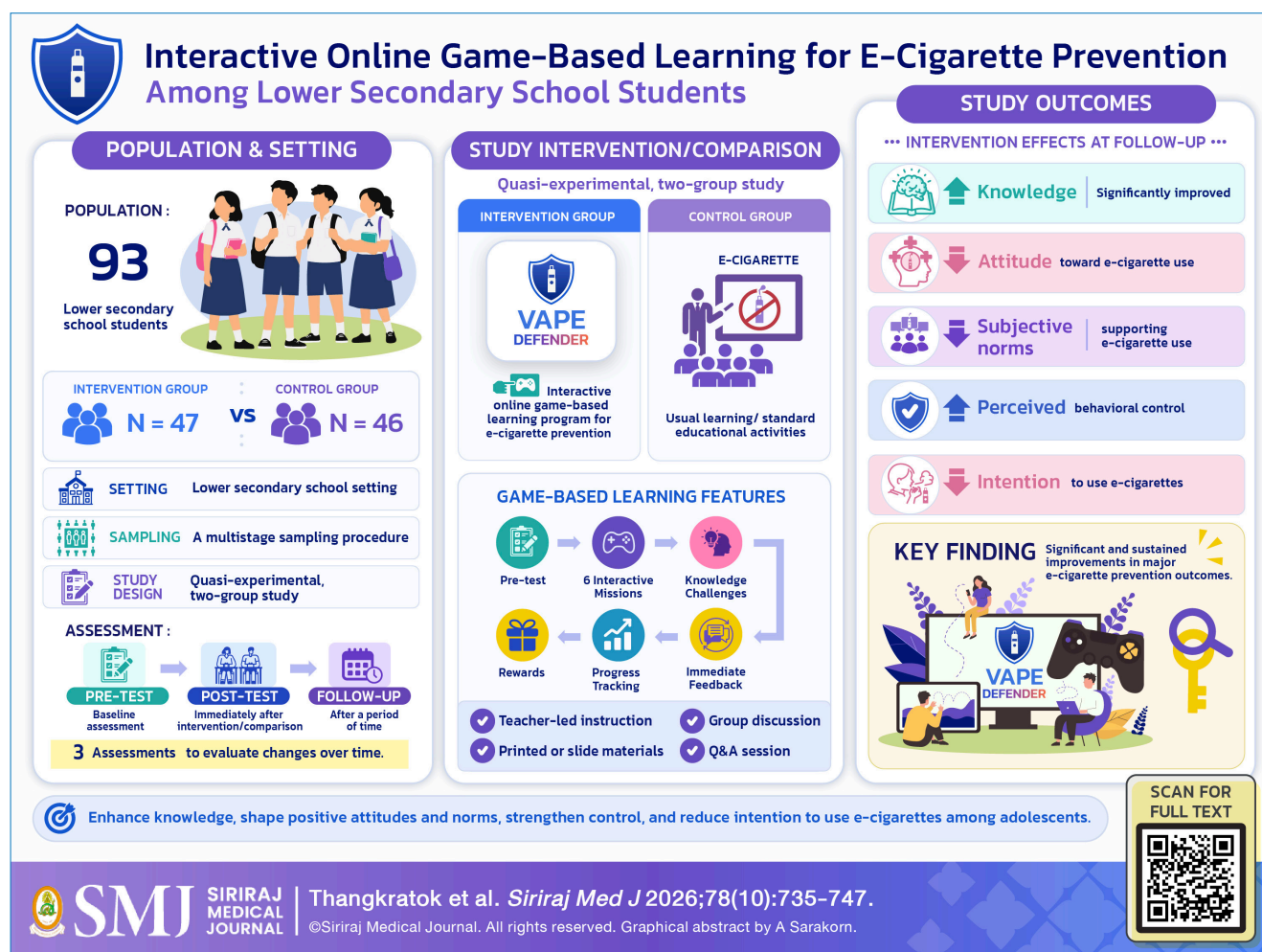


Development and Evaluation of an Interactive Online Game-Based Learning Program on Knowledge, Attitudes, Subjective Norms, Perceived Behavioral Control, and Intention to Use E-Cigarettes among Lower Secondary School Students

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ABSTRACT

Objective: This study aimed to examine the effectiveness of an interactive online game-based learning program on knowledge, attitudes, subjective norms, perceived behavioral control, and intention to use e-cigarettes among lower secondary school students.

Materials and Methods: A quasi-experimental study was conducted in two lower secondary schools, with one school assigned to the intervention condition and the other to the comparison condition. Ninety-three students participated (intervention, $n = 47$; comparison, $n = 46$). Knowledge, attitudes, subjective norms, perceived behavioral control, and intention to use e-cigarettes were assessed at pretest, posttest, and follow-up. Longitudinal changes were analyzed using repeated-measures models. Because each condition included only one school, between-group findings were considered exploratory and may reflect school-level effects.

Results: Compared with the comparison school, students in the intervention school showed greater improvements in knowledge at posttest and follow-up. Attitudes, subjective norms, and intention scores decreased at both assessments, indicating less favorable attitudes toward e-cigarette use, lower perceived social pressure to use e-cigarettes, and lower intention to use e-cigarettes. Perceived behavioral control showed little immediate change but increased at follow-up.

Conclusion: Participation in the interactive online game-based learning program was associated with favorable changes in knowledge and psychosocial determinants related to e-cigarette use. However, the observed differences cannot be separated from school-level effects. Studies involving multiple schools in each condition are needed to confirm intervention effectiveness.

Keywords: Electronic nicotine delivery systems; vaping; adolescents; students; prevention program; intention (Siriraj Med J 2026;78(10):735-747)

INTRODUCTION

Over the past decade, the use of electronic cigarettes (e-cigarettes) among Thai youth has shown a continuous upward trend.^{1,2} Although the sale of e-cigarettes remains illegal in Thailand, these products are still easily accessible through online platforms.³ This issue is particularly concerning among lower secondary school students, who are at a developmental stage characterized by identity formation, a strong desire for peer acceptance, and exploratory behaviors.⁴ E-cigarettes have become increasingly attractive to adolescents due to their modern appearance, appealing flavors, and aggressive online marketing strategies.⁵ The proportion of students who had experimented with or were currently using e-cigarettes increased compared with previous years.⁶ Most adolescents obtained misleading information regarding the safety of e-cigarettes through social media and were also influenced by peers who used these products.³ This situation highlights the urgent need for preventive measures and age-appropriate educational interventions to promote accurate understanding of the harmful effects of e-cigarettes, particularly among lower secondary school students.

Despite various measures implemented to prevent and reduce e-cigarette use among Thai youth, these interventions have not adequately addressed the behavioral patterns and

social contexts of the digital era.⁷ Government agencies, including the Ministry of Public Health, have enforced bans on the importation and sale of e-cigarettes in Thailand and have launched public awareness campaigns regarding the dangers of e-cigarette use.⁸ Educational activities and training programs have also been conducted in schools, particularly at the secondary school level. However, many campaigns still rely on traditional communication methods, such as lectures, brochures, and informational videos, which may not effectively engage contemporary adolescents or significantly influence their attitudes and behaviors.^{9,10} Many young people continue to receive misleading information and persuasive advertising about e-cigarettes through social media, particularly messages portraying e-cigarettes as a “safer alternative” to conventional cigarettes.³

Although attempts have been made to educate adolescents about the harmful effects of e-cigarettes, there remains a lack of innovative educational approaches integrating digital technologies, such as educational games and interactive learning systems, that align with adolescents’ learning preferences. Many existing programs focus primarily on providing information and knowledge, while insufficient attention has been paid to behavioral psychology principles, including intrinsic

motivation, critical thinking, and rational decision-making. Furthermore, most educational media and learning materials are developed by adults or experts without directly involving adolescents in identifying their needs or preferences, resulting in a mismatch between the content provided and the interests of the target audience. The development of positive knowledge and attitudes should involve collaboration among schools, teachers, parents, and peers, all of whom represent influential social groups in adolescents' lives.¹¹ However, many interventions continue to operate independently and lack systematic continuity and integration.

Traditional learning approaches that focus solely on providing information may be insufficient to effectively change adolescents' behaviors. In contrast, the design of Interactive Game-Based Learning programs has considerable potential to enhance learner engagement, memory retention, and decision-making processes.¹² A systematic review of digital games used for the prevention, assessment, and treatment of substance use, as well as for promoting positive youth development, found that approximately half of the reviewed studies (50%) reported that digital games were effective in reducing substance use behaviors. Regarding attitudes toward substance use, 65% of the studies demonstrated statistically significant improvements in attitudes, while studies focusing on positive youth development showed effectiveness in 35.7% of cases. These findings suggest that digital games have strong potential as educational and intervention tools capable of both reducing risky substance-use behaviors and promoting positive life skills among adolescents.¹²

Furthermore, a pilot study evaluating the short-term effects of an interactive video game on changes in knowledge, beliefs, risk perception, and intentions to use e-cigarettes, cigarettes, and other tobacco products employed a one-group pretest–posttest design. Participants engaged in four 60-minute gameplay sessions over a four-week period. The results showed increased knowledge of e-cigarettes and other tobacco products, greater perceived risks associated with cigarette and e-cigarette use, and more favorable beliefs regarding tobacco prevention. However, no significant change was observed in intentions to use tobacco products. Nevertheless, the findings suggested that brief exposure to an interactive gaming intervention—a total of four hours over four weeks—may have the potential to improve adolescents' knowledge and promote attitudes supportive of tobacco-use prevention, particularly regarding e-cigarettes.¹³

The Theory of Planned Behavior (TPB) was used as the conceptual framework for both intervention design and outcome evaluation. According to the TPB, behavioral

intention is determined by attitudes toward the behavior, subjective norms, and perceived behavioral control.¹⁴ In this study, activities addressing the health, legal, and social consequences of e-cigarette use were designed to reduce favorable attitudes; peer-pressure and social-influence simulations targeted subjective norms; and refusal-skills and decision-making exercises were intended to strengthen perceived behavioral control. Intention to use e-cigarettes was specified as the proximal behavioral outcome. Knowledge was included as an additional cognitive outcome because accurate understanding of health risks and legal consequences may support less favorable attitudes and more informed decisions. The hypothesized pathway was that the game-based program would improve knowledge, attitudes, subjective norms, and perceived behavioral control, thereby reducing intention to use e-cigarettes.

Preliminary observations revealed that most students had acquired knowledge regarding the harmful effects of e-cigarettes from multiple sources, including classroom instruction, educational activities conducted by school personnel, peer warnings from senior students, and exposure to media content.¹⁵ However, such awareness remains influenced by personal and environmental factors, individuals' ability to critically evaluate information, and peer pressure, all of which may shape attitudes and behaviors related to e-cigarette use. Therefore, the development of educational tools that promote a deeper understanding of the harmful effects of e-cigarettes, while simultaneously strengthening decision-making skills and rational coping strategies for dealing with social pressure, is highly important. This is particularly relevant when educational media are designed in formats that are accessible, engaging, and aligned with adolescents' digital lifestyles, such as interactive online game-based learning programs.¹⁶ Such programs may enhance learner participation and contribute to long-term changes in attitudes and behaviors. Consequently, this study aimed to evaluate the effectiveness of an interactive online game-based learning program by comparing knowledge regarding e-cigarettes, attitudes toward e-cigarette use, subjective norms, perceived behavioral control, and intention to use e-cigarettes between the intervention and control groups at baseline, posttest, and follow-up. A secondary objective was to evaluate satisfaction with the program among students in the intervention group.

MATERIALS AND METHODS

This study employed a quasi-experimental research design with an intervention group and a comparison group. Data were collected at three time points: before the

intervention (T0: pretest), immediately after completion of the program (T1: posttest), and 2 weeks after T1 (T2: follow-up). The pretest, intervention, and posttest were conducted on May 15, 2026, with the posttest administered immediately after completion of the program. The follow-up assessment was completed on May 29, 2026, 2 weeks after the posttest. The study was registered with the Thai Clinical Trials Registry (TCTR20260505009). Ethical approval was obtained from the Human Research Ethics.

Study population

The target population consisted of lower secondary school students enrolled in private secondary schools under the Office of the Private Education Commission in Dusit District, Bangkok. Eligible participants were students studying in Grades 7–9 (Matthayom 1–3), aged 12–17 years, who were able to use a smartphone or computer with internet access, had obtained parental consent and provided student assent, and were willing to participate in the study. The age range of 12–17 years was specified to accommodate variation in age within the eligible grade levels, including students who entered school later or had repeated a grade.

Eligibility regarding e-cigarette use was assessed before enrollment using a confidential self-administered screening form. Students who self-reported regular e-cigarette use or nicotine dependence at baseline were excluded; biochemical verification was not performed. After enrollment and assignment according to school, inability to complete the intervention or follow-up assessments was treated as attrition rather than as an exclusion criterion.

Sample size determination

An initial participant-level sample size calculation was performed using G*Power (F tests: repeated-measures ANOVA, between–within interaction) assuming a medium effect size ($f = 0.25$), $\alpha = 0.05$, power = 0.80, two groups, three measurement occasions, a correlation of 0.50 among repeated measures, and $\epsilon = 1.00$. This calculation yielded an estimated minimum of approximately 80 students. Allowing for approximately 15% attrition, the recruitment target was increased to 94 students. However, this initial calculation did not account for the school-level allocation or intracluster correlation. Because the actual design included only two schools, with one school assigned to each study condition, the intervention condition was completely confounded with school and the effective number of independent allocation units was two rather than the number of participating students. Therefore, the originally specified 80% statistical power does not apply

to the estimation of a school-level intervention effect. The present study should be regarded as an exploratory two-cluster quasi-experimental study, and the participant-level sample size was used to guide student recruitment rather than to establish adequate power for confirmatory intervention-effect inference.

Sampling procedure

A multistage sampling procedure was used. First, Dusit District, Bangkok, was purposively selected as the study area because it includes several private secondary schools under the Office of the Private Education Commission. A sampling frame was then constructed comprising seven private schools offering lower secondary education in the district. Two schools were selected using probability proportional to size (PPS) sampling based on student enrollment, with reserve schools identified in case a selected school declined participation.

After the two participating schools agreed to participate, the schools were randomly assigned at the school level, with one school allocated to the intervention condition and the other to the comparison condition. Thus, the study included two school-level clusters, with one school representing each study condition.

Within each participating school, students in Grades 7–9 (Mathayom 1–3) who met the predefined eligibility criteria were purposively recruited. Parental consent and student assent were obtained before enrollment. Recruitment continued until the planned number of participants was reached, resulting in 47 students from the intervention school and 46 students from the comparison school.

Because only one school was allocated to each study condition, school and study condition were completely confounded, and there was no independent replication at the level of allocation. Consequently, comparisons between students in the two schools were considered exploratory and descriptive and were not interpreted as confirmatory estimates of an intervention effect.

Intervention

The intervention consisted of an interactive online game-based learning program, “Vape Defender”, developed to prevent e-cigarette use among lower secondary school students. The program was delivered by the researchers through a web-based interactive learning platform. Participants completed one structured session lasting approximately 25–30 minutes using an internet-enabled device.

The program was guided by the Theory of Planned Behavior and comprised six interactive game missions

designed to address knowledge, attitudes, subjective norms, perceived behavioral control, and intention related to e-cigarette use prevention. The six missions were: (1) Item Scanner, which introduced participants to e-cigarette devices, components, and related products; (2) Toxic Vapor, which focused on harmful substances and the health consequences of e-cigarette use; (3) Bomb Disposal, which used problem-solving activities to reinforce recognition of e-cigarette-related risks and consequences; (4) Decode, which challenged participants to interpret and evaluate information related to e-cigarettes; (5) Face-Off, which presented simulated situations involving peer and social influences and allowed participants to practice decision-making and refusal skills; and (6) Spread the Message, which reinforced prevention messages and encouraged participants to communicate knowledge and attitudes supportive of avoiding e-cigarette use. Gamification features, including scores, achievement feedback, rewards, and progress tracking, were incorporated to promote active participation and engagement.

Participants in the comparison school did not receive the Vape Defender interactive game-based program during the study period and continued with the usual health education and routine learning activities provided by the school. No additional game-based intervention was provided by the researchers to the comparison group. The comparison condition was not specifically

matched to the intervention condition for contact time or attention.

Outcomes in both schools were assessed at three time points: before the intervention (T0: pretest), immediately after completion of the program (T1: posttest), and 2 weeks after T1 (T2: follow-up).

Research instruments

The research instruments used in this study consisted of several questionnaires designed to assess knowledge, attitudes, subjective norms, perceived behavioral control, intentions regarding e-cigarette use, and participant satisfaction with the program.

The e-cigarette knowledge questionnaire consisted of 10 multiple-choice items assessing knowledge of the health effects, harmful substances, addictive properties, and legal issues related to e-cigarettes. The questionnaire was adapted from relevant literature and existing evidence on e-cigarette prevention among adolescents.² Each correct response was scored 1 and each incorrect or “do not know” response was scored 0, yielding a total score ranging from 0 to 10, with higher scores indicating greater knowledge about e-cigarettes.

The attitude toward e-cigarette use questionnaire was adapted from the Electronic Cigarette Attitudes Survey developed by Alduraywish et al. (2023).¹⁷ The instrument consisted of 10 items rated on a five-point Likert scale

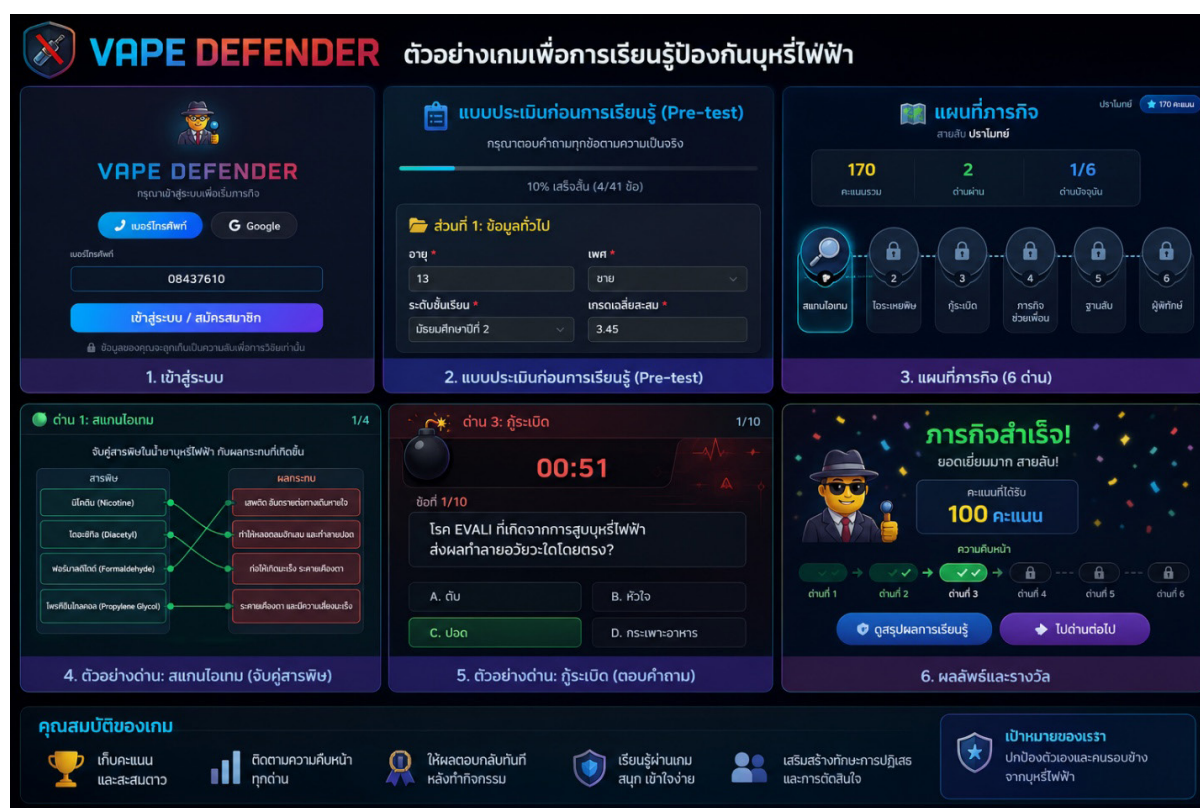


Fig 1. User interface screens of the interactive online game-based learning program.

ranging from strongly disagree (1) to strongly agree (5). Items 4 and 7 were reverse-coded before calculation of the scale score. After reverse coding, an item mean score was calculated across the 10 items, yielding a possible range of 1.00–5.00. Higher mean scores indicated more favorable attitudes toward e-cigarette use, whereas lower mean scores indicated less favorable or more negative attitudes toward e-cigarette use.

The subjective norm questionnaire regarding e-cigarette use was developed based on the Theory of Planned Behavior and relevant literature.^{2,14} The questionnaire consisted of six items assessing perceived social influence from significant others and social sources, including peers, family members, celebrities, and online media, regarding e-cigarette use. Each item was rated on a five-point Likert scale ranging from 1 to 5. An item mean score was calculated across the six items, yielding a possible range of 1.00–5.00. Higher mean scores indicated stronger perceived social influence or pressure supporting e-cigarette use, whereas lower mean scores indicated weaker perceived social influence supporting e-cigarette use.

The perceived behavioral control questionnaire was developed based on the Theory of Planned Behavior and relevant literature.^{2,14} The instrument consisted of six items assessing participants' perceived ability and confidence to resist or avoid e-cigarette use in situations in which they might encounter opportunities or social pressure to use e-cigarettes. Each item was rated on a five-point Likert scale ranging from 1 to 5. All items were scored in the same direction so that higher values consistently represented greater perceived behavioral control. An item mean score was calculated across the six items, yielding a possible range of 1.00–5.00. Higher mean scores indicated greater perceived behavioral control over avoiding e-cigarette use, whereas lower scores indicated lower perceived behavioral control.

The intention to use e-cigarettes questionnaire was developed by the researchers based on the Theory of Planned Behavior and relevant literature.^{2,14} The instrument consisted of five items assessing participants' intentions to try or use e-cigarettes at present, within the next six months, or if an opportunity to use e-cigarettes arose. Each item had three response options: "No" (1 point), "Maybe" (2 points), and "Yes" (3 points). An item mean score was calculated across the five items, yielding a possible range of 1.00–3.00. Higher mean scores indicated stronger intention to use e-cigarettes, whereas lower mean scores indicated weaker intention to use e-cigarettes.

Participants' experiences and satisfaction with the intervention program were assessed using a five-item

satisfaction questionnaire rated on a five-point Likert scale ranging from 1 (very low satisfaction) to 5 (very high satisfaction). A mean item score was calculated across the five items, yielding a possible range of 1.00–5.00, with higher scores indicating greater satisfaction. Mean scores were interpreted using equal-width intervals as follows: 1.00–1.80, very low; 1.81–2.60, low; 2.61–3.40, moderate; 3.41–4.20, high; and 4.21–5.00, very high satisfaction.

All research instruments were evaluated for content validity by three experts with expertise in adolescent health, e-cigarette prevention, and behavioral research. Item-Objective Congruence (IOC) values ranged from 0.67 to 1.00. The instruments were subsequently pilot-tested with 30 adolescents who had characteristics similar to those of the target population but were not included in the main study.

For the 10-item dichotomously scored knowledge questionnaire, internal consistency was assessed using the Kuder–Richardson Formula 20 (KR-20), yielding a coefficient of 0.80. Cronbach's alpha coefficients in the pilot sample were 0.93 for attitude, 0.93 for subjective norm, 0.89 for perceived behavioral control, 0.92 for intention to use e-cigarettes, and 0.80 for program satisfaction.

Data collection procedures

Before data collection, the researchers and research assistants were trained in the study protocol, including participant recruitment, parental consent and student assent, questionnaire administration, operation of the online learning platform, data recording, confidentiality, and protection of participants' privacy. The instruments and study procedures were pilot-tested with 30 adolescents who were not included in the main study to assess questionnaire comprehension, completion time, procedural clarity, and instrument reliability. Necessary equipment and internet access were prepared before implementation.

Eligible students were screened according to the predefined eligibility criteria. The study objectives, procedures, potential benefits and risks, confidentiality safeguards, and voluntary nature of participation were explained to students and their parents or guardians. Written parental consent and student assent were obtained before enrollment. At baseline (T0), participants completed demographic questions and measures of e-cigarette knowledge, attitude, subjective norm, perceived behavioral control, and intention to use e-cigarettes. Research personnel provided standardized instructions and checked submitted questionnaires for completeness.

After the baseline assessment, students in the intervention school participated in the Vape Defender

interactive online game-based learning program delivered by the researchers. The program consisted of six interactive game missions and was completed in one session lasting approximately 25–30 minutes. Implementation information, including attendance, completion of the game activities, duration of participation, and technical problems, was recorded to assess intervention fidelity. Students in the comparison school continued their usual school-based health education and routine learning activities and did not receive the Vape Defender program during the study period. The comparison condition was not specifically matched to the intervention condition for contact time or attention.

The posttest (T1) was administered immediately after completion of the intervention using the same outcome measures as at baseline. The follow-up assessment (T2) was conducted 2 weeks after T1. The same assessment schedule was applied to participants in the comparison school. Participant completion and missing outcome data were documented at each assessment point. After completion of the T2 assessment, participants in the comparison school were offered access to the Vape Defender program; data collected after this access were not included in the primary analyses.

Data analysis

Descriptive statistics were used to summarize participant characteristics and outcomes. The prespecified primary outcome was intention to use e-cigarettes; knowledge, attitude, subjective norm, and perceived behavioral control were secondary outcomes. Longitudinal patterns across T0, T1, and T2 were examined using mixed-effects models with participant-specific random intercepts and adjustment for age and GPA.

Because only one school represented each study condition, school and intervention condition were completely confounded; therefore, between-school comparisons were interpreted as exploratory rather than confirmatory intervention effects. Secondary-outcome analyses were also considered exploratory because of multiple comparisons.

Outcome distributions were examined for ceiling and floor effects. Given the pronounced floor effect in intention and ceiling effect in knowledge, robust and non-parametric sensitivity analyses were conducted. These analyses assessed the robustness of the observed patterns but did not resolve school-level confounding.

RESULTS

A total of 94 students were enrolled in the study. One participant did not complete the follow-up (T2) questionnaire and was excluded from the final analysis. Thus, 93 students were included in the analysis, comprising 47 students in the intervention group and 46 students in the control group. Complete outcome data were available for these 93 participants at T0, T1, and T2.

Baseline characteristics are presented descriptively in Table 1. The intervention and comparison schools had similar observed distributions of age, GPA, knowledge, attitude, subjective norm, and perceived behavioral control. Baseline intention scores were lower in the intervention school than in the comparison school (1.17 ± 0.48 vs. 1.40 ± 0.53). Because each study condition was represented by only one school, baseline differences may reflect school-level contextual characteristics rather than study condition. Accordingly, subsequent changes in intention were interpreted descriptively and may also be influenced by baseline differences and regression to the mean.

TABLE 1. Baseline characteristics of participants by group.

Variable	Intervention school (n = 47)	Comparison school (n = 46)
Age, mean $\pm$ SD	14.28 $\pm$ 1.14	14.28 $\pm$ 1.07
GPA, mean $\pm$ SD	3.46 $\pm$ 0.49	3.44 $\pm$ 0.44
Knowledge, mean $\pm$ SD	7.28 $\pm$ 1.83	6.87 $\pm$ 2.15
Attitude, mean $\pm$ SD	2.67 $\pm$ 1.04	2.72 $\pm$ 0.97
Subjective norm, mean $\pm$ SD	2.34 $\pm$ 1.27	2.63 $\pm$ 1.25
Perceived behavioral control, mean $\pm$ SD	4.11 $\pm$ 1.02	4.07 $\pm$ 0.87
Intention, mean $\pm$ SD	1.17 $\pm$ 0.48	1.40 $\pm$ 0.53

Descriptive results showed that students in the intervention school had increased knowledge scores from pretest to follow-up, whereas those in the comparison school showed relatively little change. Attitude, subjective norm, and intention scores decreased over time in the intervention school, indicating less favorable attitudes toward e-cigarette use, weaker perceived social influence supporting e-cigarette use, and lower intention to use e-cigarettes, respectively. Perceived behavioral control remained relatively stable at posttest and increased at follow-up, indicating greater perceived ability to avoid e-cigarette use. These patterns are interpreted descriptively because school and study condition were completely confounded.

Exploratory linear mixed-effects models were used to examine longitudinal patterns in the five outcomes. Models included group, time, and group-by-time interaction terms, with participant-specific random intercepts and adjustment for age and GPA. Because one school represented each study condition, the interaction estimates reflect differences in change between the two schools and should not be interpreted as causal intervention effects. Students in the intervention school showed greater increases in knowledge than those in the comparison school at posttest ($\beta = 1.10$, 95% CI [0.50, 1.70]) and follow-up

($\beta = 2.36$, 95% CI [1.75, 2.96]). Greater reductions were also observed in attitude at posttest ($\beta = -0.49$, 95% CI [-0.88, -0.11]) and follow-up ($\beta = -0.46$, 95% CI [-0.85, -0.08]), and in subjective norm at posttest ($\beta = -0.64$, 95% CI [-1.05, -0.24]) and follow-up ($\beta = -0.99$, 95% CI [-1.40, -0.59]). Perceived behavioral control showed little between-school difference in change at posttest ($\beta = 0.04$, 95% CI [-0.38, 0.46]) but was higher at follow-up ($\beta = 0.80$, 95% CI [0.38, 1.23]). For the prespecified primary outcome, intention to use e-cigarettes, greater reductions were observed in the intervention school at posttest ($\beta = -0.23$, 95% CI [-0.38, -0.09]) and follow-up ($\beta = -0.47$, 95% CI [-0.62, -0.33]). Given the baseline imbalance and pronounced floor effect in intention at follow-up, these findings should be interpreted descriptively and cautiously.

Overall, the exploratory analyses showed favorable changes in knowledge, attitude, subjective norm, perceived behavioral control, and intention among students in the intervention school relative to those in the comparison school. Larger between-school differences were observed at follow-up for several outcomes; however, these findings should not be interpreted as evidence of sustained or strengthened intervention effects because no direct posttest-versus-follow-up contrast with valid cluster-

TABLE 2. Descriptive statistics of outcomes by group and time point.

Outcome	School	Pretest	Posttest	Follow-up
		Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Knowledge, total score (0–10)	Intervention	7.28 $\pm$ 1.83	8.72 $\pm$ 1.46	9.91 $\pm$ 0.46
	Comparison	6.87 $\pm$ 2.15	7.22 $\pm$ 2.12	7.15 $\pm$ 2.19
Attitude, mean item score (1–5)	Intervention	2.67 $\pm$ 1.04	2.17 $\pm$ 1.08	2.24 $\pm$ 0.55
	Comparison	2.72 $\pm$ 0.97	2.72 $\pm$ 0.89	2.75 $\pm$ 0.85
Subjective norm, mean item score (1–5)	Intervention	2.34 $\pm$ 1.27	1.71 $\pm$ 1.06	1.38 $\pm$ 0.55
	Comparison	2.63 $\pm$ 1.25	2.63 $\pm$ 1.19	2.66 $\pm$ 1.14
Perceived behavioral control, mean item score (1–5)	Intervention	4.11 $\pm$ 1.02	4.08 $\pm$ 1.41	4.76 $\pm$ 0.60
	Comparison	4.07 $\pm$ 0.87	4.00 $\pm$ 0.85	3.91 $\pm$ 0.76
Intention, mean item score (1–3)	Intervention	1.17 $\pm$ 0.48	1.06 $\pm$ 0.22	1.00 $\pm$ 0.00
	Comparison	1.40 $\pm$ 0.53	1.52 $\pm$ 0.51	1.70 $\pm$ 0.51

Note: Knowledge was reported as a total score ranging from 0 to 10, with higher scores indicating greater knowledge. Attitude, subjective norm, and perceived behavioral control were reported as mean item scores ranging from 1 to 5. Lower attitude scores indicated less favorable attitudes toward e-cigarette use, and lower subjective norm scores indicated weaker perceived social influence supporting e-cigarette use. Higher perceived behavioral control scores indicated greater perceived ability to avoid e-cigarette use. Intention was reported as a mean item score ranging from 1 to 3, with lower scores indicating weaker intention to use e-cigarettes.

TABLE 3. Exploratory group-by-time interaction estimates from linear mixed-effects models.

Outcome	Group-by-time interaction	β	SE	95% CI	p-value
Knowledge	Intervention $\times$ Posttest	1.10	0.31	0.50 to 1.70	<.001
	Intervention $\times$ Follow-up	2.36	0.31	1.75 to 2.96	<.001
Attitude	Intervention $\times$ Posttest	-0.49	0.20	-0.88 to -0.11	.013
	Intervention $\times$ Follow-up	-0.46	0.20	-0.85 to -0.08	.019
Subjective norm	Intervention $\times$ Posttest	-0.64	0.21	-1.05 to -0.24	.002
	Intervention $\times$ Follow-up	-0.99	0.21	-1.40 to -0.59	<.001
Perceived behavioral control	Intervention $\times$ Posttest	0.04	0.21	-0.38 to 0.46	.864
	Intervention $\times$ Follow-up	0.80	0.21	0.38 to 1.23	<.001
Intention (primary outcome)	Intervention $\times$ Posttest	-0.23	0.07	-0.38 to -0.09	.002
	Intervention $\times$ Follow-up	-0.47	0.07	-0.62 to -0.33	<.001

Note: Models included participant-specific random intercepts and were adjusted for age and GPA. The comparison school and pretest were the reference categories. β represents the estimated difference in change over time between students in the intervention and comparison schools. Negative coefficients for attitude, subjective norm, and intention indicate greater reductions in the intervention school, whereas positive coefficients for knowledge and perceived behavioral control indicate greater increases. Intention to use e-cigarettes was the prespecified primary outcome; the remaining outcomes were secondary and interpreted exploratorily. Because only one school represented each study condition, school and study condition were completely confounded. Accordingly, confidence intervals and nominal p-values should be interpreted descriptively and not as confirmatory evidence of an intervention effect.

level inference was performed. The observed patterns may also reflect maturation, school-level contextual differences, contamination, regression to the mean, and ceiling or floor effects. In particular, intention reached the minimum possible score at follow-up in the intervention school (1.00 ± 0.00), indicating a complete floor effect and requiring cautious interpretation.

Table 4 presents students' satisfaction toward the interactive online game-based learning program among participants in the experimental group ($N = 47$). Overall, students reported a very high level of satisfaction with the program, with an overall mean score of 4.66 ± 0.47 . The item with the highest mean score was "Learning through games helped me understand the content better"

TABLE 4. Satisfaction toward the interactive online game-based learning program ($N = 47$).

Satisfaction Items	Mean $\pm$ SD	Interpretation
The games or activities in the program were interesting.	4.71 $\pm$ 0.52	Very high
The content within the games was easy to understand and appropriate.	4.62 $\pm$ 0.58	Very high
The game system was convenient, fast, and easy to use.	4.55 $\pm$ 0.63	Very high
Learning through games helped me understand the content better.	4.74 $\pm$ 0.49	Very high
Learning through games encouraged greater participation.	4.68 $\pm$ 0.54	Very high
Overall satisfaction	4.66 $\pm$ 0.47	Very high

Note: Satisfaction items were rated on a five-point Likert scale ranging from 1 (very low) to 5 (very high). Mean item scores were interpreted using equal-width intervals: 1.00–1.80 = very low, 1.81–2.60 = low, 2.61–3.40 = moderate, 3.41–4.20 = high, and 4.21–5.00 = very high satisfaction.

(4.74 ± 0.49), followed by “The games or activities in the program were interesting” (4.71 ± 0.52) and “Learning through games encouraged greater participation” (4.68 ± 0.54). In addition, students rated the content within the games as easy to understand and appropriate at a very high level (4.62 ± 0.58), while the convenience, speed, and ease of use of the game system also received a very high rating (4.55 ± 0.63). These findings indicate that the interactive online game-based learning program was well accepted by lower secondary school students and was perceived as engaging, understandable, user-friendly, and supportive of active participation and learning.

DISCUSSION

The findings showed favorable changes in knowledge and psychosocial factors related to e-cigarette use among students in the intervention school compared with those in the comparison school. These observed patterns suggest the potential usefulness of interactive online game-based learning for e-cigarette prevention; however, they should be interpreted cautiously because school and study condition were completely confounded.

Adolescents may be influenced by social media, peers, the modern appearance of e-cigarette products, attractive flavors, and misleading information regarding the safety of e-cigarettes.¹⁸ In this context, preventive activities relying solely on lectures or printed materials may be insufficient to engage adolescents in the digital era. Interactive online game-based learning may provide a more engaging and accessible approach by promoting active participation and connecting prevention-related knowledge with situations relevant to adolescents' everyday lives.¹⁹⁻²¹

The greater increase in e-cigarette-related knowledge observed among students in the intervention school may be related to the interactive nature of the program, which incorporated game-based activities, matching exercises, quizzes, simulations, and problem-solving tasks. These activities addressed e-cigarette types and components, addictive mechanisms, health effects, legal consequences, and social impacts. Previous studies have highlighted adolescents' exposure to misleading information about e-cigarettes through social media, including perceptions that e-cigarettes are safer than conventional cigarettes.¹⁸ Interactive game-based learning may therefore provide opportunities for students to actively evaluate information, correct misconceptions, and receive immediate feedback.²² However, the substantial ceiling effect in knowledge scores at follow-up and the confounding between school and study condition warrant cautious interpretation of these observed changes.

Regarding attitudes toward e-cigarette use, students in the intervention school showed a decrease in attitude scores, indicating less favorable attitudes toward e-cigarette use. This pattern may be related to the program's emphasis on health risks, addiction, effects on learning, social and family consequences, and legal implications. Previous studies have shown that e-cigarettes may be portrayed to adolescents as modern, attractive, and socially acceptable through online marketing, flavors, and product imagery.⁵ Interactive activities that encouraged students to evaluate persuasive messages and potential consequences may have supported more critical perceptions of e-cigarette use. This observed pattern is consistent with the Theory of Planned Behavior, in which less favorable attitudes toward a behavior may be associated with lower behavioral intention.¹⁴ However, the findings should be interpreted cautiously because school and study condition could not be separated in the present design.

Regarding subjective norms, students in the intervention school showed lower scores over time, indicating weaker perceived social influence supporting e-cigarette use. This pattern is consistent with previous evidence that early adolescence is a period in which peer acceptance is highly valued and adolescents may be particularly influenced by peers and social groups.²³ The program addressed persuasion, peer pressure, and simulated situations involving responses to offers of e-cigarettes. Such interactive activities may provide opportunities for students to recognize social influences, practice refusal skills, and consider more independent health-related decisions. However, the observed changes cannot be attributed solely to the program because school-level contextual influences could not be separated from the study condition.

For perceived behavioral control, students in the intervention school showed little change immediately after the program but higher scores at follow-up. The program included scenario-based activities and decision-making tasks that provided opportunities to practice refusal skills and responses to social pressure. Such experiential activities may support confidence in managing situations involving e-cigarette use.²⁴ This approach is consistent with prevention strategies that extend beyond knowledge provision to include decision-making, self-regulation, and coping with social influences.^{24,25} However, the greater change observed at follow-up should not be interpreted as evidence of a delayed or strengthened intervention effect, as maturation, school context, and other unmeasured factors may also have contributed to the observed pattern.

Furthermore, the lower intention to use e-cigarettes

observed among students in the intervention school is consistent with the Theory of Planned Behavior, which proposes that attitudes, subjective norms, and perceived behavioral control are related to behavioral intention.¹⁴ The observed reductions in intention occurred alongside less favorable attitudes toward e-cigarette use, weaker perceived social influence supporting e-cigarette use, and higher perceived behavioral control. These patterns are consistent with the theoretical framework underlying the program. However, the present study did not test mediation or causal pathways among attitudes, subjective norms, perceived behavioral control, and intention; therefore, the observed change in intention cannot be attributed to changes in these factors.

Satisfaction was a prespecified secondary outcome. Students reported high satisfaction with the program, indicating favorable perceptions of its content, usability, and learning activities. This finding is consistent with previous work suggesting that adolescent e-cigarette prevention may benefit from accessible and engaging approaches aligned with adolescents' digital lifestyles.^{26,27} High acceptability may support engagement with school-based prevention activities. When implementing similar programs, consideration should be given to device and internet availability, teacher support, and measures to minimize contamination between study groups. Recent studies have documented persistent misconceptions about e-cigarettes among Thai young adults and highlighted the respiratory and airway harms associated with vaping, underscoring the importance of accurate risk communication in prevention programs.^{28,29} For school-based implementation, consideration should also be given to device and internet availability, teacher support, and strategies to minimize contamination between study conditions.

Strengths and limitations

This study has several strengths. The intervention was guided by the Theory of Planned Behavior and incorporated interactive online game-based learning relevant to adolescents' digital learning environments. Outcomes were assessed at three time points and included knowledge, attitude, subjective norm, perceived behavioral control, and intention to use e-cigarettes.

The principal limitation is the allocation of only one school to each study condition. With no independent replication at the school level, school and intervention condition were completely confounded, making it impossible to distinguish intervention-related differences from underlying school-level differences. Consequently, participant-level P values and confidence intervals from

the longitudinal models do not provide valid confirmatory tests of an intervention effect and should be regarded as exploratory and interpreted cautiously.

Additional limitations include the recruitment of students from private schools in one district of Bangkok, which limits generalizability; reliance on self-reported measures, which may be subject to social desirability and reporting bias; the short follow-up period; baseline differences in intention; and substantial ceiling and floor effects in some outcomes. In addition, the study assessed psychosocial outcomes and behavioral intention rather than actual e-cigarette use. Future studies should include multiple independently allocated schools in each study condition, longer follow-up periods, and behavioral outcomes to establish intervention effectiveness.

CONCLUSION

The findings suggest that interactive online game-based learning may be a feasible and promising approach for e-cigarette prevention among lower secondary school students. Students in the intervention school showed favorable changes in knowledge, attitudes, subjective norms, perceived behavioral control, and intention to use e-cigarettes; however, these changes cannot be attributed solely to the program because only one school represented each study condition. The findings therefore provide preliminary evidence for feasibility and hypothesis generation rather than confirmation of intervention effectiveness. Future studies should employ multi-school cluster-randomized designs with adequate school-level replication, larger and more diverse samples, longer follow-up periods, and measures of actual e-cigarette use to determine the effectiveness and sustainability of the program.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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DECLARATION

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Conflict of Interest

The authors declare that they have no conflicts of interest relevant to this study. No financial or personal relationships influenced the design, conduct, analysis, interpretation, or reporting of the research.

Registration Number of Clinical Trial

Thai Clinical Trials Registry (TCTR) identification number is TCTR20260505009 (<https://www.thaiclinicaltrials.org/show/TCTR20260505009>).

Author Contributions

Conceptualization, P.T., T.T., and P.N.; Methodology, P.T., T.T., P.N., and P.A.; Investigation, P.T., T.T., P.N., P.A., S.M., C.S., W.S., P.U., and A.R.; Formal analysis and interpretation, P.T., T.T., P.N., P.A., S.M., C.S., W.S., P.U., and A.R.; Writing – original draft, P.T. and T.T.; Writing – review and editing, P.T., T.T., and N.P.; Funding acquisition and resources, T.T., P.N., and P.A. All authors have read and agreed to the final version of the manuscript.

Use of Artificial Intelligence

Artificial intelligence-assisted tools were used to support language editing, grammar checking, and improvement of manuscript clarity. The authors carefully reviewed, verified, and revised all AI-assisted outputs. The authors take full responsibility for the accuracy, integrity, originality, and final content of the manuscript. No AI tool was used as an author, and no AI tool was responsible for study design, ethical approval, data collection, data interpretation, or final scientific conclusions.

Institutional Review Board Statement

This study was conducted in accordance with the ethical principles for research involving human participants. The study was registered with the Thai Clinical Trials Registry under the identification number TCTR20260505009. Data collection was conducted from May 15, 2026, to May 31, 2026. Ethical approval was

obtained from the Human Research Ethics Committee of the Srisavarindhira Thai Red Cross Institute of Nursing, Thailand, with the Certificate of Approval No. 005/2026 and IRB-STIN 038/2568. Participation was voluntary, and participants were informed that they could withdraw from the study at any time without penalty. All data were kept confidential and used only for research purposes. No personal identifying information was reported in this manuscript. The authors confirm that the conduct of the study complied with institutional research ethics requirements and relevant national ethical guidelines.

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