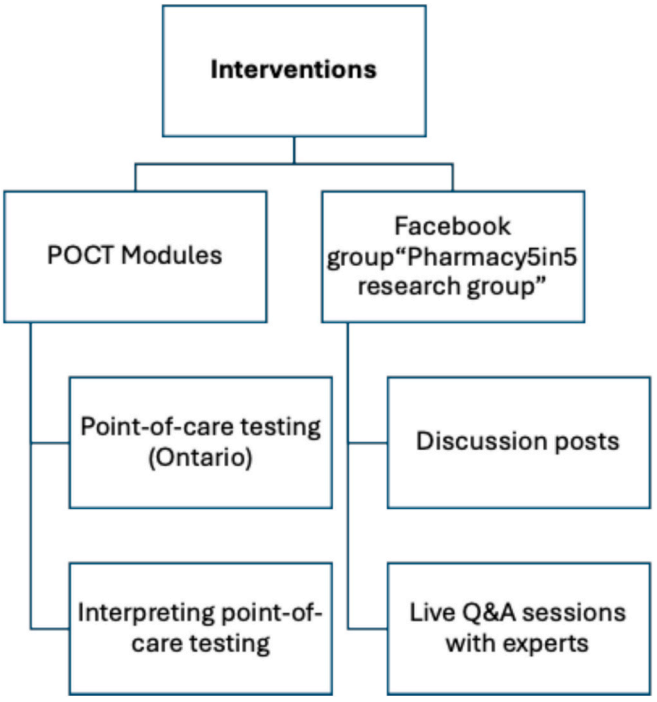

Fig. 2. Study interventions.

2.7. Outcome measures

The primary outcome measure was the difference in the number of POCTs performed by the two study groups. All users were asked to fill out a monthly report of the number of POCTs performed at their pharmacy. All secondary outcomes were assessed using self-reported surveys at three points: baseline, after completing the module and after three months, as follows:

a. Psychometric measures: using a 5-point Likert scale to assess perceived behaviour control, subjective norms, behaviour intention, and self-reported behaviour;
b. Knowledge test: using multiple-choice questions (MCQs) to assess knowledge gained about the topic;
c. Overall satisfaction using the Asynchronous e-Learning (LSAe-L) instrument.[36]

Surveys were pilot tested by faculty members from the School of Pharmacy and external pharmacists to assess the internal consistency.

2.8. Instruments development

2.8.1. Knowledge test development and validation

We drafted a knowledge test that included 33 questions to address the learning objectives of the POCT modules. Next, we conducted two rounds of face and content validation with a convenience sample of pharmacy experts ($n = 9$). The experts were asked to rate the relative importance of each question based on the learning objectives as follows (1 = Not relevant; 2 = Somewhat relevant; 3 = Quite relevant; 4 = Very relevant). They were also asked to suggest recommendations to improve clarity. Next, we calculated the content validity index for each item (i-CVI) by dividing the number of experts who gave a rating of 3 or 4 by the total number of experts. Items with an i-CVI value less than 0.79 required revisions, and items with i-CVI < 0.70 were deleted. For the first round, three questions were deleted; Q11b had an i-CVI score of 56, and Q16 and Q22 were deleted because experts felt they were repetitive. Six questions were revised, answers were reworded, and more context was added for clarity. The second draft of the knowledge test included 29 questions. For the second round, seven experts participated, and one more question was deleted as experts found it confusing. Five questions were revised and reworded. The third draft of the knowledge test (28 questions) was piloted with five pharmacists. We also performed item analysis using the item difficulty index based on the first 60 responses. Four questions had an item difficulty index above 0.90 and were deleted. A total of 24 questions were included in the final knowledge test.

2.8.2. Theory of planned behaviour[37] survey development

We developed the survey based on guidelines from Francis et al. (2004).[38] The first draft (16 items) included the following constructs: perceived behavioural control (the perceived ability to perform the behaviour), subjective norms (the perceived social pressure to perform the behaviour), attitudes toward behaviour (whether a person favours performing the behaviour), behaviour intention to perform the behaviour, and self-reported behaviour. See Fig. 3 for the domains the Theory of planned behaviour. The target behaviours included performing the following POCTs: A1c, glucose, INR/PT, and lipids. Four items assessed perceived behavioural control, i.e., how difficult pharmacists find performing a POCT, how confident pharmacists feel about performing a POCT, and how much control pharmacists feel over performing a POCT. Negative items were reverse coded so that higher scores indicated a higher control over the behaviour. Four items assessed attitude, i.e., how pharmacists judged performing a POCT (pleasant/unpleasant; useful/useless), and the outcomes (beneficial/harmful). Higher scores indicated a positive attitude toward performing a POCT. Three items assessed subjective norms and whether the opinions of individuals or organizations can impose social pressure. Higher scores indicated greater social pressure to perform a POCT. Three questions assessed behaviour intention, including "I intend to… in the next three months, "; "I want to… in the next three months," and "I expect to… in the next three months ", with higher scores indicating higher intention to perform a POCT. Two additional items were added to assess self-reported behaviour. All items used a 5-point Likert scale for responses. The first draft of the survey was shared with six pharmacists to review the content. A cognitive interview using a think-aloud protocol was used. Two questions were deleted because pharmacists found them too general or repetitive, and six were revised and reworded. The final draft included 14 items.

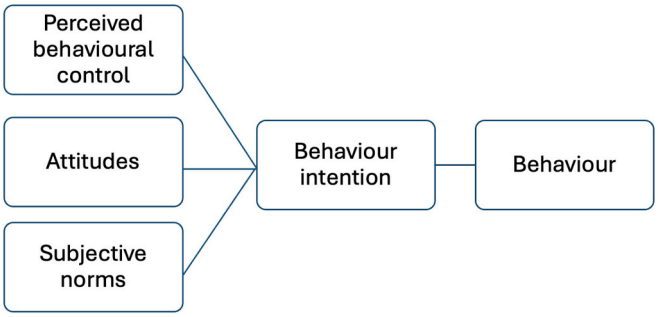

Fig. 3. The domains the Theory of planned behaviour.

2.8.3. Satisfaction survey

The Learner Satisfaction with Asynchronous e-Learning (LSAe-L) instrument[36] was used to assess users' satisfaction with the online learning system consisting of Pharmacy5ini5 modules and the Facebook group. The pre-validated survey included 17 items that assessed users satisfaction with: 1) content (4 items), 2) learner interface and ease-of-use (5 items), 3) learning community and ability to discuss questions (4 items), and 4) personalization and ability to manage learning progress (4 items). Five additional items were added to assess overall satisfaction with the Facebook group and the modules. All items used a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating a higher level of satisfaction with the online learning system.

2.9. Data analysis

The primary outcome measure (number of POCTs performed) was reported as frequency and percentages, secondary outcome measures (behaviour intention and knowledge gain) were reported as mean ± standard deviation. The number of POCTs was analyzed between groups and within groups after one, two and three months using generalized linear models (GLM) with negative binomial distribution. The negative binomial distribution was more suitable than the Poisson distribution due to the wide dispersion in the number of POCTs data. Knowledge gain was analyzed within groups at baseline, after taking the module and after three months using repeated measures ANOVA. If the ANOVA results were significant, a paired *t*-test was used for pot-hoc comparisons. Binomial regression models were used to analyze knowledge gain between study groups at baseline, after taking the module and after three months to adjust for baseline scores. Attitudes, perceived behaviour control and behaviour intention were analyzed between study groups using a two-sample t-test and within groups using a paired sample t-test at baseline and after three months. Generalized linear regression models were used to assess the relationship between outcomes and confounding factors such as gender, practice location and other sociodemographic factors. $P < .05$ was considered statistically significant. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 29 statistical package (IBM Corp, New York, NY, USA).[39] Content analysis was used to analyze open-ended responses to explore participants' feedback and reflections.

3. Results

3.1. Demographics of the study respondents

Of the 261 Ontario pharmacists recruited;131 participants were randomized to the intervention group and 130 to the control group. A total of 200 participants completed the pre-study survey (102 in the intervention group and 98 in the control group). Not all participants completed the demographics section of the pre-study survey; 102 participants in the intervention group and 98 participants in the control group completed the demographics section. Most respondents were female (55 %), received their qualifying pharmacy training in Canada (62.4 %), held a bachelor's degree (50 %), had one to five years of pharmacy practice experience (56 %), were staff pharmacists (57.9 %), and were practising in a chain or franchise community pharmacies (45.5 %). The demographic characteristics of the two groups did not differ significantly, except for primary place of practice (Table 1).

Among the types of POCT services provided, 42.9 % of pharmacists

Table 1
Demographics of the study respondents.

Demographics (n = 193)	Intervention group n = 100 (%)	Control group n = 93 (%)	P value
Years of pharmacy practice experience			
Less than one year	1 (0.98 %)	0	0.72
1–5 years	31(30.4 %)	25 (27.2 %)	
6–10 years	26 (25.5 %)	25 (27.2 %)	
11–20 years	23 (22.54 %)	28 (30.43 %)	
More than 20 years	19 (20.6 %)	15 (14.2 %)	
Gender			
Woman	55 (54.9 %)	55 (59.8 %)	0.86
Man	42 (42.2 %)	35 (36.9 %)	
Prefer not to disclose	3 (2.9 %)	3 (3.3 %)	
Location of qualifying pharmacy training			
Canada	63 (63.7 %)	62 (66.3 %)	0.78
United States	5 (4.9 %)	3 (3.3 %)	
Outside North America	32 (31.4 %)	28 (30.4 %)	
Highest level of education			
Bachelor's degree	57 (55.8 %)	45 (47.8 %)	0.15
Entry level PharmD	24 (23.5 %)	18 (19.6 %)	
Master's degree	12 (11.8 %)	14 (15.2 %)	
Post-graduate	6 (5.8 %)	15 (16.3 %)	
PharmD			
PhD	2 (1.9 %)	0	
Other	1(0.98 %)	1 (1.1 %)	
Employee status			
Pharmacy owner	14 (14.7 %)	16 (16.3 %)	0.48
Pharmacy manager	17 (16.7 %)	19 (20.7 %)	
Staff pharmacist	61 (65.7 %)	55 (63.1 %)	
Other	8 (1.9 %)	3 (3.3 %)	
The Primary site of practice			
Community: independent	36 (37.3 %)	38 (40.2 %)	0.037**
Community: chain or franchise	56 (54.9 %)	36 (39.1 %)	
Hospital inpatient	5 (4.9 %)	12 (13 %)	
Primary care clinic	1 (0.98 %)	5 (5.4 %)	
Other	2 (1.96 %)	2 (2.2 %)	
POCT services offered (n = 196)			
Glucose	46(45.5 %)	37 (39.8 %)	0.469
A1C%	42 (41.6 %)	31 (33.3 %)	0.299
Lipids	33 (33.7 %)	17 (18.7 %)	0.022**
Prothrombin time and INR	9 (8.9 %)	10 (10.8 %)	0.81

Chi-square and Fisher's exact tests were used to compare demographics between the study groups.
** p value <.05.

offered blood glucose POCT, followed by A1c% POCT (37.2 %) and lipids POCT (25.5 %). Only 9.7 % of the pharmacists provided INR and PT, and 37.8 % did not offer any POCT services.

3.2. Knowledge test

The average scores for the pre-knowledge test for the two study groups were 16.2 ± 3.8 for the intervention group and 14.9 ± 3.8 for the control group. Binomial regression models were used to examine the knowledge test scores between the two groups after considering the demographic factors and POCT availability (which is a score given from zero to four based on the number of types of POCT services offered at the pharmacy, where zero means the pharmacy was not offering any POCT services, and four means that the pharmacy was offering all types of POCT services). The two study groups did not differ in their average pre-test scores (P = .156), after accounting for demographic factors. The average knowledge test score for the intervention group increased by 13.4 % after one week, while the average knowledge test score for the control group increased by 6.5 %. Table 2 shows there was a significant difference between the two groups in the one-week post-test scores (P = .001). There was also a significant difference between the two groups in the three-month post-test scores (P < .001). After three months, the average knowledge test score increased by 18.2 % for the intervention group and by 5.5 % only for the control group. Furthermore, when accounting for the initial difference between the two study groups in the pre-study period, the difference observed in the one-week and the three-month post-study period was still statistically significant. The analysis also showed that years of experience (more than 20 years of experience) and master's education level had a statistically significant association with pre-test scores.

Among the control group, the knowledge test scores did not change significantly throughout the study period. There was no significant difference between the pre-test, the one week and the three-month post-test scores (F = 2.073, P = .137). On the other hand, the knowledge test scores improved significantly throughout the study period among the intervention group (F = 8.997, P < .001). There was a significant difference between the knowledge test mean scores at the pre-test and the one-week post-test and between the pre-test mean scores and the three-month post-test mean scores. However, there was no significant difference between the knowledge test mean scores after one week and after three months.

3.3. Theory of planned behaviour (TPB) domains analysis

A total of 192 participants completed the TPB pre-study survey. The pre-study mean scores for the four domains were calculated out of five as follows: attitude was 3.9 ± 0.5, followed by 3.7 ± 0.7 for perceived behaviour control, 3.3 ± 0.8 for behaviour intention and 3.2 ± 0.7 for subjective norm. The internal consistency of the four TBP domains assessed using Cronbach alpha (α) was acceptable (subjective norm 0.86; attitudes 0.86; perceived behaviour control 0.85; and behaviour intention 0.91).

There were no statistically significant differences between the two groups' pre-survey mean scores of the TPB domains (Table 3). Moreover, there were no statistically significant differences between the two groups' three-month post-survey mean scores of the TPB domains. Furthermore, subjective norm, perceived behaviour control, and intention did not change significantly for both groups after three months. However, attitude scores improved significantly after three months. A

Table 2
Change in knowledge test scores for the study groups.

	Intervention group				Control group				
	Pre-test score (n = 102)	One-week post-test score (n = 74)	Three-month post-test score (n = 53)	P value*	Pre-test score (n = 98)	One-week post-test score (n = 61)	Three-month post-test score (n = 51)	P value*	P value **
Knowledge test score (mean ± SD)	16.24 ± 3.82	18.41 ± 3.99	19.2 ± 3.3	<0.001	14.97 ± 3.82	15.95 ± 4.6	15.8 ± 4.8	0.444; 0.48; 0.88	0.156 [a] 0.001 [b] <0.001 [c]

P value* Repeated measure ANOVA was used to compare the outcomes among study groups at three time points: pre-test, one-week post-test, and three-month post-test. A paired sample t-test was used for post hoc comparison.
P value** Binomial regression models were used to compare the outcomes between the control and intervention groups at three time points to account for baseline demographic factors: [a] pre-test, [b] one-week post-test, [c] three-month post-test score.

Table 3
The mean scores of the Theory of Planned Behaviour domains for the pre-study and the 3-month-post-study surveys.

Theory of Planned Behaviour domains	Intervention group			Control group ($n = 93$)			P value **	*P*-values of diff-in-diff model coefficients
	Pre-study survey (mean ± SD) ($n = 99$)	Three-month post-study survey (mean ± SD) ($n = 52$)	*P* value*	Pre-study survey (mean ± SD) (n = 93)	Three-month post-study survey (mean ± SD) ($n = 50$)	*P* value*		
Subjective norm	3.2 ± 0.7	3.2 ± 0.7	0.557	3.3 ± 0.7	3.2 ± 0.5	0.232	0.725[a] 0.617[b]	0.410
Perceived behaviour control	3.6 ± 0.6	3.7 ± 0.6	0.275	3.6 ± 0.7	3.5 ± 0.6	0.280	0.490[a] 0.919[b]	0.221
Attitudes	3.6 ± 0.6	3.95 ± 0.5	<0.001	3.5 ± 0.6	3.8 ± 0.5	<0.001	0.162[a] 0.815[b]	0.696
Behaviour intention	3.3 ± 0.8	3.3 ± 0.8	0.914	3.2 ± 0.8	3.3 ± 0.7	0.490	0.657 [a] 0.445[b]	0.799

P value * A paired sample t-test was used to compare the outcomes among study groups at two time points: pre-test and three-month post-test.
P value** A two-sample t-test was used to compare the outcomes between the control and intervention groups at two time points: [a] pre-test survey and [b] three-month post-study survey.

difference-in-differences (diff-in-diff) model was also used to assess the significance of the change in each TPB domain after adjusting for baseline TPB scores, which showed that there was no significant change in TPB scores between the two study groups over the two study periods.

A linear regression was used to assess the association between the pre-study TPB domains and demographics at baseline. Pharmacists' intention, behavioural control, and subjective norm scores were positively associated with the number of POCTs available at the pharmacy. Pharmacists trained outside North America had better subjective norm and intention scores than pharmacists trained inside Canada and the United States. Staff pharmacists had a lower behavioural control scores than pharmacy managers and owners. Pharmacists' attitudes toward performing POCTs was not associated with any demographic variable.

Linear regression models were used to assess the correlation between intention score and other TPB domain scores, with the intention score as the dependent variable and the other TPB domain scores as the independent variables. The analysis showed a statistically significant association between pre-study intention scores and subjective norms and attitudes scores for all groups. Overall, the TPB constructs explained 34 % of the variance in reported pre-study intentions to perform POCTs. For the post-study intention scores, the analysis showed a statistically significant association between the post-study intention scores and subjective norms and perceived behavioural control scores for all groups. Overall, the TPB constructs explained 28 % only of the variance in reported post-study intentions to perform POCTs. Furthermore, the constructs of subjective norms was the strongest predictor for behaviour intention.

Six regression models were used to assess the correlation between the intention scores, other TPB domain scores and the availability of POCTs (See Table 4). After accounting for the demographic variables, the TPB constructs and the availability of POCTs explained 46 % of the variance in pre-study intentions to perform POCTs. Only attitudes and availability of POCTs were positively correlated with pre-study intention scores after adjusting the *p*-value for multiple comparisons using Bonferroni correction ($P = .0004$; $P = .0006$, respectively). For the post-study intention scores, the TPB constructs and the availability of POCTs explained 30 % of the variance in post-study intentions to perform POCTs. The analysis showed a positive correlation between the post-study intention score and subjective norms. Furthermore, subjective norms was still the strongest predictor for behaviour intention even after adjusting the p-value ($P = .0076$).

Negative binomial regression models were used to assess the correlation between the self-reported behaviour, measured by the number of POCTs provided, and the TPB domain scores (pre-study and three-month post-study). The number of POCTs provided was the dependent variable and the TPB domain scores were the independent variables (see Table 5). The analysis showed that only the intention scores (pre- and three-month post-study) were significantly correlated with the number

Table 5
Negative binomial regression models evaluating the association between TPB constructs and the actual number of POCT provided (pre-study, three-month post-study).

Independent variables	Pre-study		Three-month post study	
	Estimate (β)	P value	Estimate (β)	P value
Subjective norm	0.0868	0.789	0.5690	0.0703
Perceived behaviour control	0.5598	0.0677	0.3466	0.291
Attitudes	−0.5735	0.0955	−0.437	0.239
Intention	1.244	<0.001	0.705	0.0068

Table 4
Linear models evaluating the association between TPB constructs, demographics and intention to provide POCTs (pre-study, three-month post-study).

		Model	Subjective norm		Perceived behaviour control		Attitudes		Availability of POCTs	
		Adjusted R-squared	Estimate (β)	P value	Estimate (β)	P value	Estimate (β)	P value	Estimate (β)	P value
Pre-study	Control group	0.532	0.236	0.136	0.347	0.048	0.395	0.074	0.075	0.553
	Intervention group	0.435	0.219	0.204	−0.302	0.088	0.519	0.006*	0.228	0.036
	All groups	0.463	0.246	0.018	0.0028	0.978	0.419	0.0004*	0.236	0.0006*
Three-month post study	Control group	0.282	0.646	0.0086*	0.0053	0.979	0.440	0.088	0.0187	0.880
	Intervention group	0.350	0.508	0.020	0.650	0.027	−0.149	0.628	−0.082	0.514
	All groups	0.300	0.369	0.0076*	0.226	0.107	0.217	0.199	0.046	0.537

Adjusted $p < .0083$ (Bonferroni correction).

of POCTs provided.

3.4. Self-reported behaviour

3.4.1. Monthly reports

A total of 131 participants completed the first monthly report (71 from the intervention group and 60 from the control group), 121 participants completed the second monthly report (66 from the intervention group and 55 from the control group), and 109 participants completed the third monthly report (57 from the intervention group and 52 from the control group). The total number of POCT services provided throughout the study duration was as follows: 673 tests in the first month, 515 in the second month, and 443 in the third month.

A generalized linear model with a negative binomial distribution was used to assess the differences in the number of POCT services provided by the two study groups after one, two and three months. There were no statistically significant differences in the number of POCT services provided between the two study groups after one, two and three months, except for the A1c and lipid POCTs performed in the first month (see Table 6). Moreover, a generalized linear model with negative binomial distribution was used to assess whether there was a significant difference in the number of POCTs performed by each study group over the three-month study duration, with the number of POCTs performed as the dependent variable and the months as the independent variables with the first month as the baseline. The analysis showed that the number of POCTs performed by each study group did not change significantly over the study period, except for a significant drop in the number of lipid POCTs performed by the control group between the first and third months.

A generalized linear model was used to assess the association between the number of POCTs performed and demographics. Pharmacists with less than 10 years of experience had a significant positive association with the number of POCTs performed. Moreover, pharmacists trained outside Canada had a significant negative association with the number of POCTs performed. Furthermore, there was a significant positive association between the number of POCTs performed and the availability of POCTs at the pharmacy.

3.4.2. Self-reported behaviour for performing POCT services and adapting a prescription

A total of 192 users completed the pre-study survey to assess self-reported behaviour for performing POCT services and adapting a prescription based on the result of POCT services. The results indicate that most participants had never or rarely performed a POCT service during the past three months. For example, 61.9 % never or rarely performed a blood glucose POCT, 73.4 % never or rarely performed an A1c% POCT, 81.3 % never or rarely performed a lipid POCT, and 90.1 % never or rarely performed a prothrombin time and INR POCT. On the other hand, 18.8 % performed a blood glucose POCT once weekly or more in the past three months, 13 % performed an A1c POCT once weekly or more in the past three months, 9.9 % performed a lipid POCT once weekly or more, and 4.7 % performed an INR POCT service once weekly or more.

The results also indicate that most participants had never or rarely adapted a prescription based on the result of a POCT in the past three months. For example, 87.5 % never or rarely adapted a diabetic medication based on a blood glucose POCT result, 88 % never or rarely adapted a diabetic medication based on an A1c POCT result, 91.1 % never or rarely adapted a medication based on a lipid POCT result, and 92.2 % never or rarely adapted a medication based on an INR POCT result.

There were no statistically significant differences between the two groups' pre-survey and three-month post-survey scores for the frequency of providing POCT services and the frequency of adapting a prescription based on the result of a POCT. Moreover, for both groups, the frequency of providing POCT services and the frequency of adapting a prescription based on the result of a POCT did not change significantly after three months.

3.4.3. Number of devices purchased throughout the study duration

When asked about the number of devices purchased, four devices were purchased in the first month of the study (three by the intervention group and one by the control group). Three devices were purchased in the second month (two by the intervention group and one by the control group). Only one device was purchased in the third month by the control group.

3.4.4. Accessing a clinical viewer

When asked about using a clinical viewer to check lab values before joining the study, 55.8 % of the intervention group and 58 % of the control group reported using a clinical viewer to check lab values in general ($P = .820$). After three months, most respondents reported using a clinical viewer to check lab values for blood glucose (63.5 % of the intervention group Vs. 58 % of the control group), A1c (67.3 % of the intervention group Vs. 56 % of the control group), lipid (63.5 % of the intervention group Vs. 56 % of the control group) and other lab values such as eGFR, CBC and electrolytes (73 % of the intervention group Vs. 68 % of the control group). However, only 19.2 % of the intervention group and 22 % of the control group reported using a clinical viewer to check INR/PT lab values. There were no statistically significant differences in the three-month responses to accessing clinical viewers for the

Table 6
Total number of POCTs performed by the two study groups at three time points: one month, two months and three months.

	Intervention group				Control group				
Number of POCTs performed	First month (n = 71)	Second month (n = 66)	Third month (n = 57)	P value*	First month (n = 60)	Second month (n = 55)	Third month (n = 52)	P value*	P value **
Glucose	132 (48.5 %)	129 (49.6 %)	123 (57.5 %)	0.699	119(29.7 %)	111 (43.5 %)	92 (40 %)	0.657	0.8463[a] 0.8619[b] 0.5567[c]
A1c%	54 (19.9 %)	53 (20.4 %)	28 (13.1 %)	0.458	150(37.4 %)	86 (33.7 %)	71 (30.9 %)	0.0845	0.0148[a]** 0.297[b] 0.0772[c]
Lipids	32 (11.8 %)	33 (12.7 %)	13 (6.1 %)	0.324	101(25.2 %)	68 (26.7 %)	36 (15.7 %)	0.030	0.0309[a]** 0.375[b] 0.2283[c]
Prothrombin time and INR	54 (19.9 %)	49 (18.8 %)	50 (23.4 %)	0.842	35(8.7 %)	42 (16.5 %)	31 (13.5 %)	0.606	0.5274[a] 0.737[b] 0.4143[c]
Total	272	260	214		401	255	230		

P value* Generalized linear models with negative binomial distribution were used to compare the outcomes among the study groups.
P value** Generalized linear models with negative binomial distribution were used to compare the outcomes between the control and intervention groups at three time points: [a] first month, [b] second month, [c] third month.

two study groups.

3.5. Assessment of access to the Pharmacy5in5 POCT modules

Out of the 102 intervention group participants who were invited to access the Pharmacy5in5 POCT modules, 75 participants (73 %) attempted to access at least one of the two POCT modules for this study. Only 67 participants (65.7 %) of the intervention group completed all quizzes in the two POCT modules, 64 of whom completed the one-week post-test. Out of the 74 participants who completed the one-week post-test, five completed only one module, and four did not complete either module.

Binomial regression models were used to assess the correlation between completing the Pharmacy5in5 POCT modules and the one-week and three-month post-test scores among the intervention group. After adjusting for pre-study scores, the analysis showed that completing the first module was significantly associated with the one-week post-test scores ($P < .001$) but not with the three-month post-test scores ($P = .578$). Additionally, the analysis showed that completing the second module was not significantly associated with the one-week post-test knowledge scores ($P = .447$). There was no sufficient data to examine the association between completing the second POCT module and the three-month post-test scores.

3.6. Assessment of participants' reaction to the Facebook group "Pharmacy5in5 research group"

Out of the 102 intervention group participants, 75 (73.5 %) joined the Facebook group.

The average number of comments was 27.8, the average number of likes was 51, and the average number of votes was 27.3. After three months, the respondents were asked how often they checked Facebook in general and the Facebook group. Most respondents checked Facebook and the Facebook group weekly; in particular, 42.3 % checked Facebook weekly, and 45.1 % checked the Facebook group weekly.

Binomial regression models were used to investigate the relationship between joining the Facebook group and the one-week and three-month post-test scores among the intervention group participants. After adjusting for pre-study scores, the analysis showed a significant association between joining the Facebook group and the one-week post-test scores ($P < .001$). There was no sufficient data to assess the relationship between joining the Facebook group and the three-month post-test scores.

3.7. Satisfaction

A total of 53 users of the intervention group completed the satisfaction survey to assess their experience with the online learning system that included the Pharmacy5in5 modules "Point-of-care testing (Ontario)" and "Interpreting Point-of-Care Tests (Ontario)" and the Facebook group "Pharmacy5in5 research group" after three months of the study. Overall, 90.6 % of respondents were satisfied with the online learning system as a whole, and 71.7 % of respondents thought that the online learning system was successful. Respondents were highly satisfied with the learner interface (mean 4.4, SD 0.58), personalisation (mean 4.3, SD 0.75), and learning community (mean 4, SD 0.84). Respondents were also satisfied with the content (mean 3.9, SD 0.72).

3.8. Nonrespondents' analysis (lost to follow-up)

Of the 261 pharmacists who were randomized, 200 completed the pre-test (76.6 %), 135 (51.7 %) completed the one-week post-test and 104 (39.8 %) completed the three-month post-test. For the intervention group, 77.8 % (102/131) completed the pre-test, 56.5 % (74/131) completed the one-week post-test, and 40.4 % (53/131) completed the three-month post-test. The analysis showed that the baseline demographics characteristics of respondents and nonrespondents in the intervention group did not differ significantly.

For the control group, 75.4 % (98/130) completed the pre-test, 46.9 % (61/130) completed the one-week post-test and 39.2 % (51/130) completed the three-month post-test. Furthermore, there were significant differences in gender ($P = .004$), location of practice ($P = .032$) and level of education ($P = .041$) between respondents and nonrespondents in the control group.

3.9. Important insights or reflections regarding providing POCTs

Study participants provided a total of 136 reflections with their monthly reports throughout the study duration. Participants highlighted key barriers and challenges regarding providing POCT services in their pharmacies. The lack of necessary POCT devices was the most frequently mentioned barrier. Pharmacists reported that their pharmacies were only offering basic tests like glucose monitoring, but did not have the necessary equipment to do INR, A1c or lipids tests. Another significant barrier identified was that the provision of POCT services is highly influenced by pharmacy managers and owners' decisions to offer these services. Pharmacists working at chain pharmacies mentioned how corporate policies limited their autonomy to carry out POCT services. Pharmacists also mentioned the financial concerns with the high cost of POCT tests and devices and how the limited reimbursement for the services provided was another major barrier to POCT services. See Table 7 for the main barriers reported by study participants regarding providing POCTs.

4. Discussion

A three-month randomized controlled trial assessed the effect of an online learning system that consisted of a computer-based education platform and an online discussion group to enhance pharmacists' knowledge and behaviour in providing POCTs. The study showed that the pharmacists' knowledge was significantly improved and retained for three months. Moreover, pharmacists were highly satisfied with the online learning system. However, the online learning system did not improve pharmacists' self-reported behaviour in providing POCTs.The study also showed that the online learning system did not improve behaviour determinants, including behaviour intention, behavioural control and subjective norms after three months. However, attitudes improved significantly for both study groups after the three-month study period.

This study showed that computer-based education improved pharmacists' short and long-term knowledge of POCTs. Several studies have reported the positive impact of computer-based education on pharmacists' knowledge.[33,40,41] A 2021 pre-post study in Belgium showed that a blended learning program enhanced community pharmacists' knowledge of preconception, pregnancy and lactation.[42] The study also showed a retention in knowledge after three to six months. Similarly, a study by Vandael et al.[43] assessed the effect of an e-learning program on community pharmacists' knowledge of the risk of QTc-prolongation. The study reported a significant increase in knowledge that was sustained for up to 10 months after the intervention. Another study by Garreau et al.[44] assessed the effect of an e-learning program on pharmacists' knowledge of atopic dermatitis and reported a significant increase in the post-test knowledge scores after completing the e-learning program and nine months later. This indicates the efficacy of computer-based education in developing sustainable knowledge in different contexts.

This study showed that computer-based education did not appear to influence pharmacists' behaviour regarding the provision of POCTs. This result aligns with previous studies that showed the limited effect of computer-based education on changing behaviour among healthcare professionals.[45–47] This could be attributed to environmental and organizational barriers reported by the study participants, particularly

Table 7
A summary of study participants' insights or reflections regarding providing POCTs.

Theme	Quotations	Frequency
Limited POCT availability due to lack of devices and equipment.	*"Our pharmacy is currently not doing any POCT."* *"Do not have any POC T devices."*	38
Limited support form pharmacy managers and owners to adopt POCTs, especially in chain or franchise pharmacies (e.g., Rexall, Costco).	*"Trying to get corporate to allow this [POCTs.]"* *"Manager and owner still not ready to move in this direction."* *"I am struggling with the pharmacy manager to actually follow through with introducing POC testing."*	33
Financial concerns and limited reimbursement for providing POCTs.	*"Pharmacy [is] not willing to invest in devices yet- waiting to see more data supporting the financial benefits."* *"Where I work, the lack of reimbursement for testing means the owner is not motivated to purchase testing equipment and offer services."* *"Didn't buy any machines due to financial reason.s"* *"Stopped A1c due to cost of the testing apparatus, would be unsustainable practice."*	27
High workload and limited staffing might prevent pharmacists from providing POCTs.	*"Staffing issues prohibit me from pushing for this [POCTs] - it is unfortunate.e"* *"I have limited capacity to offer testing."* *"No financial benefit and already too busy with other daily routines."*	22
Limited demand from patients and lack of perceived need.	*"We don't seem to be getting a call for any [POCTs]."* *"[POCT]services slow during the summer months."* *"Patients generally ask only for blood glucose tests."*	15
Plans for future implementation of POCT services.	*"Currently looking into A1c and lipid devices."* *"Currently looking into devices that may be useful to my practice."* *"We might start doing A1c or lipid profile sometime in the future."*	14

limited accessibility to POCT equipment. The study participant reported other barriers, such as limited managerial support due to financial concerns and lack of patient interest. A similar result was reported by a 2024 scoping review by Abdellatife & Makowsky,[48] which included 43 studies and explored barriers to implementing POCTs in community pharmacies. The review highlighted two key implementation factors: patient needs (e.g., lack of patient awareness about POCT services, lack of perceived need) and external policies and incentives (e.g., limited reimbursement, and insufficient prescribing authority).[48] This indicates that improving patient awareness, providing reimbursement, and changing policies to grant prescribing authority to pharmacists could facilitate change in pharmacists' practice. Future studies should consider providing participants with POCT equipment and adding medical directives, when applicable, as part of the study to fully assess the effect of their intervention.

The study showed that computer-based education had minimal effect on behavioural determinants, including behaviour intention, perceived behavioural control or subjective norms. However, both study groups' attitudes improved significantly toward providing POCTs. Our study allowed both groups to learn more about POCT implementation, which could explain pharmacists' positive attitudes. Furthermore, positive experiences providing POCTs during the study period might explain pharmacists' positive attitudes.[49,50] Previous studies indicated that attitudes could be the strongest predictor for behaviour intention of practice change among community pharmacists,[46–50] but this study found no correlation between attitudes and behaviour intention of providing POCTs. Furthermore, a scoping review by Luetsch et al.,[51] highlighted that pharmacists' attitudes toward extended pharmacy services were mostly positive despite limited actual implementation. On the other hand, subjective norms, which was the strongest predictor of intention, did not change significantly possibly due to low demand from patients, where 21 % of participating pharmacists reported that patients were mainly interested in blood glucose test training and calibration. This could indicate that patients might be more familiar with getting an established POCT service at a clinic rather than getting a new service at their community pharmacy. Moreover, their primary healthcare provider can provide a more efficient post-test follow-up (e.g., provide a diagnosis, prescribe a treatment) compared to their pharmacists.[51–54]Perceived behavioural control did not change significantly despite the significant change in attitude. A possible explanation is that 65 % of participating pharmacists were staff pharmacists who felt they did not have control over initiating new service provision without approval from their managers. Previous studies have reported how a staff pharmacy position can hinder actual behavioural control.[51,55] Overall, these findings indicate that educational interventions that target environmental and organizational barriers are needed to enhance the successful implementation of POCT services.

4.1. Limitations

This study has several limitations that merit discussion. First, the study duration was relatively short at three months, which may have influenced the depth of engagement and sustainability of observed effects. Another limitation is the social desirability or recall bias with participants' responses to self-reported surveys that assessed TPB domains and the number of POCT provided, which could have overestimated their actual behaviours and beliefs.[47,56] This could have been addressed by using objective measures to assess the number of POCTs performed, such as pharmacy billing records or actual patient encounters. Moreover, nonresponse bias might have influenced the study's findings, as the loss-to-follow-up analysis showed a significant difference between respondents' and nonrespondents' demographics including gender, location of practice, and level of education. Additionally, enhancing pharmacists' participation in the Facebook group was challenging to enforce, and only a limited number of participants consistently engaged with the group's digital content. Finally, as the study was conducted entirely online, the absence of in-person interaction components might have attenuated the impact of the intervention on behaviour change.

5. Conclusion

This study demonstrated the effectiveness of computer-based education in enhancing pharmacists' knowledge of POCTs but not influencing pharmacists' practices to enhance POCT service provision. Furthermore, pharmacists' subjective norms, perceived behavioural control, and intention to provide POCTs did not change significantly. The study also highlighted key barriers to delivering POCTs, including limited access to POCT devices, lack of managerial support, and patient demand. Future studies should focus on managing organizational factors to support POCT provision among community pharmacists, rather than focusing on knowledge and skills. Furthermore, rates of POCT services can be enhanced by granting prescribing authority for pharmacists, better reimbursement, and raising public awareness.

Funding

This work was supported by the Canadian Foundation of Pharmacy.

CRediT authorship contribution statement

Rand Hussein: Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nardine Nakhla:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Kyu Min Shim:** Writing – review & editing, Writing – original draft, Software, Formal analysis. **Joslin Goh:** Writing – review & editing, Supervision, Software, Methodology, Formal analysis. **Rosemary Killeen:** Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Conceptualization. **Kelly Grindrod:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no competing interests.

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