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Effectiveness of a web-based educational program on climate change awareness, climate activism, and pro-environmental behavior among primary health care in rural areas: a randomized controlled trial

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Abstract

Background Climate change-related environmental impacts, such as heatwaves, droughts, floods, and hurricanes, can significantly impact individuals' physical and mental well-being. Therefore, leveraging nurses' awareness of this looming issue is crucial.

Introduction Despite the correlation between climate change and health, research is scarce in nursing. Therefore, interactive web-based educational programs can effectively leverage nurses' knowledge of climate change by promoting participatory teaching and expanding their awareness through digital media.

Aims To assess the impact of web-based educational programs on improving climate change awareness, climate activism, and pro-environmental behavior of primary health care rural nurses.

Method A randomized control trial design was adopted according to the Consolidated Standards of Reporting Trials guidelines (CONSORT). One hundred twenty-four nurses completed pre- and post-intervention assessments using the Climate Change/Global Warming Knowledge Questionnaire, Environmental Self-Efficacy Scale, and Pro-Environmental Behavior Scale. Then, they are equally divided into intervention and control groups.

Results Effect sizes for climate awareness showed substantial influence, with η^2 values of 0.351 and 0.229; climate self-efficacy and Pro-Environmental Behavior PEBS demonstrated notable effect sizes (η^2=0.292 and 0.141, respectively).

Conclusion Participants who received the web-based educational program demonstrated significant improvements in climate change knowledge, environmental self-efficacy, and pro-environmental behavior. These findings highlight

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the effectiveness of digital-based interventions in enhancing climate-related competencies among primary healthcare nurses. Future initiatives should explore the scalability of such programs to broader healthcare settings to further promote climate literacy and sustainable practices.

Implication for Nursing Providing primary care nurses working in rural areas with comprehensive knowledge can enable nurse managers to advocate for environmental sustainability and stewardship, promoting community health resilience.

Implication for Nursing Policy Implementing a web-based educational program related to climate change will enable policymakers and decision-makers to ensure that primary care nurses in rural areas optimally contribute to climate advocacy and environmental health initiatives. This approach aligns with the World Health Organization's Global Strategic Directions for Nursing and Midwifery 2021–2025, which aims to achieve global health goals.

Trial registration NCT: 06196476.

Keywords Climate change awareness, Environmental activism, Environmental Self-Efficacy, Interactive digital health, Primary health care, Rural nurses

Introduction

Nurses are strategically positioned to acknowledge people's health, well-being, and the associated health consequences of climate shifts through research, training, and practice [1–6]. Increased awareness of climate conditions among nurses can contribute to global planetary health and the global development of climate-resilient health systems [7, 8]. Therefore, integrating planetary health education into nursing practice is crucial for achieving Sustainable Development Goals (SDGs) and health equity benefits [9, 10]. A systematic review by Akore et al., [11] underscores the importance of enhancing nurses' awareness of climate change and sustainable practices. It can help healthcare managers and policymakers prioritize environmental sustainability and carbon reduction criteria in procurement and service delivery decisions. It emphasizes that nurses' involvement can be pivotal in advancing a net-zero agenda. Furthermore, it was stated that providing education on environmental sustainability and stewardship is essential for empowering nurses to mitigate climate change impacts [12]. In this regard, PHC nurses should reboot the climate agenda by becoming more aware of this looming crisis and engaging in environmental activism to effectively address climate-related issues, especially in rural areas where access to resources and training may be limited [13].

Environmental activism or self-efficacy influences nurses' thoughts, emotions, motivation, and actions [14]. Fielding, et al., [15], define environmental activism as "purposeful and effortful engagement in behaviors aimed at preserving or improving the quality of the environment and increasing public awareness of environmental issues." This activism can involve protests, holding rallies, signing petitions, educating the public, lobbying governments and companies, participating in direct actions like blockades, or doing voluntary conservation and revegetation work. Environmental psychologists have thoroughly studied self-confidence in specific areas, particularly in actions like recycling [16–18] and intentions to save electricity [19]. A meta-analysis study verified that environmental activism or self-efficacy for climate change is a significant precursor of pro-environmental behavior and climate change concerns [19]. Despite this, research scarcely explores environmental self-efficacy in broader contexts beyond recycling, energy use, or sustainable consumption self-efficacy, especially in nursing [20, 21].

Indeed, the inseparable nexus between climate change and human health underscores the urgency for emergency preparedness strategies tailored to climatic conditions and the need for resilient health systems capable of withstanding such challenges. Rosa and Upvall [22] have recommended a transition from "global nursing" to "planetary nursing," which opens new opportunities for nurses to participate in global health projects relating to ecological health. In this regard, the interactive web-based educational program could be a promising intervention in enriching nurses with knowledge geared toward saving planetary and population health [23]. Beyond knowledge acquisition, interactive digital-based educational scenarios can help PHC maximize its active role in the health implications of climate change. Alvarez-Nieto et al. [24] demonstrated that using case-based learning with virtual reality techniques increases ecological consciousness and fosters positive attitudes toward climate change.

Rural communities in Egypt heavily rely on agriculture, which can impose hardships compared to their urban counterparts. These communities also have limited access to resources and support to address adverse climatic consequences such as straw fires, deteriorating soil salinity, and other climate-related disruptions [25]. As such, PHC nurses, as leaders, should examine their healthcare systems for the immediate, secondary, and ecosystem-based health determinants, identifying implications and developing preemptive plans [26]. National nursing associations have underscored the importance

of educational programs related to climate change to include nursing professionals in climate change mitigation [27]. This facet would meet the 2030 sustainable development goals and thereby advance the health and well-being of both present and future generations alongside the planet [8]. Despite this global concern, there remains a gap in the literature regarding implementing interactive digital-based educational programs, and limited research focuses explicitly on PHC rural nurses. Therefore, addressing this knowledge gap would provide an opportunity to develop and implement tailored educational programs that address this demographic's unique needs and challenges.

Methods

Aim of the study

The research aimed to evaluate the effectiveness how web-based training programs impact primary healthcare rural nurses' climate change awareness, climate activism, and pro-environmental behavior.

The study hypothesized that

(1) Primary health care rural nurses who received an interactive web-based educational program exhibited a higher awareness level related to climate change than the control group.

(2) In the face of climate change, Primary health care rural nurses who received an interactive digital-based educational program exhibited higher levels of climate activism and pro-environmental action than the control group.

Research design

A randomized controlled trial (RCT) design adhered to the Consolidated Standards of Reporting Trials (CONSORT) guidelines and was conducted between September 2023 and January 2024. To enhance methodological transparency, the assessors were blinded to group allocation, while participants were aware of their assignment. This single-masked approach was implemented to minimize assessment bias while ensuring practical feasibility. Additionally, standardized assessment protocols were followed, and objective outcome measures were used where applicable to further reduce potential biases.The study was registered with the reference number Trial registration: NCT: 06196476.

Setting and participants

The study took place at Meniet El Nasr Hospital, affiliated to the Ministry of Health which is located in Dakahleya Governorate, Egypt. This facility is an essential facility for primary health care in the region. As a primary care center, it likely offers a range of services, including general medical consultations, preventive care, vaccinations, and treatment for common health issues. Its affiliation with the Ministry of Health indicates that it adheres to national health policies and standards, ensuring quality care for the community it serves. It is the only healthcare facility in the rural area of Meniet El Nasr and boasts 280 beds, 5 floors, and 10 departments. Currently, the hospital employs a total of 350 staff nurses.

Sample size, randomization, and allocation

We employed the G* Power version 3.1.9.7 software program to calculate the sample size based on the specified parameters. The program recommended a minimum sample size of 54 PHC nurses, given an effect size of 0.5, α error probability of 0.05, two sets, and a correlation among repeated measures of 0.5. However, the researchers decided to recruit 130 PHC nurses for both the control and study groups.

The study involved recruiting PHC nurses through a process of data collection. Initially, recruitment information was disseminated to PHC nurses through WhatsApp messages and study flyer units. Interested nurses were approached to contact the researchers openly for further data about the study. Eligibility criteria included being a primary healthcare nurse, being at least 20 years old, having a smartphone, not taking any courses about climate change, and expressing willingness to participate. Nurses who expressed continued interest provided their phone numbers to the researchers, who then sent a personalized link to the online pretest assessment, which included informed consent.

The sample selection process employed a blind methodology, utilizing a systematic random sampling technique to identify participants from the total pool of nurses. The procedure included the following steps:

a. A collective list of 350 nurses was compiled, and each nurse was screened to determine if they met the predetermined inclusion criteria.
b. Relevant data of all nurses were compiled; 28 were not eligible, either refused or did not meet inclusion criteria. The remaining 322 were listed and digitized into a computerized randomization program.
c. *While G* Power recommended a minimum sample size of 54 participants, the researchers decided to recruit 130 PHC nurses to enhance statistical power, account for potential attrition, improve the generalizability of findings, and align with best practices in randomized controlled trial design. This approach also ensured a robust and representative sample for detecting meaningful effects of the intervention.
d. From this list of 322, 130 nurses were selected through a random sampling process by this

randomization program to ensure fairness and minimize bias.

e. The 130 participating nurses were randomly recruited to the intervention or control group ($n = 130$) in a 1:1 ratio using Research Randomizer version 4.0. The study group comprised 65 PHC nurses, while the control group included 65 PHC nurses.
Blinding procedures were implemented to minimize biases during randomization and assessment. The systematic random sampling process was conducted using a computerized randomization program to ensure fairness and eliminate selection bias. Additionally, allocation concealment was maintained by using Research Randomizer version 4.0, which assigned participants to either the study or control group without researcher influence. The researchers responsible for data collection and analysis were blinded to group assignments to prevent assessment bias. Furthermore, participants were not informed of their specific group allocation to reduce expectancy effects. These measures helped ensure the integrity and objectivity of the study findings.

Intervention

Program development validity

To develop the educational program, the researcher first utilized existing literature and resources on climate change education [9, 28–31]. Drawing from these sources, the program was structured to increase nurses' understanding of climate change, its impacts on health, and its role in addressing environmental challenges.

The initial program draft was then reviewed by nursing, environmental psychology, and environmental science experts to ensure its accuracy, relevance, and effectiveness in engaging rural healthcare nurses. The experts provided feedback and suggestions for improvements, leading to the revision of the program content and format.

After revisions, the program underwent validity testing to assess its appropriateness and effectiveness in achieving its educational goals. A pilot study was conducted among rural nurses to measure the program's clarity, comprehensibility, and impact on their awareness, self-efficacy, and environmental activism regarding climate change.

This rigorous development process refined the educational program to enhance its relevance, accessibility, and effectiveness for PHC rural nurses. The involvement of experts and the pilot study helped ensure that the program accurately addressed the needs and challenges nurses face in rural settings, ultimately aiming to empower them to contribute to environmental sustainability and health promotion in their communities.

The study involved two groups: the control group and the intervention group. On the other hand, the intervention group received information on climate change through a structured program developed specifically for this study.

The intervention group was split into six subgroups; due to the number of participants in the intervention group, six groups were formed, with the same two researchers providing the program to the nurses, each consisting of 10–11 participants. The participants completed the descriptive characteristics Form online, and a meeting was scheduled in collaboration with each subgroup. The intervention program offered to the participants consisted of **six** sessions, 90 min for each group. Over six weeks, the participants recorded and practiced one of their consultations, and these recordings were used to provide feedback to the participants during the last 30 min of each session (Supplement. 1).

This group's participants received an interactive web-based educational program to promote literacy, pro-environmental attitudes, self-efficacy, and reducing climate concerns (Supplement. 2). The program's procedure was divided into two phases.

Phase I consisted of one session focused on the interactive web-based educational program's general goals and participants' expectations.

Phase II concentrated on topics promoting climate literacy, environmental attitudes, self-efficacy, and reducing climate change anxiety (see Table 2). The course comprised five essential elements.

Procedures and ethical considerations

The study proposal underwent review by the Ethical Committee of Mansoura University's Faculty of Nursing and was approved (Ref. no. 0563), a prerequisite for commencing the current research. Additionally, the researchers obtained an agreement from the administrator of Meniet El Nasr Hospital after explaining the study's purpose. Participants were briefed on the study's objectives, and their informed consent was obtained. Data confidentiality was upheld throughout the study, with completed forms accessible only to the researchers. Each nurse in the program provided informed written consent after a thorough explanation of the program's aims. Measures were taken to protect the confidentiality and anonymity of the nurses. Participants were informed of their right to decline participation or withdraw from the research at any point.

Follow up

Participants in the control group were notified that their involvement in the program would be postponed until

the conclusion of the test period. All participants in both groups completed the initial assessment (T0) for the study tools. The study group began its **digital**-based educational program on climate change. The study demonstrated an impressive retention rate, as **only 6** PHC nurses chose not to continue, resulting in 62 PHC nurses in each control and study group. The **low** attrition rate suggests that the risk of systematic bias was minimal. The high retention rate and complete participant data provided a strong foundation for analyzing the program's effectiveness in fostering awareness, self-efficacy, and environmental activism regarding climate change among primary healthcare rural nurses (Fig. 1).

After completing the program, a survey was conducted to measure the program's effectiveness. The study and control groups completed the survey within 4 to 7 days of finishing the program. A post-two-month test was conducted on both groups using the same assessment tools to evaluate the long-term retention of the climate change program concepts.

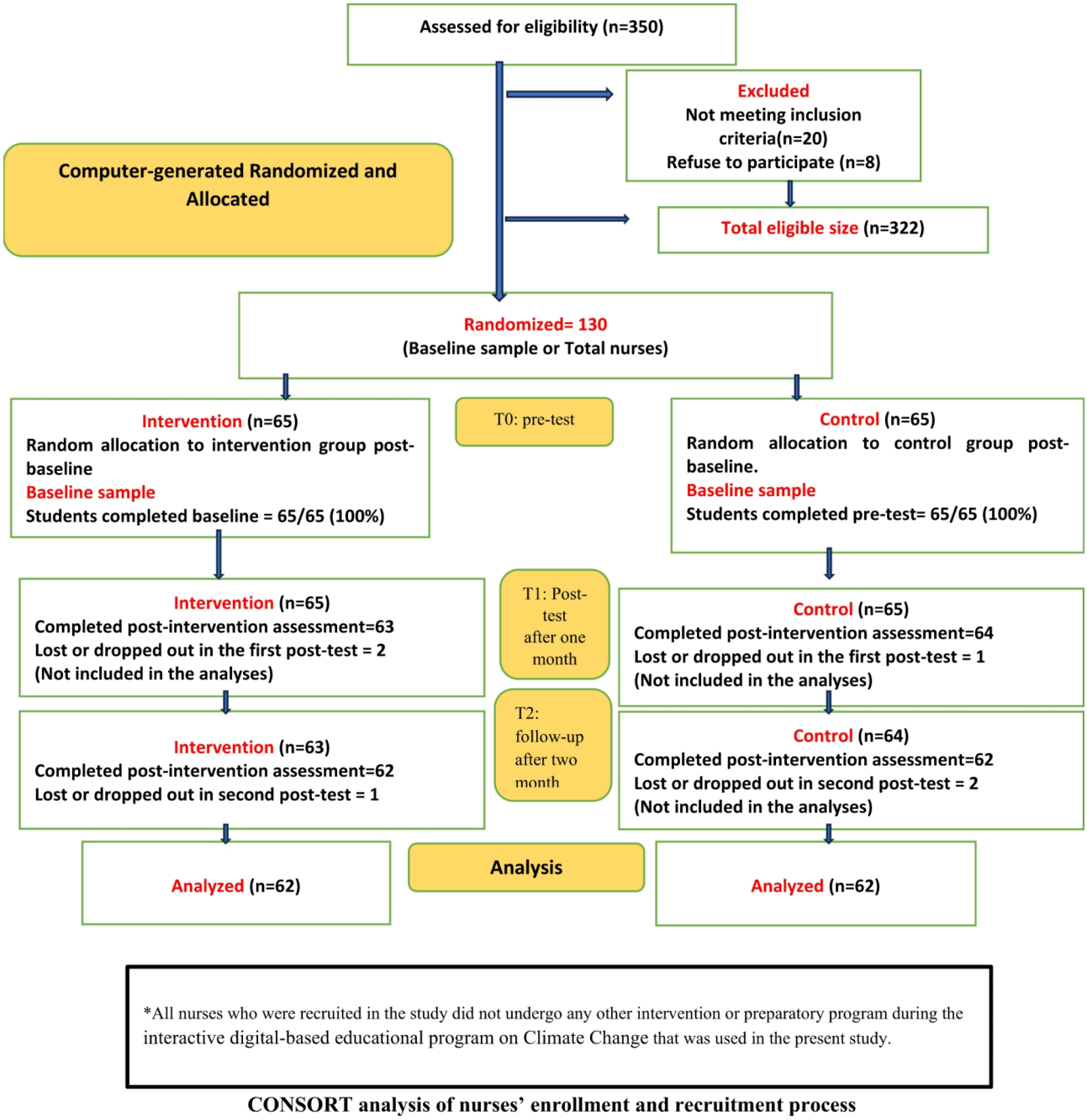

Fig. 1 CONSORT analysis of nurses' enrollment and recruitment process

Participant engagement was monitored through session duration and group discussions. Each session of the digital-based educational program lasted between 30 min and 1 h. Additionally, responses were collected in group settings, allowing participants to discuss their feedback on the program. These engagement metrics provide insight into the level of participation and interaction with the program content, which is essential for assessing its effectiveness.

Data collection

underwent surveys at three distinct time points: baseline (T0), post-intervention (T1), and follow-up (T2), with a specific emphasis on gathering sociodemographic details and information about health and climate. The data was collected through questionnaires, assessing knowledge of climate change, the environmental self-efficacy scale, and pro-environmental behavior. These questionnaires were distributed using an internet-based survey platform, and each participant was given a unique identifying number to ensure confidentiality.

Data collection measures

Tool (1) Nurse's data form: consists of two parts

Part (1) personal and job characteristics data includes age (years), gender, marital status, education qualification, and experiences.

Part (2) Health and climate-related data include medical illnesses related to climate change, the most common climate change, climate change mainly caused by human activities, and the primary source of your information about climate change [32].

Tool (2) climate change/global warming knowledge questionnaire (CCWKQ)

The scale was created by Salem et al., [33], which introduced a metric to evaluate people's comprehension of global warming, climate change, and their related impacts. The questionnaire includes 15 questions. The percentage score of knowledge was classified as knowledgeable if it was 70% or greater and as not familiar if it was less than 70% [33]. The questionnaire has a high level of reliability and validity, as indicated by its Cronbach's alpha rating of 0.879.

Tool (3) environmental self-efficacy scale (ESE)

The Environmental Self-Efficacy Scale (ESE) was developed by Moeller [34]. It consists of 20 questions evaluated on an 11-point Likert scale. A score of 0 indicates a complete inability to perform a task, while a score of 10 indicates a strong belief in one's ability. Higher scores indicate greater environmental self-efficacy. The tool's content covers various aspects of ESE, including specific categories and challenges. The scale has strong validity and reliability, with an internal consistency coefficient of 0.94.

Tool (4) the Pro-Environmental Behavior (PEB) scale

Mateer et al., [35] created a PEB scale to evaluate how frequently people engaged in environmentally conscious behavior over the previous six months. The measure consists of 11 items, divided into two sub-scales: private behaviors and public behaviors. Respondents rate their participation on a seven-point Likert scale, ranging from 0 ("never") to 6 ("as frequently as possible"). Higher scores indicate a greater level of environmentally conscious behavior. Reliability analyses were conducted, revealing internal solid consistency for both sub-scales. The private behaviors sub-scale demonstrated a reliability coefficient of 0.82, while the public behaviors sub-scale exhibited a reliability coefficient of 0.90. This indicates high levels of reliability for both sub-scales across different populations with varying levels of environmental involvement.

Ethical consideration

The study proposal underwent review by the Ethical Committee of Mansoura University's Faculty of Nursing and was approved (**Ref. no. 0563**), a prerequisite for commencing the current research. The study strictly adhered to local laws, regulations, and the ethical principles of the Declaration of Helsinki to ensure the rights and well-being of all participants. Before participation, both written and oral informed consent were obtained after providing a clear explanation of the study's objectives. Additionally, participants were informed of their right to withdraw from the study at any time without facing any repercussions.

Statistical analysis

The data underwent sorting, coding, organization, and categorization before being transferred into specially designed formats. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS), version 29.0, developed by IBM Corporation. Categorical variables were presented using numbers and percentages. Comparisons between groups for categorical variables were assessed using the Chi-square test. The student t-test compared two categories of normally distributed quantitative variables. In contrast, ANOVA with repeated measures followed by Adjustment Bonferroni was used to compare the three periods in each group. The Bonferroni method was chosen for its simplicity, conservative control of Type I error, and suitability for studies with a small number of comparisons. Effect sizes were reported as Partial Eta Squared (η^2), with values interpreted as follows: small effect (around 0.01), moderate effect (around 0.06), and large effect (around 0.14).

Table 1 Demographic characteristics of the study participants

Variables	Total (*n* = 124) *n* (%)	IG (*n* = 62) *n* (%)	CG (*n* = 62) *n* (%)	X^2	*P*
Age in years					
20 - >30	42 (33.9)	20 (32.3)	22 (35.5)	0.144	0.930
30 - >45	43 (34.7)	22 (35.5)	21 (33.9)		
45–60	39 (31.5)	20 (32.3)	19 (30.6)		
Gender					
Male	38 (30.6)	20 (32.3)	18 (29)	0.152	0.846
Female	86 (69.4)	42 (67.7)	44 (71)		
Nursing Qualification					
Diplomat	3 (2.4)	3 (4.8)	0 (0)	3.114	0.374
Technical institute	54 (43.5)	26 (41.9)	28 (45.2)		
Bachelor's degree	42 (33.9)	21 (33.9)	21 (33.9)		
Post-graduate studies	25 (20.2)	12 (19.4)	13 (21)		
Working experience in years					
> 5	38 (30.6)	19 (30.6)	19 (30.6)	0.189	0.910
5–15	48 (38.7)	23 (37.1)	25 (40.3)		
> 15	38 (30.6)	20 (32.3)	18 (29)		
Marital status					
Married	60 (48.4)	29 (46.8)	31 (50)	0.352	0.950
Single	34 (27.4)	17 (27.4)	17 (27.4)		
Widowed	16 (12.9)	8 (12.9)	8 (12.9)		
Divorced	14 (11.3)	8 (12.9)	6 (9.7)		

X^2 = Chi-square test, IG = Intervention Group, CG = Control Group

Nursing diplomat (intermediate education), nursing technical institute (upper-intermediate education), bachelor's degree in nursing (high education), master's degree in nursing (post-graduate education)

Table 2 Health and climate-related data

Variables	Total (*n* = 124) *n* (%)	IG (*n* = 62) *n* (%)	CG (*n* = 62) *n* (%)	X^2	*P*
Do you have medical illnesses related to climate change?					
No	53 (42.7)	25 (40.3)	28 (45.2)	0.346	0.951
Respiratory problems	51 (41.1)	27 (43.5)	24 (38.7)		
Heat-related illnesses	12 (9.7)	6 (9.7)	6 (9.7)		
Waterborne diseases	8 (6.5)	4 (6.5)	4 (6.5)		
From your point of view, what climate change do you know the most about?					
Extreme weather events	59 (47.6)	30 (48.4)	29 (46.8)	1.151	0.886
Water scarcity	43 (34.7)	22 (35.5)	21 (33.9)		
Global warming	1 (0.8)	0 (0)	1 (1.6)		
Ocean/ River acidification	9 (7.3)	4 (6.5)	5 (8.1)		
Biodiversity	12 (9.7)	6 (9.7)	6 (9.7)		
Do human activities mainly cause climate change?					
Yes	98 (79)	48 (77.4)	50 (80.6)	0.195	0.826
No	26 (21)	14 (22.6)	12 (19.4)		
Which of the following is the primary source of your information about climate change?					
Internet and social media	85 (68.5)	41 (66.1)	44 (71)	0.894	0.979
Websites of governments	24 (19.4)	13 (21)	11 (17.7)		
Television Programs	2 (1.6)	2 (3.2)	0 (0)		
Books and newspapers	9 (7.3)	4 (6.5)	5 (8.1)		
Family and friends	4 (3.2)	2 (3.2)	2 (3.2)		

X^2 = Chi square test, IG = Intervention Group, CG = Control Group

The significance of the results obtained was determined at the 5% level.

Results

Demographic, health, and climate-related data

Table 1 reveals a well-matched distribution of demographic characteristics between the study's Intervention Group (IG) and Control Group (CG). Age categories, gender representation, nursing qualifications, working experience, and marital status show no significant differences between the two groups, as indicated by Chi-square tests ($P > 0.05$). These findings fortify the study's internal validity, assuring that any subsequent observed effects can be confidently attributed to the intervention rather than variations in sociodemographic factors between the groups.

In Table 2, which presents health and climate-related data, the distribution of medical illnesses related to climate change showed that approximately 42.7% of participants reported no such illnesses. Respiratory problems were the most prevalent (41.1%), followed by heat-related illnesses (9.7%) and waterborne diseases (6.5%). Regarding perceptions of climate change, 47.6% identified extreme weather events as the most known aspect, and the majority believed climate change is mainly caused by human activities (79%). The primary sources of information were the internet and social media (68.5%). Notably, there were no significant differences between the IG and CG across these categories ($p > 0.05$), suggesting a consistent distribution of responses between the groups. These findings provide a comprehensive overview of participants' health conditions, perceptions, beliefs, and information sources related to climate change, highlighting baseline similarities between the intervention and control groups.

Effect of the intervention

As shown in Table 3, at baseline (T0), there is no significant difference in CCWKQ scores between IG and CG ($t = 0.646$, $p = 0.644$). However, at post-intervention time points (T1 and T2), IG exhibits significantly higher CCWKQ scores than CG (T1: $t = 7.525$, $p < 0.001$; T2: $t = 9.033$, $p < 0.001$). Additionally, ESES scores at T0 show no significant difference between IG and CG ($t = 0.374$, $p = 0.709$), but at T1 and T2, IG scores significantly surpass CG scores (T1: $t = 6.546$, $p < 0.001$; T2: $t = 7.828$, $p < 0.001$). Moreover, PEB scores at T0 exhibit no significant difference ($t = 0.484$, $p = 0.315$), yet at T1 and T2, IG scores significantly exceed CG scores (T1: $t = 4.984$, $p < 0.001$; T2: $t = 5.446$, $p < 0.001$). These findings

Table 3 Comparison of WEPS, FSA, and PCOP-SV scores at the three-time points between the intervention group and the control group

Outcomes	Time points	IG ($n=62$)	CG ($n=62$)	Mean difference	95% CI for difference		t-test (P)	Two-way repeated measures ANOVA					
		Mean ± SD	Mean ± SD		Lower bound	Upper bound		Interaction group × time		Within group		Between groups	
								F	P/η^2	F	P/η^2	F	P/η^2
CCWKQ	T0	9.24 ± 2.1	9.06 ± 2.14	0.177	− 0.57963	0.93447	0.646 (0.644)	(2, 122) = 65.987	< 0.001*** /0.351	(2, 122) = 65.946	< 0.001*** /0.351	(1, 122) = 42.462	< 0.001*** /0.258
	T1	12.19 ± 2.27	9.16 ± 2.21	3.0322	2.23459	3.82993	7.525 (< 0.001)***						
	T2	12.62 ± 20.3	9 ± 2.15	3.629	2.83370	4.42436	9.033 (< 0.001)***						
ESES	T0	44.82 ± 16.3	43.74 ± 15.86	1.0806	-4.644	6.805	0.374 (0.709)	(2, 122) 36.242	< 0.001*** /0.229	(2, 122) 56.638	< 0.001*** /0.317	(1, 122) = 50.412	< 0.001*** 0.292
	T1	67.59 ± 20.3	46.62 ± 14.9	20.967	14.626	27.309	6.546 (< 0.001)***						
	T2	85.29 ± 34.2	48.2 ± 14.82	37.080	27.703	46.458	7.828 (< 0.001)***						
PEB	T0	21.76 ± 9.7	20.33 ± 9.21	0.8225	-2.542	4.1873	0.484 (0.315)	(2, 122) 20.079	< 0.001*** /0.141	(2, 122) 31.799	< 0.001*** /0.207	(1, 122) 18.681	< 0.001*** /0.133
	T1	28.69 ± 10.6	20.09 ± 8.46	8.596	5.180	12.0128	4.984 (< 0.001) ***						
	T2	32.12 ± 11.7	21.93 ± 8.89	10.1935	6.4881	13.8989	5.446 (< 0.001) ***						

*Correlation is significant at the 0.05 level, **Correlation is important at the 0.01 level (2-tailed), *** significant difference compared to the reference category ≤ 0.001

F = Two-way repeated measures ANOVA, IG = intervention group, CG = control group, T0 = Pre-intervention, T1 = Post 1 intervention, T2 = Post 2 intervention

CCWKQ = Climate Change/Global Warming Knowledge Questionnaire, ESES = Environmental Self-Efficacy Scale, PEB = Pro-Environmental Behavior

SD Standard Deviation, 95% CI for difference, 95% Confidence Interval for Difference, t = Independent sample t-test

η^2 = Partial Eta Squared (Small Effect: Around 0.01, Moderate Effect: Around 0.06, Large Effect: Around 0.14)

emphasize the intervention's substantial positive impact on climate change knowledge, environmental self-efficacy, and pro-environmental behavior within the IG compared to the CG across the study duration.

This table also shows that the two-way repeated measures ANOVA results indicate significant interaction effects between group and time for CCWKQ, ESES, and PEB. For CCWKQ, the F-statistic ($F = 65.987$, $p < 0.001$) signifies that the changes in scores over time are not uniform between the IG and CG. Within-group changes for both IG ($F = 65.946$, $p < 0.001$) and CG ($F = 42.462$, $p < 0.001$) further emphasize the significance of temporal changes in CCWKQ scores. Similarly, ESES demonstrates significant interaction effects ($F = 36.242$, $p < 0.001$), with substantial within-group changes in both IG ($F = 56.638$, $p < 0.001$) and CG ($F = 50.412$, $p < 0.001$). Lastly, PEB scores exhibit a significant interaction effect ($F = 20.079$, $p < 0.001$), along with within-group changes in both IG ($F = 31.799$, $p < 0.001$) and CG ($F = 18.681$, $p < 0.001$). These findings underscore the differential impact of the intervention on the three outcomes over time and highlight the substantial within-group changes, emphasizing the program's effectiveness in influencing participants' knowledge, self-efficacy, and pro-environmental behavior. The effect sizes (η^2) indicate the intervention's moderate to significant impact on these outcomes, further supporting the significance of the observed changes.

Effect sizes in Table 3, indicated by partial eta-squared (η^2), underscore the substantial impacts of the interaction between time and group, as well as the main effects of time, in our study. Notably, for CCWKQ, the interaction effect ($\eta^2 = 0.351$) and the within-group effect ($\eta^2 = 0.229$) both represent large effects, signifying a considerable influence of the interactive digital-based educational program on improving climate change knowledge among participants. Similarly, for ESES, the between-group effect size ($\eta^2 = 0.292$) also reflects a large effect, highlighting the significant impact of the intervention in enhancing participants' environmental self-efficacy. For PEB, the between-group effect size ($\eta^2 = 0.141$) indicates a moderate effect, demonstrating that the intervention effectively fostered pro-environmental behavior, albeit to a slightly lesser extent compared to knowledge and self-efficacy outcomes. These findings collectively emphasize the effectiveness of the web-based educational program in promoting climate change awareness, environmental self-efficacy, and pro-environmental behavior among primary healthcare nurses in rural areas.

Table 4 compares the studied measures' pairwise comparisons at different time points within the intervention and control groups. For CCWKQ (Fig. 2), ESES (Fig. 3), and PEB (Fig. 4) within the intervention group, significant differences were observed between T0 and both T1 and T2 ($p < 0.001^{***}$). In the control group, no significant differences were found at any time point. These findings

Table 4 Pairwise comparisons of CCWKQ, ESES, and PEB scores at different time points within intervention and control groups

Variable	Group	Time		Mean Difference	P#	95% CI for Difference	
						Lower Bound	Upper Bound
CCWKQ	Intervention	T0	T1	-2.952	< 0.001***	-3.558	-2.345
		T0	T2	-3.387	< 0.001***	-4.049	-2.725
		T1	T2	-0.435	< 0.001***	−0.761	−0.110
	Control	T0	T1	-0.097	1.000	-0.703	0.510
		T0	T2	0.065	1.000	-0.597	0.726
		T1	T2	0.161	0.692	-0.164	0.486
ESES	Intervention	T0	T1	-22.774	< 0.001***	-27.784	-17.765
		T0	T2	-40.468	< 0.001***	-48.697	-32.238
		T1	T2	-17.694	< 0.001***	-25.805	-9.582
	Control	T0	T1	-2.887	0.493	-7.897	2.122
		T0	T2	-4.468	0.570	-12.697	3.762
		T1	T2	-1.581	1.000	-9.692	6.530
PEB	Intervention	T0	T1	-7.532	< 0.001***	-10.110	-4.955
		T0	T2	-10.968	< 0.001***	-14.173	-7.762
		T1	T2	-3.435	0.001***	-5.718	-1.153
	Control	T0	T1	0.242	1.000	-2.335	2.819
		T0	T2	-1.597	0.687	-4.802	1.609
		T1	T2	-1.839	0.158	-4.121	0.444

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level (2-tailed), *** significant difference compared to the reference category ≤ 0.001

T0 = Pre-intervention, T1 = Post 1 intervention, T2 = Post 2 intervention

CCWKQ = Climate Change/Global Warming Knowledge Questionnaire, ESES = Environmental Self-Efficacy Scale, PEB = Pro-Environmental Behavior

95% CI for difference and 95% Confidence Interval for Difference

#Adjustment for multiple comparisons: Bonferroni

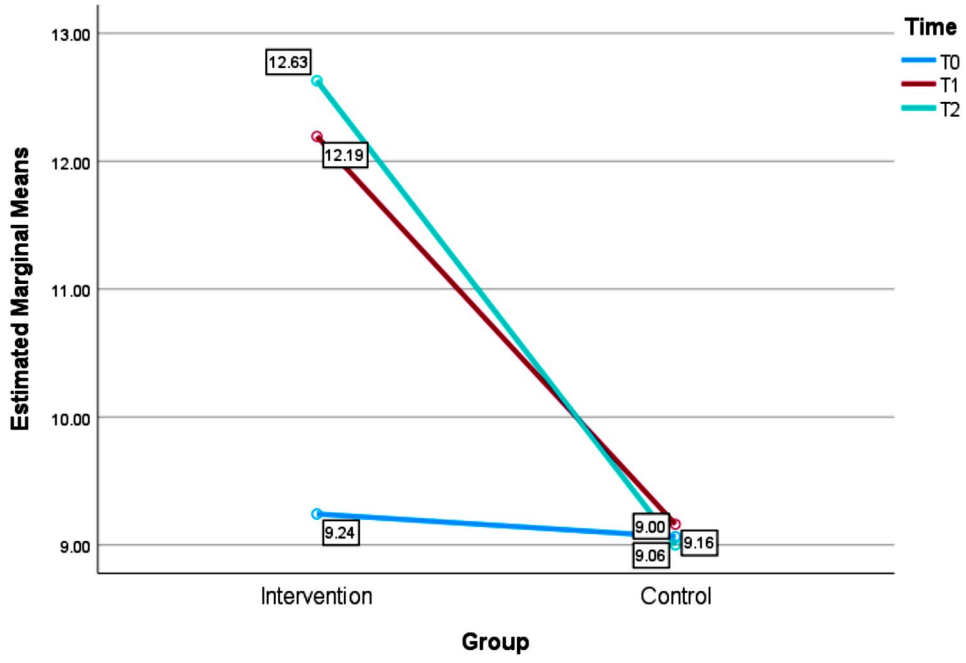

Fig. 2 Estimated marginal means of climate change/global warming knowledge

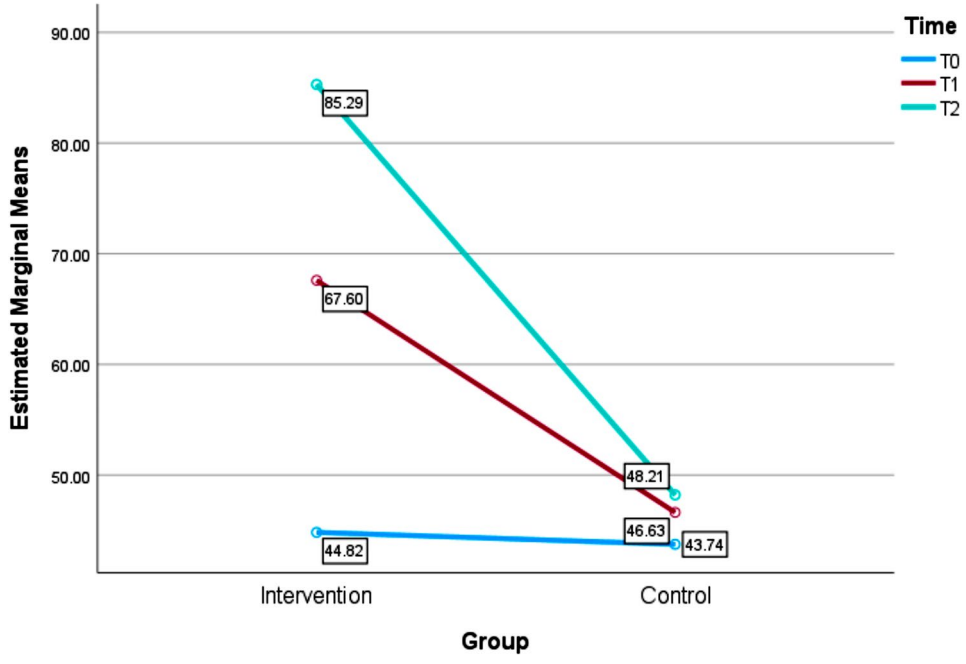

Fig. 3 Estimated marginal means of environmental self-efficacy

underscore the impact of the interactive digital-based educational program on climate change knowledge, environmental self-efficacy, and pro-environmental behavior within the intervention group, as demonstrated by significant changes throughout the study.

Discussion

Despite the critical role of PHC rural nurses in addressing the challenges of climate change and promoting environmental sustainability within their communities, effective educational interventions tailored to this demographic are needed [34, 36]. Therefore, this study aims to evaluate the effectiveness of an interactive digital-based educational program in unleashing awareness, self-efficacy, and

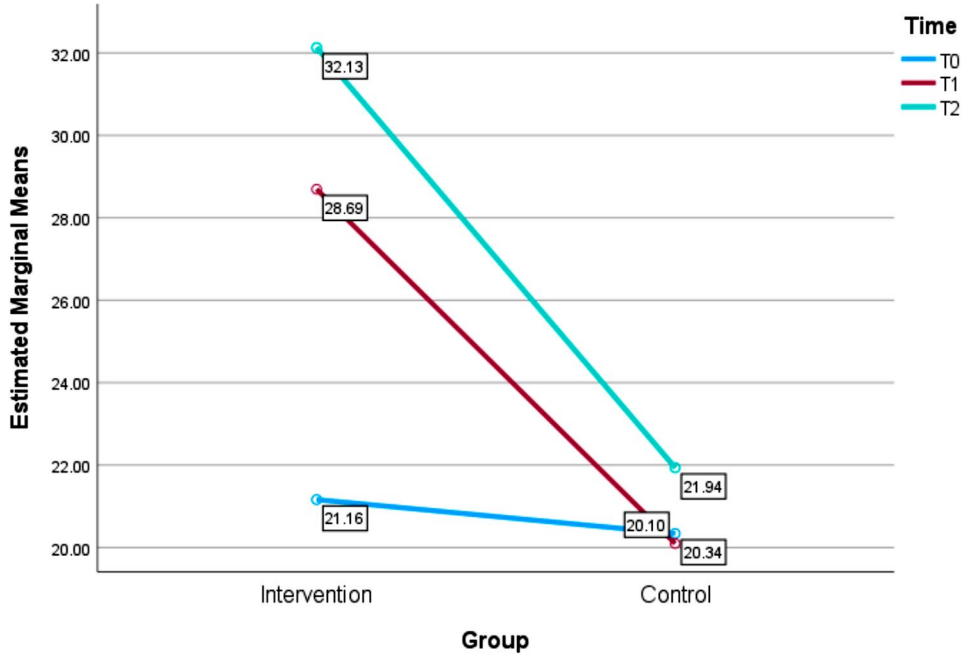

Fig. 4 Estimated marginal means of pro-environmental behavior

environmental activism among PHC rural nurses facing the challenges of climate change.

Program effectiveness on climate awareness

The existing findings have shown that the awareness level of PHC increased following the implementation of the web-based educational program. This is consistent with the collective findings of Ghazy and Fathy, and Mohammed et al. [37, 38], which underscore the significant impact of educational interventions on enhancing awareness, attitudes, and knowledge regarding climate change among various populations. These burgeoning results might be explained by the structured nature of the applied interventions, which facilitate the dissemination of accurate information regarding the intricate interplay between climate change and its health impacts. Through targeted intervention, participants are educated about climate change's direct and indirect health consequences, including heat-related illnesses, respiratory problems, waterborne diseases, food insecurity, and the spread of vector-borne diseases.

Similarly, Mahmoud and Mahmoud [39] found that by highlighting these health risks, nurses become more acquainted with and motivated to take action and advocate for sustainable practices that can mitigate the impacts of climate change on health.

Program effectiveness on pro-environmental behavior

Moreover, implementing web-based educational interventions fosters heightened awareness among PHCs regarding their imperative role in mitigating the adverse health impacts of climate change within their communities [40]. These interventions provide practical strategies for adopting pro-environmental behaviors and promoting environmental sustainability, such as reducing waste, conducting waste audits and energy conservation projects, conserving energy and water, and promoting sustainable transportation. Engaging in practical activities and a commitment to protecting the environment leads to an increase in implementing eco-friendly behaviors. These actions contribute to environmental protection and empower nurses to advocate for sustainable healthcare practices in their professional and personal lives.

Supporting this, a recent randomized controlled trial by Eweida et al. [41] demonstrated the effectiveness of a video-based climate change program in enhancing eco-cognizance, emotional response, and self-efficacy among rural nursing students. The study highlights how educational interventions can significantly improve individuals' environmental awareness and motivation to engage in pro-environmental behaviors, aligning with the present findings that underscore the role of web-based education in fostering sustainability practices.

In addition, Li et al. [42] delve into the intricate dynamics of pro-environmental behavior and the implementation of green human resource management practices. They concluded that an organizational climate infused with environmentally conscious principles catalyzes employee engagement in pro-environmental behaviors, enhancing overall environmental performance.

Program effectiveness on climate self-efficacy

Comparing the intervention and control groups in the current study, climate self-efficacy within the intervention group was higher than in the control group. These findings signal that the web-based educational program's interactive features have positively affected the completers' self-efficacy.

For instance, simulations and real-world scenarios related to building efficiency provided the intervention group with immersive learning experiences and allowed for hands-on exploration of sustainable practices [43]. The program's emphasis on case studies and practical applications within healthcare settings created direct relevance to their professional roles, fostering a sense of efficacy in implementing environmentally sustainable measures. Similarly, incorporating feedback mechanisms and continuous assessments in the digital program enabled the intervention group to gauge their understanding and competence in building efficiency concepts, reinforcing their self-efficacy.

The existing findings underscore the distinct impact of the applied web-based educational intervention on the three targeted outcomes across the study period by highlighting the variability in changes observed over time between the intervention and control groups. This differentiation suggests that the training program uniquely influenced each outcome compared to the control group.

Moreover, the substantial within-group changes observed in the intervention and control groups underscore the program's potency in shaping participants' knowledge, self-efficacy, and pro-environmental behavior throughout the study. This phenomenon indicates a notable advancement in participants' cognitive understanding, confidence levels, and behavioral inclinations regarding climate change, indicative of the program's transformative potential. Furthermore, the effect sizes (η^2) observed, ranging from moderate to large, support the significance of the observed changes. These effect sizes serve as quantitative indicators of the strength of the relationship between the intervention and the outcomes and highlight the program's considerable impact on participants' attitudes and actions toward climate change.

Limitations of the study

This study has several limitations that should be considered. One key limitation is the reliance on self-reported data, which introduces the possibility of social desirability bias. Additionally, the short-term assessment captures only immediate changes, without evaluating the long-term sustainability of the intervention's effects.

Another limitation is the study's focus on rural nurses, which may not fully represent the experiences or needs of nurses in urban or suburban settings. This focus may also exclude individuals with limited access to technology or lower digital literacy, potentially impacting the generalizability of the findings.

Although the study achieved a high retention rate, we recognize that even a small number of dropouts could introduce some level of bias. Future research should consider analyzing attrition patterns to assess whether dropouts were systematically different from those who completed the study, thereby strengthening methodological rigor.

Implication for nursing

- Equipping nurses with comprehensive knowledge and skills to address the health impacts of climate change. Nurses are pivotal in advocating for environmentally sustainable practices and promoting health resilience in communities, especially in rural areas where vulnerabilities to climate change are pronounced.
- The study highlights the effectiveness of digital-based educational programs in enhancing nurses' environmental self-efficacy and pro-environmental behavior, suggesting integrating such programs into nurse professional development initiatives.
- Utilizing innovative educational approaches, such as interactive digital platforms, to engage learners and enhance their understanding of complex issues like climate change.

Implication for nursing policy

- Advocates for the integration of climate change education into nursing curricula. Educational institutions should consider incorporating digital-based educational programs focused on climate change into their nursing programs, ensuring that future nurses are equipped with the knowledge and skills needed to address the health challenges posed by climate change.
- Nursing policies should emphasize nurses' participation in climate advocacy activities. This could include providing resources for nurses to lead community education sessions, participate in policy advocacy, and engage in environmental health initiatives. Policies should also recognize and reward nurses for their contributions to climate activism.
- Fostering partnerships and collaborative efforts, nursing professionals can contribute to a holistic approach to climate change mitigation and adaptation strategies. This can be facilitated through joint training programs, collaborative research projects, and interdisciplinary forums for knowledge exchange.

- Future research could explore the long-term impacts of such interventions and their scalability across diverse healthcare settings.

Conclusion

The study's results indicate that the interactive digital-based educational program positively impacted climate change knowledge, environmental self-efficacy, and pro-environmental behavior among primary health care rural nurses. The intervention group showed significantly higher scores in these areas than the control group, with effect sizes indicating a moderate to significant impact of the program.

The findings also highlight the importance of targeted educational programs in enhancing nurses' capacity to address climate change-related health issues. The program's effectiveness was evident in the significant changes observed in the intervention group over time compared to the control group. These results underscore the potential of digital-based educational interventions in promoting climate awareness, self-efficacy, and environmental activism among healthcare professionals.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12912-025-03031-x.

Supplementary Material 1

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Author contributions
Study design: MHRA, RSE, SMF, AASData collection: MHRA, SMAData analysis: AHE Study supervision: MHRA, RSEManuscript writing: ESA, ISA, MAE, SMF, AASCritical revisions for important intellectual content: MHRA, ESA, ISA, AHE, RSE. All authors have agreed on the final version and meet at least one of the following criteria (recommended by the ICMJE [http://www.icmje.org/recommendations/]: Substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data. Drafting the article or revising it critically for important intellectual content.

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Data availability
Upon request for scientific purposes, the researcher of correspondence will provide researchable information of the research.

Declarations

Ethical approval
The study proposal underwent review by the Ethical Committee of Mansoura University's Faculty of Nursing and was approved (Ref. no. 0563), a prerequisite for commencing the current research. The study strictly adhered to local laws, regulations, and the ethical principles of the Declaration of Helsinki to ensure the rights and well-being of all participants. Prior to participation, both written and oral informed consent were obtained after providing a clear explanation of the study's objectives. Additionally, participants were informed of their right to withdraw from the study at any time without facing any repercussions. The study was registered with reference number NCT:06196476.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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