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Effectiveness of Nutrition Literacy Program on Oral Health among Thai Village Health Volunteers: A Mixed Methods Study

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Background and Objectives: Oral health disparities remain a major public health challenge in Thailand, particularly in areas with limited dental care access. While village health volunteers (VHVs) are crucial for community health education, their role in promoting oral health through nutrition literacy remains underutilized. This study evaluated a nutrition literacy program's impact on VHVs' oral health knowledge, skills, and practice using mixed-methods research.

Materials and Methods: This study was conducted from January to March 2024 in Health Region 1, northern Thailand, using a mixed methods embedded experimental design. Sixty VHVs from mountainous areas with high oral health needs and limited dental access received a three-day training program delivered by dentists and nutritionists. Training covered nutrition literacy, communication skills, and practical community application. Data collection included pre-post tests using a researcher-developed 16-item knowledge assessment ($\alpha = 0.78$) validated by experts, skill evaluations (6-item checklist, $\alpha = 0.85$), observations from 5 qualified observers, and focus group discussions. Data analysis included paired t-tests and thematic analysis with methodological triangulation ($p < 0.05$).

Results: Participants (mean age 52.15 ± 7.20 years, 95% female) demonstrated significant knowledge improvement (mean difference = 7.38; $p < 0.001$) and effectiveness indices of 88.16/88.33, surpassing the 80/80 benchmark. Mean skill scores were 15.67 ± 2.319 out of 18 points. Qualitative results showed increased confidence, teamwork, technology use, leadership skills, and effective community knowledge application.

Conclusion: The program effectively enhanced VHVs' oral health knowledge and skills. Recommendations include: (1) incorporating the program into regular VHV training curricula with quarterly assessments, (2) establishing mentorship systems between experienced and new VHVs, (3) developing community-based oral health monitoring systems utilizing VHVs' enhanced skills, and (4) creating local support networks for continuous knowledge exchange and skill reinforcement. These recommendations aim to strengthen community oral health promotion by enhancing VHV capacity.

Keywords: Health Literacy, Mixed Methods, Nutrition, Oral Health, Thailand, Village Health Volunteers

Journal of Health Literacy

Received: 03 June 2025
Accepted: 08 October 2025
Doi: 10.22038/jhl.2025.84303.1675

Introduction

Oral health disparities persist as a significant public health challenge in Thailand, particularly in Health Region 1, where a low proportion of the population receives oral health check-ups and meets the criteria for functional dentition (1, 2) .

In Thailand, approximately 74.3% of elderly individuals have untreated oral health problems, including gingivitis (48.7%), severe periodontitis (18.7%), untreated dental caries (60.0% averaging 2.1 teeth per person), root caries (35.5%), and dry mouth (3.7%). These conditions can progress without timely care, causing pain, functional impairment, tooth loss, and reduced quality of life. The disease prevalence and behaviors, a fundamental gap exists linking nutrition literacy to oral health outcomes. No established community-based education approach through Village Health Volunteers exists, justifying interventions targeting VHVs as nutrition literacy agents for oral health promotion. Health Region 1 in northern Thailand features mountainous high-altitude area facing transportation barriers to healthcare. Geographic isolation, ethnic diversity, agricultural economy, lower education, and aging demographics exacerbate elderly oral health problems (74.3% untreated conditions), necessitating Village Health Volunteer-based nutrition literacy interventions. They provided reinforced knowledge, monitored progress, and encouraged proper oral hygiene practices.

Nutrition literacy positively correlates with healthy eating behaviors (3,4), encompassing the ability to access, understand, analyze, and apply nutrition information effectively (5) .Village health volunteers (VHVs), as a vital workforce in community health (6), play a strategic role in promoting health literacy (7, 8). A literature review reveals several important research gaps. Firstly, there is a lack of nutrition literacy programs specifically designed for oral health. Existing programs often separate nutrition and dental health knowledge, lacking the integration necessary for effective oral health promotion. Furthermore, limitations exist in evaluating nutrition literacy programs for VHVs, as previous studies primarily used quantitative assessments (9), failing to provide in-depth understanding of the learning

process and changes that occur. Lastly, the lack of empirical evidence on factors contributing to the success of health literacy programs in the context of Thai VHVs, who have specific cultural and community health system characteristics, is another significant gap that needs to be addressed.

The study employs a Mixed Methods Experimental Design, and the combination of these theories and concepts will help the program respond to learners' contexts and achieve expected outcomes effectively. Despite few elderly people in Health Region 1 care for their teeth daily, 60% still have untreated dental caries, and only minority use interdental cleaning devices. Nutrition literacy addresses this gap by teaching not just what foods affect oral health, but how to make informed dietary choices that prevent dental problems. However no previous research in Thailand has tested whether nutrition education can effectively improve oral health outcomes. This study fills that critical evidence gap by training Village Health Volunteers to deliver nutrition literacy education and measure whether this approach reduces oral health problems in communities with limited access to dental services.

Materials and Methods

Study Design and Conceptual Framework

This study employs a Mixed-Methods Experimental Design under the Embedded Design framework (13), integrating quantitative and qualitative approaches to comprehensively evaluate a nutrition literacy program for Village Health Volunteers (VHVs). The embedded design combines a single-group pretest-posttest experimental study with embedded qualitative components (participant observation and focus group discussions), facilitating understanding of both program effectiveness (quantitative) and underlying learning mechanisms (qualitative), addressing the research questions from complementary perspectives. The study comprised three sequential phases: pre-experimental phase (baseline assessment and readiness observation), during-experimental phase (intervention delivery with continuous monitoring of learning behaviors and participation patterns), and post-experimental phase (outcome assessment and focus group discussions with trained observers).

Population and Study Setting

The primary population included Village Health Volunteers actively working in Health Region 1, northern Thailand, specifically in mountainous terrain districts with limited dental service accessibility and documented high oral health needs among elderly populations.

Time and Place of Study

The study was conducted from January to March 2024 in Health Region 1, northern Thailand. The three-day training workshop was implemented in January 2024, with follow-up assessments completed by March 2024.

Sample Size and Sampling Method

The study employed purposive sampling to select 60 VHVs from communities identified as having significant oral health challenges. Sample size was determined using Krejcie and Morgan's formula (14), accounting for the population of active VHVs in the target region and ensuring adequate statistical power for paired comparisons. Additionally, five health professionals with expertise in dental public health and qualitative research methods served as trained observers for qualitative data collection.

Inclusion criteria for VHVs: age 25-60 years, ability to read and write Thai, minimum one year of active service as VHV, and provision of written informed consent.

Exclusion criteria: inability to fully participate in the three-day program or voluntary withdrawal request.

Observer inclusion criteria: minimum one year of qualitative research experience, dental health knowledge, and availability to observe throughout the entire project.

All participants provided written informed consent before enrollment, acknowledging voluntary participation and commitment to complete program activities.

Variables

The independent variable was the nutrition literacy program for oral health. Dependent variables were measured according to Bloom's Taxonomy (12), encompassing Cognitive Domain (knowledge acquisition), Affective Domain (attitudes and satisfaction), and Psychomotor Domain (practical skills application).

Intervention Description

The intervention consisted of a three-day intensive training program (18 total hours: 6 hours daily) delivered by a multidisciplinary team of dentists and nutritionists with expertise in community health education. The program was structured around six core competency areas: accessing information, understanding, questioning, decision-making, application, and

communication, following principles of Adult Learning Theory (10) and Nutbeam's health literacy framework (11).

Day 1 (6 hours): Introduction to oral health and nutrition literacy concepts, information access and evaluation skills, interactive lectures with multimedia presentations, group discussions, and hands-on practice with digital information searching.

Day 2 (6 hours): Understanding and questioning techniques, critical thinking development, case-based learning scenarios, role-playing exercises for patient communication, and small group problem-solving activities.

Day 3 (6 hours): Decision-making and application skills, practical community implementation strategies, action planning workshops, peer teaching practice sessions, and program evaluation.

Training materials included illustrated manuals, visual aids, digital resources, case study examples reflecting local community contexts, and practical assessment tools. All materials were developed specifically for VHVs and validated by content experts.

Instrumentation

Quantitative Instruments

Instruments were developed based on Bloom's Taxonomy framework (12), covering cognitive, affective, and psychomotor domains through a systematic five-step process: studying relevant theories and research, creating items and scoring criteria, verifying content validity by five experts, revising based on expert suggestions, and piloting with 30 VHVs from non-study areas.

Knowledge Assessment Tool: A 16-item multiple-choice test assessing cognitive understanding of nutrition literacy for oral health (Cronbach's $\alpha = 0.78$). Content validity index (CVI) ranged from 0.67-1.00, with all items achieving acceptable validity thresholds. Items covered nutrition principles, oral health relationships, information evaluation, and community application strategies. Scoring: 1 point per correct answer, total score range 0-16, with scores ≥12 indicating adequate knowledge.

Satisfaction Assessment: A 5-point Likert scale questionnaire (1=lowest, 5=highest satisfaction) evaluating training content, instructors, facilities, and perceived learning outcomes. CVI = 0.89.

Skill Assessment Form: An 18-point observational checklist evaluating practical competencies during training activities (Cronbach's α = 0.85), including analytical thinking, communication, creativity, knowledge application, teamwork, and task completion. Scoring: 0-3 points per dimension based on demonstrated proficiency, with total scores ≥14 indicating satisfactory skill development.

Qualitative Instruments

Semi-structured interview guides and structured observation forms were developed following established qualitative methodology (13). Interview guides included open-ended questions about learning experiences, confidence changes, perceived barriers, and application intentions. Observation forms, grounded in Bloom's Taxonomy and integrated with Structured Observation and Participant Observation principles, documented behavioral changes, participation patterns, and skill demonstration throughout training. All instruments were reviewed by three qualitative research experts and piloted before implementation.

Data Collection Procedures

Quantitative data collection: Pre-training knowledge assessment was administered on Day 1 before instruction. Post-training assessment occurred immediately after Day 3 completion. Skill assessments were conducted continuously throughout training by five independent observers who completed standardized training on observation protocols and inter-rater reliability calibration. Satisfaction surveys were administered at program conclusion.

Qualitative data collection: Five trained observers systematically documented participant behaviors, interactions, and skill demonstrations throughout the three-day program using structured observation forms. Audio-recorded focus group discussions with observers were conducted after program completion, exploring observed changes, learning processes, and implementation readiness. All audio recordings were transcribed verbatim for analysis.

Data Analysis

Quantitative analysis: Descriptive statistics characterized participant demographics and outcome distributions. Paired t-tests compared pre-post knowledge scores, with statistical significance set at $p < 0.05$. Program efficiency was evaluated using E1/E2 criteria, where E1 represents process efficiency (performance during training) and E2 represents outcome efficiency (post-training achievement), with 80/80 as the standard threshold for effective programs.

Qualitative analysis: Thematic Analysis following Braun and Clarke's six-phase approach (13) was employed. This involved familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report. Multiple researchers independently coded transcripts, met to discuss emerging themes, and reached consensus through iterative discussion.

Data Integration Strategy

Data integration followed the "merging data" approach (13), where quantitative findings addressed program effectiveness ("whether" the intervention works) while qualitative insights explained processes and contextual factors ("how" and "why" changes occurred). Integration involved analyzing data separately, comparing for consistency, synthesizing to answer research questions, and presenting integrated results. Methodological triangulation (combining observation, interviews, and assessments) and data triangulation (multiple observer perspectives) enhanced result credibility and comprehensive understanding.

Validation and Quality Assurance

Quantitative validity: Content validity was established through expert review (five experts in dental public health, nutrition, and health education), with Index of Item-Objective Congruence (IOC) values ranging 0.67-1.00. Internal consistency reliability was confirmed through pilot testing (Cronbach's $\alpha > 0.70$ for all scales).

Qualitative rigor: Multiple validation strategies ensured trustworthiness following Lincoln and Guba's criteria. Credibility was established through prolonged engagement (three-day observation period), investigator triangulation (five independent observers), and member checking (participants verified interpretation accuracy). Transferability was enhanced through thick description of context and participants. Dependability was maintained through detailed documentation of procedures and decision-making processes. Confirmability was supported by maintaining audit trails of data analysis steps and researcher reflexivity.

Result

1. Pre-experimental Phase

Participant Characteristics

VHV Context:

The study participants were 60 VHVs working in an area facing challenges in access to dental public health services and tooth loss among the elderly. Most of the participants were female

(95%), with an average age of 7.20 ± 52.15 years, ranging from 29 to 61 years. Most had an educational level below a bachelor's degree (90%).

In addition to their role as health volunteers, the participants also held other positions, such as local officials (36.67%), elderly caregivers (26.67%), and social development and human security volunteers (5%).

Regarding experience in nutrition literacy training for oral health, 45% had previously attended training, while 55% had not. However, all participants were unsure whether the training they attended followed the principles of health literacy.

The diversity of the sample in terms of age, education, and experience will provide insights from different perspectives, which will be beneficial for further development of an effective nutrition literacy skill training program for oral health.

Observer Context

The study context included five observers working at the International Dental Public Health Center. All observers had undergone training in observation based on Bloom's theory and had experience observing VHV behavior in fluoride drinking water projects, oral cancer projects, and health literacy projects for VHVs. The observers consisted of three public health academics, one dental public health officer, and one international relations officer, with observation experience ranging from 2 to 8 years. All had completed a bachelor's degree in fields related to health sciences and international communication. The diversity of professions in the observer team strengthens the data collection process by providing comprehensive perspectives on health, communication, and cultural dimensions, leading to the credibility of the qualitative data in this study.

2. During-experimental Phase

2.1 Pre- and Post-training Achievement

This study compared the pre- and post-training achievement of 60 VHVs. The analysis using Paired Samples t-test revealed significant changes, as shown in **Table 1.**

Table 1 Comparison of Pre- and Post-training Achievement (N = 60)

Test	Full Score	Mean	SD	t	p-value
Pre-training	16	6.75	3.133	-18.866	< .001
Post-training	16	14.13	2.012		

The post-training score (2.012 ± 14.13) was significantly higher than the pre-training score (3.133 ± 6.75) (t = -18.866, p < .001) out of a total score of 16. Furthermore, the decrease in standard deviation from 3.133 to 2.012 reflects a reduction in the dispersion of post-training scores, indicating the consistency of learning outcomes among the trainees.

These results demonstrate that the training program effectively developed the knowledge and understanding of the trainees, with clear and consistent improvement.

2.2 Evaluation of Training Program Efficiency

This study evaluated the efficiency of the training program for 60 VHVs using the E1/E2 efficiency criteria. The analysis results are presented in **Table 2.**

Table 2. Efficiency of the Training Program

Evaluation	N	Full Score	Total Score	Mean	Percentage
During Training (E1)	60	30	1,586.80	26.45	88.16
Post-training (E2)	60	16	848.00	14.13	88.33

The efficiency of the process (E1), assessed from the training behavior and individual practice during the training, had a mean score of 26.45 out of a total score of 30, equivalent to 88.16%.

The efficiency of the outcome (E2), evaluated from the post-training test, had a mean score of 14.13 out of a total score of 16, equivalent to 88.33%.

The analysis revealed that the developed training program had an efficiency of 88.16/88.33, which is higher than the standard criterion of 80/80. The interpretation is based on the following criteria: below 77.49 is considered below the criterion, 77.50-82.49 meets the criterion, and above 82.50 is considered above the criterion.

2.3 Evaluation of Volunteer Satisfaction with the Training

The satisfaction assessment of 60 VHVs who participated in the nutrition literacy training program for oral health found that the participants had the highest overall satisfaction with the program, with a score of 0.581 ± 4.37. When considering each aspect, all aspects were also rated at the highest level. The aspect of speakers and presentation received the highest score (0.591 ± 4.42), followed by the training content (0.581 ± 4.37) and the training room and services (0.556 ± 4.28), respectively.

Moreover, the evaluation of participants' understanding reflected clear improvement after the training. The level of understanding increased from a high level before the training (0.756 ± 4.07) to the highest level after the training (0.675 ± 4.45).

These evaluation results demonstrate the effectiveness of the developed training program in enhancing the knowledge and skills of VHVs in nutrition literacy for oral health. The participants expressed high satisfaction with all components of the program, including content, speakers, and facilities, along with significant improvement in their understanding of the content. These positive outcomes reflect the quality and appropriateness of the program in developing the capacity of VHVs, which will be beneficial for promoting oral health and nutrition literacy at the community level.

2.4 Evaluation of Behavior During Training in the Program

The evaluation results from the observers' ratings showed satisfactory effectiveness of the program, focusing on the development of four aspects: analytical thinking, communication, creativity, and knowledge application. The sample of 60 participants had an average total score of 1.40 ± 10.78 out of a total score of 12, reflecting a high level of skills.

When considering each aspect, the VHVs excelled in analytical thinking according to the given tasks (0.42 ± 2.81) and the ability to apply information in real-life situations (0.48 ± 2.72), while creativity had the lowest score but still at a satisfactory level (0.51 ± 2.52).

The score distribution showed that 81.6% of the VHVs had a total score higher than 10, with 28.3% achieving a perfect score of 12. This data indicates that the training program successfully developed the skills of most VHVs to a high level. However, a small number of VHVs (3.4%) had scores lower than 6, indicating a need for further development.

2.5 Evaluation of Practice Quality

The evaluation of practice quality during the skill training of the sample group (n = 60), based on the observers' ratings, found that the overall skill score was 2.319 ± 15.67 out of a total score of 18, with a minimum score of 6 and a maximum score of 18. This indicates that the sample group had a high level of skills and considerable consistency.

The analysis of each aspect revealed that the cooperation of group members had the highest score (0.26 ± 2.97), followed by the successful completion of tasks according to the steps (0.50

± 2.77) and the implementation of work according to the plan and steps (0.52 ± 2.73). The aspect of task delegation within the group had the lowest score (0.80 ± 2.33).

The score distribution showed that most of the sample group obtained scores between 16-18, particularly a score of 17 (25%), followed by a score of 18 (23.3%) and a score of 13 (20%).

The research findings suggest that the sample group had a high level of collaborative work skills, with strengths in group member cooperation. However, they should further develop the skills of task delegation within the group.

3. Post-experimental Phase

3.1 Focus Group Discussion Results

The content analysis from the focus group discussions revealed key themes:

The observations and focus group discussions conducted by five observers demonstrated the development of VHVs in five aspects across two phases. During the experiment, changes were observed in three areas: progressive and more confident learning, teamwork through exchange and support, and the use of technology for research and application of digital media. After the experiment, development was found in two areas: leadership in knowledge transfer and being a leader of change, and the ability to apply knowledge at the individual, family, and community levels. These findings reflect the effectiveness of the program in developing the potential of VHVs to become leaders in health literacy within their communities.

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Table 3. Analysis of Skill Development in VHVs

Themes	Subthemes	Significant Statements
Changes in learning	- Development of confidence - Progressive learning - Adaptation to new challenges	- "From being unconfident at first, they became able to communicate effectively" (O5) - "On day 2, they expressed more opinions" (O2) - "They can analyze according to the tasks given by the instructor" (O1)
Teamwork	- Knowledge exchange - Mutual support - Participation	- "They can gather ideas from group members" (O2) - "They help friends think of answers" (O1) - "Their creativity is fair, but they participate in group work" (O5)
Technology use	- Information search - Application of digital media - Self-directed learning	- "They use Google to search for media" (O3) - "They focus on searching for information from Google" (O5) - "They are creative and help friends find answers from Google well" (O4) - "They apply the information and write assignments" (O5)
Leadership	- Knowledge transfer - Persuading others - Responsibility	- "They can explain to friends in the group to understand" (O3) - "They speak, communicate, lead, and tell others to follow" (O4) - "They can be Teacher Kor" (O3)
Application of knowledge	- Applying in daily life - Adapting in the family - Disseminating to the community	- "They apply the information in real life at home" (O2) - "They search for information about foods that prevent tooth decay" (O3) - "They communicate and share the information with friends" (O4)

3.2 Analysis of Data During the Experiment: Development During Training

The qualitative findings demonstrating the progression of skills among the village health volunteers (VHVs) during the intervention are presented in **Table 3** as detailed below.

3.2.1 Changes in Learning of VHVs

The atmosphere of the training changed noticeably over time. The VHVs demonstrated impressive development in many aspects, especially the evident change in confidence. As one observer mentioned, "From being unconfident at first, they became able to communicate effectively" (O5). The learning of VHVs progressed steadily, reflected through the observation that "On day 2, they expressed more opinions" (O2).

Interestingly, they showed the ability to adapt to new challenges, particularly when faced with complex tasks. The participants "can analyze according to the tasks given by the instructor" (O1), demonstrating the development of stronger analytical thinking skills.

3.2.2 Teamwork of VHVs

The group work atmosphere among VHVs was full of liveliness. The sound of discussions and exchanges of opinions resonated from every group. The observers recorded the impressive participatory learning in several aspects.

The exchange of knowledge occurred naturally. The VHVs "can gather ideas from group members" (O2), combined with mutual support through "helping friends think of answers" (O1), reflecting a culture of supportive learning.

Despite individual differences, everyone demonstrated their potential through participation. As one observer noted, some "have fair creativity but participate in group work" (O5), reflecting that the success of a team is not measured by individual competence but by the synergy of learning together.

3.2.3 Use of Technology for Learning and Skill Development

In the training room, each group of VHVs "use Google to search for media" (O3) with determination. The observers recorded this interesting digital learning in various aspects.

The information search skills of VHVs developed notably. They "focus on searching for information from Google" (O5), reflecting that they "can use technology as a tool to access knowledge effectively" (O3).

The sharing of digital knowledge occurred naturally within the groups. VHVs with more skills "are creative and help friends find answers from Google well" (O4), demonstrating the application of digital media to support collaborative learning.

Impressively, the VHVs not only searched for information but also "apply the information and write assignments" (O5), reflecting the development of self-directed learning skills through technology and "communicating and sharing the information with friends" (O4).

3.3 Analysis of Data After the Experiment: Development Outcomes

3.3.1 Leadership of VHVs in Skill Training

In the skill training groups of VHVs, the image of leadership began to emerge through the training. The VHVs demonstrated outstanding potential in knowledge transfer. As one observer noted, "They can explain to friends in the group to understand" (O3).

The ability to persuade others was another skill that developed noticeably. The VHVs "speak, communicate, lead, and tell others to follow" (O4), which is an important quality of health leaders in the community.

An impressive highlight was the responsibility of being a leader of change. The observers indicated that many VHVs have the potential to "be Teacher Kor" (O3), reflecting their readiness to be leaders who will drive community health work forward.

3.3.2 Application of Knowledge by VHVs

In the skill training groups, the VHVs demonstrated the application of knowledge in concrete ways at multiple levels, starting from applying it in daily life. As one observer recorded, "They apply the information in real life at home" (O2).

The adaptation of knowledge expanded to the family level, particularly in the aspect of dental health, through "searching for information about foods that prevent tooth decay" (O3), reflecting the development of understanding and health care in the household.

A significant highlight was the expansion to the community level. The VHVs "communicate and share the information with friends" (O4), demonstrating their role as leaders of health change at the community level effectively.

4. Data Integration

Overall Summary

The merging data analysis of quantitative and qualitative data demonstrates the consistency of the study results from both parts, with linkages found in all key issues, as follows:

1. Learning and Development

The quantitative data shows a significant increase in the post-training score, corresponding with the qualitative data reflecting increased confidence and communication ability of the participants. Both parts confirm the effectiveness of the program in empowering learning and developing potential.

2. Teamwork

The quantitative results found high scores in the cooperation of group members, which is consistent with the qualitative data showing mutual support and complementarity in the learning process, reflecting the strength of teamwork.

3. Technology Use

Both the high practice skill scores and observational data confirm the development of purposeful and creative technology use potential, including the ability to assist others digitally, demonstrating the overcoming of previous limitations in accessing and utilizing technology.

4. Leadership

The process efficiency measured by the E1/E2 values, which are higher than the 80/80 criterion, aligns with the qualitative data indicating the ability to transfer knowledge, persuade, and be a role model for others to follow, confirming the development of strong leadership among the participants.

5. Application

The average skill assessment score exceeding 80% of the total score is linked to the qualitative data, which shows the actual application of knowledge at the individual, family, and community levels. Both parts of the results indicate a learning process that delves into real practice, forming the foundation for sustainable development. All data integration is summarized in **Table 4.**

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Table 4. Merging Data Analysis of Quantitative and Qualitative Data

Key Issues	Quantitative Data	Supporting Quotations	Integration/Interpretation
Learning and development	- Post-training mean score (14.13, SD=2.012) significantly higher than pre-training (6.75, SD=3.133) (p<.001)	- "From being unconfident at first, they became able to communicate effectively" (O5) - "On day 2, they expressed more opinions" (O2) - "They can analyze according to the tasks given by the instructor" (O1)	Both types of data confirm a leap in knowledge, skills, and confidence, reflecting the effectiveness of the program in empowering learning
Teamwork	- Highest mean score in cooperation of group members (Mean=2.97, SD=0.26)	- "They can gather ideas from group members" (O2) - "They help friends think of answers" (O1) - "Their creativity is fair, but they participate in group work" (O5)	Quantitative and qualitative results indicate strong teamwork abilities through mutual support and complementarity, reflecting the power of collaborative learning
Technology use	- Average practice skill score of 15.67 (SD=2.319) out of a total score of 18	"They use Google to search for media" (O3) - "They focus on searching for information from Google" (O5) - "They are creative and help friends find answers from Google well" (O4)	Quantitative and qualitative data reflect increased potential in technology use, with participants able to use digital tools critically, purposefully, and help others, demonstrating the development of digital skills beyond previous limitations
Leadership	- Process efficiency (E1/E2) = 88.16/88.33, higher than the 80/80 criterion	- "They can explain to friends in the group to understand" (O3) - "They speak, communicate, lead, and tell others to follow" (O4) - "They can be Teacher Kor" (O3)	Quantitative and qualitative data are consistent, confirming the development of leadership that can transfer knowledge and persuade others
Application	- Average skill assessment score of 10.78 (SD=1.40) out of a total score of 12	- "They apply the information in real life at home" (O2) - "They search for information about foods that prevent tooth decay" (O3) - "They communicate and share the information with friends" (O4)	Both research results confirm the ability to apply knowledge concretely at all levels, reflecting meaningful and sustainable learning

Note: O1-O5 refer to Observers 1-5

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Final Integration Summary

The merging data analysis reveals the consistency of the quantitative and qualitative research results in all dimensions, confirming the effectiveness of the program in developing the knowledge, skills, attitudes, and application of the participants. In addition to finding no conflicts between the two types of data, the integration of data helps to understand the process of change in depth, from intellectual empowerment, group dynamics development, transition to the digital age, leadership of change, to the connection to concrete practice.

The data obtained from this integration not only helps to confirm the achievements of the program but also provides important policy recommendations. That is, the design of future capacity development programs for VHVs should consider the integration of various components, including intellectual empowerment, promoting teamwork, applying technology, developing leadership, and focusing on practice, which will help create profound and sustainable changes in the community health system.

Discussion

This study successfully developed and evaluated a nutrition literacy program for Village Health Volunteers (VHVs) to enhance oral health promotion in Thai communities. The study aimed to evaluate the impact of a nutrition literacy program on VHVs' oral health knowledge, skills, and practice using a mixed-methods research approach, and to identify factors contributing to program effectiveness in developing health literacy capabilities among community health workers.

1. Program Effectiveness

The nutrition literacy program effectively developed the potential of VHVs, demonstrating substantial improvements in both knowledge and practical skills. Quantitative analysis revealed significant increases in assessment scores, with program efficiency exceeding standard criteria, reflecting the program's robust design and implementation (15). The reduction in score variability among participants indicates improved learning consistency across diverse trainee backgrounds.

Qualitative findings enriched understanding of the transformation process, with participants demonstrating enhanced confidence and ability to apply knowledge in community settings. The integration of quantitative and qualitative data revealed both the magnitude of outcomes

and the underlying mechanisms of change, aligning with Sørensen's conceptual framework that emphasizes behavioral transformation as central to health literacy development (16).

However, a small proportion of trainees (3.4%) achieved scores below the established criteria, reflecting the influence of socioeconomic factors on health education program effectiveness (17). Although the program was successful overall, qualitative data indicated that contextual differences significantly affect learning processes (18, 19), consistent with recommendations to develop flexible, individualized learning models that accommodate diverse learner needs (20).

The integration of both data types confirms program effectiveness and identifies key success factors, providing evidence-based recommendations for developing context-aligned programs that can create sustainable community health improvements.

2. Adult Learning Skills Development

The program demonstrated effectiveness in developing adult learning skills, with participants achieving high performance levels in practical skill assessments. Qualitative data supported these findings, reflecting substantial development in learner confidence, active participation, and skill application (22, 23).

Data integration clarified the mechanisms underlying learner transformation. The learner-centered design significantly influenced skill development outcomes, though the relatively short duration of qualitative data collection limited deeper longitudinal insights.

These results align with previous mixed-methods research demonstrating that age and educational background affect health literacy development trajectories (24, 44, 45). The mixed-methods approach provided substantially deeper understanding of learning factors than quantitative research alone could achieve.

The 3.4% of trainees who scored below threshold levels were found through qualitative inquiry to face challenges related to time constraints and background preparation differences (25, 26), factors not fully anticipated during program design.

Data integration suggests the importance of developing flexible teaching models that accommodate learner differences and emphasizes the need for longitudinal research to assess outcome sustainability. Future studies should employ mixed methods with extended qualitative data collection periods to comprehensively track learner development trajectories.

3. Technology for Learning

The program achieved notable success in developing technology-related competencies, with participants demonstrating substantial improvements in digital literacy skills, particularly in health information searching and management. Qualitative findings from VHV interviews consistently reflected that technology use increased work confidence and facilitated access to current information, effectively reducing knowledge gaps between VHVs and health professionals (27).

Data integration revealed strong consistency in digital empowerment outcomes, especially in developing self-directed learning skills and practice confidence—competencies essential for lifelong learning (28).

These findings align with previous research on developing digital skills among community health personnel, which emphasizes the importance of considering learner context and readiness (29). This study additionally revealed technology's critical role in enhancing VHV confidence and expanding their capacity for collaboration with health professionals.

Although quantitative results indicated challenges among older participants with digital skill acquisition, qualitative data demonstrated that older VHVs could successfully develop these competencies with appropriate peer support (30), reflecting substantial potential for digital skill development across all age groups within the VHV workforce.

Data integration leads to recommendations for future programs to prioritize essential digital skill training with VHV-specific technological adaptations (31), and to establish integrated monitoring and evaluation systems combining quantitative metrics with qualitative insights.

4. Leadership and Teamwork Development

The program demonstrated effectiveness in developing VHV leadership and teamwork capabilities, with efficiency indicators substantially exceeding standard criteria. Group member cooperation achieved particularly high levels, though task delegation skills represented an area requiring further development.

Qualitative observation data from multiple observers supported quantitative findings, revealing that participants effectively transferred knowledge and persuaded others—competencies reflecting successful leadership skill development consistent with assessment outcomes.

The integration of quantitative and qualitative data confirmed overall program effectiveness while identifying specific areas requiring additional attention, particularly in delegation skills. Study findings differ somewhat from Varmazyar et al., who found family and social factors more influential on health literacy than leadership factors (32), possibly reflecting contextual differences between adolescent populations and VHVs serving as community health change agents (33). However, results align with previous studies identifying teamwork, delegation, and management skills as essential for effective community health promotion (34, 35).

The unexpected finding of relatively lower task delegation scores may be explained by qualitative observations revealing a considerate work culture in which delegation is sometimes avoided to prevent overburdening colleagues. Future mixed-methods research should assess long-term impacts of leadership and teamwork development on public health outcomes, and examine factors influencing skill development and retention (36) for building sustainable community health systems.

5. Community Knowledge Application

Quantitative results demonstrated VHV capacity to apply nutrition knowledge effectively in community contexts, with high average skill scores. These findings were strongly supported by qualitative observations and interviews confirming concrete knowledge application at individual, family, and community levels, reflecting program success in developing empowering health literacy (37).

Data integration deepened understanding of VHV learning processes and knowledge application patterns. Quantitative data revealed capability levels through assessment scores, while qualitative data explained real-world application contexts and related factors, confirming program effectiveness and elucidating community change mechanisms (6). These findings align with Sommanustweechai et al.'s conceptualization of VHVs as critical links between health systems and communities, especially in remote and vulnerable areas (38). Results also support findings from Nigerian research linking family health literacy with nutrition decision-making (39), reflecting the importance of developing health literacy from individual to population levels (40).

However, while demonstrating clear short-term effectiveness, this study was limited in assessing long-term impacts on population behaviors and dental health outcomes. Qualitative data indicate the need to examine sociocultural factors affecting real-world knowledge

application and to expand research to more diverse geographic and demographic contexts (41).

This study supports Thailand's 20-year National Strategy in strengthening local health capacity (42) and aligns with Sustainable Development Goals in creating comprehensive health security (43). Future research should assess long-term health outcomes, explore factors facilitating or hindering knowledge application in varied contexts, and expand to diverse settings to develop effective, sustainable community health system strategies.

6. Factors Affecting Program Effectiveness

Quantitative results demonstrated overall program effectiveness in developing VHV nutrition literacy capabilities. However, qualitative data revealed that demographic and background differences—including age, education, and prior experience—influenced learning outcomes, with older and less educated participants tending to achieve somewhat lower scores.

Data integration revealed consistent patterns, with qualitative data explaining outcome variations by participant characteristics, thereby clarifying factors affecting program effectiveness.

Results align with multiple previous studies documenting relationships between age, educational level, and health literacy (44, 45, 46), with older adults and individuals with lower educational attainment often experiencing greater challenges in accessing, understanding, and applying health information. Previous training experience did not significantly differentiate outcomes, possibly reflecting appropriate program content and format accommodating participants with diverse backgrounds. However, age and educational factors did influence participant response levels, suggesting that adjusting teaching methods for diverse needs and abilities may reduce performance gaps (47).

Further research should examine interactions between demographic factors and learning styles to develop programs responsive to individual differences, particularly regarding age and education, to promote inclusive and equitable health literacy development across all community health worker populations

Study Limitations and Strengths: This study's strength lies in its convergent parallel mixed methods design, integrating quantitative assessment data with qualitative observations and focus group discussions for comprehensive, in-depth insights. The application of adult learning theory and health literacy concepts enhances academic credibility.

Limitations include the short follow-up period, inability to assess long-term sustainability, a single-area sample limiting contextual generalizability, and lack of direct assessment of VHV and public dental health indicator impacts. Future studies should address these limitations.

Conclusions

The results confirm the program's effectiveness in enhancing VHVs' potential to promote community oral health. We recommend wider implementation, integrating nutrition literacy into VHV training curricula, developing adult education-aligned materials, and establishing VHV learning exchange networks locally and nationally.

To ensure sustainability result, follow-up assessments should be conducted at 3, 6, and 12 months post-intervention. Dental health indicator assessments should be expanded to VHVs and the public, focusing on diverse populations, including the elderly and vulnerable groups, to develop targeted programs. Developing VHV-specific oral health literacy assessment tools and examining the integration of this program with other oral health promotion strategies are also recommended. These findings will inform the development of evidence-based policies and action plans for effective oral health promotion in Thailand.

Acknowledgement: The authors would like to thank Professor Kwanmuang Kaewdamkoeng and his team for their academic support on health literacy, Dr. Chalermpol Kongchit, Assoc. Prof. Waenkaew Chaiararm and the team from Chiang Mai University for their guidance on communication, and Asst. Prof. Umaporn Nimtrakul and the team from the Health Center Region 1 Chiang Mai for their advice on networking. This study was supported by the International Dental Public Health Center, Chiang Mai, Sirindhorn College of Public Health Chonburi, and Boromarajonani College of Nursing Chiang Mai.

Availability of Data and Materials: The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to ethical considerations in the research, some data cannot be publicly shared. Additionally, any third-party data used in this study is subject to reuse restrictions as imposed by the original providers.

Conflicts of interest: The authors confirmed that there is no conflict of interest in this study.

Consent for publication: Not applicable.

Ethics Approval and Consent to Participate: The study protocol received approval from the Human Research Ethics Committee of Sirindhorn College of Public Health, Chonburi (Certificate of Approval: COA 2023/T07, August 21, 2023). The research was conducted in strict accordance with the ethical principles outlined in the Declaration of Helsinki, emphasizing respect for the dignity, rights, safety, and well-being of all participants. All participants provided written informed consent after receiving comprehensive information regarding the study's purpose, procedures, potential risks and benefits, measures for confidentiality protection, and their right to voluntary participation. Participants were explicitly informed of their right to withdraw from the study at any time without any consequences. Data confidentiality was rigorously maintained through the use of anonymized coding and secure data storage, accessible solely to authorized research team members. The study protocol included detailed provisions addressing potential ethical considerations, participant protections, and compliance with

internationally accepted ethical standards. Approval from the Sirindhorn College of Public Health Human Research Ethics Committee (COA 2023/T07, August 21, 2023) ensures that all study procedures align with well-established ethical and scientific guidelines, prioritizing the welfare of study participants throughout the research process.

Funding: This research project did not receive specific research funding but rather evolved from ongoing work, utilizing research operation budgets from the Ministry of Public Health for its implementation.

Authors' Contributions: Chollada Sorasak & Choosak Yuennan & Mansuang Wongsapai: Study conception and design; study supervision; critical revisions for important intellectual content. Worayuth Nak-Ai: Study conception and design; Data collection; literature review/analysis; manuscript writing; references.

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