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Development and Exploratory Evaluation of WINDA-E, a School-Based Digital Educational Model for Anemia Prevention among Adolescent Girls

Triana W. *[1] *MSc*, Asrial A.[2] *PhD*, Haryanto H.[2] *PhD*, Elrifda S.[3] *PhD*

[1]Department of Health Promotion, Health Polytechnic of the Ministry of Health, Jambi, Indonesia
[2]Department of Chemistry Education, Faculty of Teacher Training and Education, University of Jambi, Jambi, Indonesia
[3] Department of Nursing, Health Polytechnic of the Ministry of Health, Jambi, Indonesia

Abstract

Aims: School-based iron supplementation programs need educational and behavioral support to achieve adequate adherence among adolescent girls. This study aimed to develop the WINDA-E (Warning, Information, Need, Diagnosis, Alarm, Evaluation) web-based educational model and explore four-week changes in anemia-related knowledge, attitudes, and self-reported preventive behavior among adolescent girls.

Materials & Methods: WINDA-E was developed using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) framework, reviewed by experts, and refined through a pilot usability assessment. A four-week exploratory quasi-experimental comparison was then conducted in 2025 in two purposively selected senior high schools in Jambi City, Indonesia; one school received WINDA-E (n=45) and the other received conventional education (n=45). Knowledge, attitudes, and preventive behavior were measured with questionnaires at baseline and week four and analyzed descriptively because school and intervention were completely confounded.

Findings: Expert review yielded item-level content validity indices of 0.83–1.00 and a scale-level index of 0.94. Knowledge scores increased from 56.4 to 78.9 in the intervention school and from 55.8 to 60.3 in the control school. Attitude scores increased from 48.2 to 62.7 versus 47.9 to 50.6, and behavior scores from 44.6 to 66.3 versus 45.1 to 49.2. The differences in mean change between schools were 18.0, 11.8, and 17.6 points, corresponding to baseline-standardized differences of 2.02, 1.84, and 2.48.

Conclusion: The WINDA-E school showed larger short-term increases in questionnaire scores than the comparison school. Because each condition was represented by a single school and no biological outcome was measured, these findings are exploratory and support a multi-school, cluster-randomized evaluation that includes hemoglobin and verified tablet consumption.

Keywords

Adolescent [https://www.ncbi.nlm.nih.gov/mesh/68000293];
Anemia, Iron-Deficiency [https://www.ncbi.nlm.nih.gov/mesh/68018798];
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*Corresponding Author
Tel: +62 (741) 445450
Postal Address: Health Polytechnic of the Ministry of Health Jambi, 42 Prof. Dr. G.A. Siwabessy Street, Buluran Kenali, Telanaipura District, Jambi City, Jambi, Indonesia. Postal Code: 36122
Email: trianawinda146@gmail.com
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Introduction

Adolescence is a critical period of physical growth, cognitive development, and the establishment of long-term health behaviors, and investing in adolescent health is central to Indonesia's goal of developing a healthy and productive generation by 2045. One important indicator of adolescent health is micronutrient status, particularly iron adequacy, which is essential for hemoglobin formation and oxygen transport [1, 2]. Iron deficiency and the resulting anemia cause fatigue and reduced concentration, and they may also reduce learning capacity, productivity, and future reproductive readiness. Therefore, anemia prevention among adolescent girls is a strategic life-course investment that can help break the intergenerational cycle of malnutrition [3].

Anemia among adolescent girls is a multifactorial public health problem involving biological, behavioral, social, and environmental determinants [4, 5]. Adolescent girls have higher iron requirements than boys because of menstruation. Low intake of iron relative to these requirements, low consumption of animal-source foods, unhealthy dieting practices, consumption of foods and beverages that inhibit iron absorption, and limited knowledge about the importance of supplementation are major determinants of anemia. From a behavior-change perspective, anemia prevention requires theory-based interventions that improve knowledge, foster positive attitudes, and promote sustained adherence to iron-tablet supplementation [6].

Globally, the World Health Organization (WHO) estimates that approximately 29.9% of women aged 15–49 years have anemia [7], and the WHO global nutrition target for 2025 is a 50% reduction in anemia prevalence among women of reproductive age [8]. In Indonesia, the 2018 Basic Health Research (Riskesdas) reported an anemia prevalence of 32% among adolescents [9]. Meanwhile, the 2023 Indonesian Health Survey reported an anemia prevalence of 15.5% among individuals aged 15–24 years, with a higher prevalence among females (18.0%) than among males (14.4%) [10]. Although the government has implemented a school-based iron supplementation program [3], adherence remains low; only a small proportion of adolescent girls consume the recommended 52 or more tablets per year [9]. Thus, existing interventions have not consistently changed iron-tablet consumption behavior.

The problem is also evident in Jambi City. In 2023, the Jambi City Health Office reported an anemia prevalence of 33.7% among adolescent girls, with relatively high rates in several primary health care areas, including Simpang IV Sipin and Aur Duri. Although the administrative coverage of iron-tablet distribution was high, actual consumption remained low. A preliminary survey in several senior high schools showed that many adolescent girls did not complete their iron tablets because of forgetfulness, perceived side effects, unpleasant taste, and the perception that anemia was not a serious problem. In addition, educational activities were often incidental and not integrated with technology-based monitoring suited to the digital generation.

These findings reveal a gap between program coverage and behavioral effectiveness. Although iron-tablet distribution is nearly universal, it has not substantially improved adherence. Educational strategies have tended to be one-directional, short-lived, and insufficient for addressing perceived risk, barriers, self-efficacy, and adolescents' preference for interactive learning. Moreover, reminder and digital monitoring systems that support consistent behavior change remain limited. An educational model that is not only informative but also adapted to contemporary adolescents is therefore needed [4, 11].

Previous studies have examined anemia prevention using single-theory approaches such as the Theory of Planned Behavior or the Health Belief Model, or using media-based interventions such as games and educational videos [12, 13]. However, most of these studies relied on a single behavioral theory or a single media format, and few have integrated the Health Belief Model, Social Cognitive Theory, the Technology Acceptance Model, and the Diffusion of Innovations Theory within a unified framework developed through a systematic research and development cycle.

Preventing anemia in adolescence is also an upstream strategy for improving maternal and child health, because anemia in adolescent girls is linked to adverse reproductive outcomes, pregnancy complications, low birth weight, and stunting in the next generation [3, 8]. Digital interventions are particularly relevant, because most adolescents use smartphones and social media as primary sources of information; such interventions allow engaging and flexible health communication, complemented by monitoring and reminder features that can support sustained healthy behaviors.

To address these gaps, we developed the WINDA-E educational model (Warning, Information, Need, Diagnosis, Alarm, Evaluation), a web-based model that integrates these behavior-change theories into a single conceptual and procedural framework and was developed using the ADDIE approach (Analysis, Design, Development, Implementation, Evaluation) [14]. This study aimed to describe the development of WINDA-E and to explore four-week changes in anemia-related knowledge, attitudes, and self-reported preventive behaviors, including reported iron-tablet consumption, among adolescent girls in two senior high schools in Jambi City. Because each condition was represented by one school, the

comparison was designed as exploratory and descriptive, and it assessed questionnaire-based rather than biological outcomes.

Materials and Methods

Study design

This research and development study was conducted from February to December 2025 in three sequential phases: ADDIE-guided model development, pilot and usability assessment, and an exploratory quasi-experimental comparison between two schools.

Phase 1: Model development

In the analysis phase, we identified gaps in school-based anemia education and in support for iron supplementation among adolescent girls. In the design phase, the six components of WINDA-E were mapped to anemia risk awareness (Warning), educational information (Information), perceived needs and benefits (Need), self-assessment (Diagnosis), reminders (Alarm), and feedback (Evaluation). The Warning and Need components operationalized the Health Belief Model constructs of perceived susceptibility, severity, and benefits; the Information, Alarm, and Evaluation components drew on Social Cognitive Theory through knowledge building, self-monitoring, and feedback to strengthen self-efficacy; the interface design was guided by the perceived usefulness and ease of use constructs of the Technology Acceptance Model; and school-based introduction of the platform was informed by the Diffusion of Innovations Theory. The development phase produced a web-based platform with educational modules, interactive quizzes, automated notifications, self-assessment, and monitoring features.

The content and interface were reviewed by six experts in health promotion, nutrition, and educational technology, who rated the relevance of each item on a four-point scale. Item-level content validity indices (I-CVI) ranged from 0.83 to 1.00, and the scale-level content validity index (S-CVI) was 0.94. The experts' comments informed revisions to the language, visual presentation, and navigation of the platform.

Phase 2: Pilot and usability assessment

Before the school comparison, the platform was piloted with six adolescent girls aged 15–18 years who were not included in the main study and who represented different levels of familiarity with smartphone applications and digital health information.

The pilot was conducted over three days to obtain user feedback on usability, navigation, reminders, and interactive quizzes. Participants considered the reminders helpful and the interactive quizzes engaging, and their feedback informed refinements to the interface navigation and notification timing. Because quantitative usability scores were not collected, the pilot findings were treated as qualitative user feedback.

Phase 3: School comparison

The comparison was conducted in two purposively selected senior high schools within the Simpang IV Sipin Primary Health Center service area in Jambi City. The schools were selected because they had an active iron supplementation program, reported concerns about adolescent anemia, and information technology facilities. One school received the WINDA-E intervention, and the other received conventional school-based health education. Separate schools were used to prevent contamination between groups; consequently, school identity was inseparable from intervention assignment.

Eligible participants were female students in grades X–XI, aged 15–18 years, who had experienced menarche and had access to a smartphone and the internet. Students with diagnosed chronic diseases or hematological disorders, and those receiving treatment for severe anemia, were excluded. The sampling frame consisted of lists of female students in grades X–XI obtained from each school; eligible students were identified using the inclusion and exclusion criteria, and participants were selected by simple random sampling from the list of eligible students in each school.

The sample size was calculated for an anticipated standardized difference of 0.6–0.7, 80% power, and a two-sided significance level of 0.05, yielding approximately 36 participants per group; this was increased to 45 per group (90 in total) to allow for attrition. Because this calculation assumed individual allocation and did not account for school-level clustering, the sample supports an exploratory comparison rather than a definitive evaluation of effectiveness.

Intervention and comparison condition

Students in the intervention school had access to the WINDA-E platform through internet-enabled devices for four weeks. The Warning component introduced the risks and consequences of anemia during adolescence. The Information component provided materials on the causes, signs and symptoms, consequences, and prevention of anemia, and the importance of iron supplementation. The Need component addressed perceived susceptibility to anemia and the benefits of preventive behaviors. The Diagnosis component provided self-assessment activities to raise awareness of anemia-related risks without establishing a clinical diagnosis. The Alarm component sent automated reminders for anemia-prevention activities, and the Evaluation component provided interactive quizzes, activity monitoring, and feedback to reinforce the educational content.

Students in the control school received conventional school-based health education without access to WINDA-E during the same four-week period. Platform log data (login frequency, module

completion, reminder delivery, and duration of use) and verified iron-tablet consumption records were not available for analysis; therefore, the analysis focused on questionnaire-based outcomes.

Outcomes and measurement

The three outcomes were anemia-related knowledge, attitudes toward anemia prevention, and self-reported anemia-prevention behaviors, including reported iron-tablet consumption, measured at baseline and four weeks later in both groups. Hemoglobin, serum ferritin, and anemia prevalence were not measured.

Knowledge was assessed using a 20-item questionnaire scored 0 (incorrect) or 1 (correct), giving a raw score of 0–20. Attitudes were measured using 15 items rated on a four-point scale (raw score, 15–60), and preventive behaviors using 15 frequency-based items rated on a four-point scale (raw score, 15–60). The behavior scale covered broader anemia-prevention practices, including reported iron-tablet consumption, and was therefore interpreted as a measure of self-reported preventive behavior rather than of tablet-count adherence. For analysis, scores on each scale were converted to a 0–100 scale (raw score/maximum possible score × 100) to allow comparison across the three scales. Corrected item-total correlations ranged from 0.372 to 0.784, and Cronbach's alpha was 0.812 for knowledge, 0.876 for attitudes, and 0.854 for preventive behaviors.

Data collection

Data were collected with online questionnaires at baseline and at week four in both schools by trained enumerators following standard operating procedures. Participants and enumerators were not blinded to group assignment. Each participant was assigned a unique identification code to link baseline and follow-up responses while maintaining confidentiality. Questionnaire completeness was checked before analysis; missing item responses were treated as missing values without imputation, and only complete responses for each outcome were included in the corresponding analysis.

Statistical analysis

Data were analyzed descriptively using means, standard deviations (SDs), frequencies, and percentages. Change scores (Δ) were calculated as week-four minus baseline scores, and the difference in mean change between schools was calculated as Δ(intervention) − Δ(control). To express this difference on a common scale, it was divided by the pooled baseline SD, $SD(pooled) = \sqrt{[((n_1 - 1)SD_1^2 + (n_2 - 1)SD_2^2)/(n_1 + n_2 - 2)]}$, yielding a baseline-standardized difference in change. Because each condition was represented by only one school, intervention was completely confounded with school; therefore, p-values, confidence intervals, and covariate-adjusted estimates were not calculated, as they would not provide valid inference about an intervention effect [16].

Table 1. Baseline characteristics of the participants in the two schools

Characteristic	Intervention school (n=45)	Control school (n=45)
Age (years), mean ± SD	16.2 ± 0.8	16.1 ± 0.7
Age at menarche (years), mean ± SD	12.6 ± 1.1	12.7 ± 1.0
History of anemia, n (%)	13 (28.9)	12 (26.7)
Previous iron-tablet consumption, n (%)	14 (31.1)	15 (33.3)
Digital literacy score, mean ± SD	65.4 ± 7.2	66.1 ± 6.9
Parental support score, mean ± SD	70.3 ± 8.1	69.8 ± 7.9

SD, standard deviation. Digital literacy was assessed with a researcher-developed questionnaire covering access to, understanding of, evaluation of, and use of digital health information, and parental support with a researcher-developed questionnaire on parental involvement in and support for anemia-prevention practices; both scores were transformed to a 0–100 scale.

Table 2. Questionnaire scores at baseline and week four and differences in mean change between the schools

Outcome	School	Baseline, mean ± SD	Week 4, mean ± SD	Δ	Difference in Δ	Standardized difference
Knowledge	Intervention	56.4 ± 8.7	78.9 ± 7.5	22.5	18.0	2.02
	Control	55.8 ± 9.1	60.3 ± 8.4	4.5		
Attitudes	Intervention	48.2 ± 6.3	62.7 ± 5.8	14.5	11.8	1.84
	Control	47.9 ± 6.5	50.6 ± 6.1	2.7		
Preventive behavior	Intervention	44.6 ± 7.2	66.3 ± 6.9	21.7	17.6	2.48
	Control	45.1 ± 7.0	49.2 ± 7.3	4.1		

SD, standard deviation; Δ, week-four mean minus baseline mean. Difference in Δ, mean change in the intervention school minus mean change in the control school. Standardized difference, difference in Δ divided by the pooled baseline SD (n=45 per school); this is a descriptive statistic, not an adjusted intervention effect. Confidence intervals were not calculated because the one-school-per-condition design does not support valid inference about an intervention effect.

Findings

Model development and pilot

The ADDIE-guided process produced the web-based WINDA-E platform with six components that incorporated anemia education, interactive quizzes, self-assessment, automated reminders, activity monitoring, and feedback. Expert review confirmed adequate content validity (I-CVI, 0.83–1.00; S-CVI, 0.94) and led to revisions of the language, visual presentation, and navigation, and pilot feedback led to refinements of navigation and notification timing.

Participant characteristics

The comparison included 90 adolescent girls, 45 in the WINDA-E school and 45 in the conventional education school; all 90 completed both assessments and were included in the analysis. The two schools

had similar baseline characteristics (Table 1). The mean age was 16.2 ± 0.8 years in the intervention school and 16.1 ± 0.7 years in the control school. A history of anemia was reported by 13 (28.9%) and 12 (26.7%) participants, respectively, and previous iron-tablet consumption by 14 (31.1%) and 15 (33.3%).

Changes in knowledge, attitudes, and behavior

Knowledge scores increased by 22.5 points in the intervention school and by 4.5 points in the control school, a difference of 18.0 points (baseline-standardized difference, 2.02). Attitude scores increased by 14.5 and 2.7 points, respectively (difference, 11.8; standardized difference, 1.84), and self-reported preventive-behavior scores by 21.7 and 4.1 points (difference, 17.6; standardized difference, 2.48; Table 2). In both schools, all three scores were higher at week four than at baseline, but the increases were consistently larger in the WINDA-E school.

Discussion

In this exploratory study, the school that used WINDA-E showed larger four-week increases in knowledge, attitude, and self-reported behavior scores than the comparison school. These findings are consistent with a short-term association between WINDA-E exposure and the questionnaire outcomes, but they do not demonstrate effectiveness, improved iron status, or reduced anemia, which are distinct clinical outcomes [15]. Because only one school represented each condition, the observed differences may reflect the intervention, school-specific characteristics, or both, which underlines the importance of distinguishing between the units of allocation and analysis in studies involving clusters [16].

The Jaga Diri intervention is the closest comparator; it used digital education and reminders over four weeks among Indonesian schoolgirls and improved knowledge and adherence to weekly iron-folic acid supplementation [11]. Unlike the present study, it defined adherence by tablet consumption and measured hemoglobin, although its two-school design shared the difficulty of separating intervention effects from school context. Differences in platforms, adherence definitions, instruments, and clinical measurements prevent direct comparison of effect sizes. Moreover, the present behavior score combines multiple practices and should not be interpreted as the proportion of prescribed tablets consumed; recommendations for self-reported adherence measurement emphasize defining the specific behavior assessed and considering the validity and limitations of the instrument [17].

Similarly, an animated-video study showed that digital educational content can improve adolescents' anemia knowledge [12], although knowledge is a narrower outcome than verified adherence or anemia reduction. A systematic review of iron supplementation adherence among adolescent girls found heterogeneous measurements and multiple barriers [4]. Together, these studies support the further evaluation of educational support while emphasizing the need to distinguish questionnaire responses from sustained tablet intake and biological outcomes.

Several mechanisms could explain the score changes: reminders may reduce forgetting, quizzes may reinforce learning, and risk information may increase motivation. A meta-analysis found that mobile text messaging improved medication adherence among adults with chronic diseases [18], although this evidence may not apply equally to adolescent iron supplementation. Research on learning techniques identifies practice testing as an effective strategy for improving retention [19], which offers a plausible explanation for the improvement in knowledge scores. Reminders, feedback, and self-monitoring are distinct behavior change techniques [20], but because the contribution of each WINDA-E component and the theoretical constructs (perceived susceptibility, self-efficacy, perceived usefulness, and technology acceptance) were not evaluated as mediators, these explanations remain hypotheses.

The large standardized differences also require caution. The definition of the effect-size numerator and the choice of standardizing SD affect interpretation in pretest–posttest control-group designs [21], and different standardizers produce statistics with different meanings [22]. Here, the standardized differences describe the difference in mean change relative to the pooled baseline SD and do not represent causal intervention effects. Repeated exposure to the same questions and the alignment of educational content with test items may have contributed to the knowledge gains, and social desirability may have influenced reported behavior [17, 20]. Differences in educator attention, school leadership, supplementation supervision, prior education, and digital resources between the schools may also have contributed.

This study has several limitations. First, intervention was completely confounded with school, and neither a larger sample nor statistical adjustment can remove this problem. Second, purposive school selection and the smartphone and internet eligibility criteria limit generalizability. Third, the four-week follow-up cannot establish whether the changes are sustained, and online self-reported questionnaires may be influenced by recall, social desirability, and test familiarity. Finally, the lack of platform log data prevented assessment of dose–response relationships, and the lack of hemoglobin and ferritin measurements prevented assessment of biological benefit. Nevertheless, the study provides a theory-based, expert-reviewed, and pilot-tested

digital model and preliminary evidence that justifies its rigorous evaluation.

Future studies should recruit multiple schools per arm, preferably with randomized allocation and a prespecified cluster-aware analysis; document participant flow; measure actual platform use and tablet consumption; and include longer follow-up and hemoglobin and iron-status outcomes, to determine whether the observed changes generalize beyond the participating schools and translate into reduced anemia.

Conclusion

The WINDA-E digital educational model was developed through a systematic, theory-based process, and the school that used it showed larger short-term increases in questionnaire-based knowledge, attitudes, and preventive behavior than the comparison school. Because one school represented each condition and no biological outcome was assessed, these findings are exploratory and do not establish effectiveness or a reduction in anemia; a multi-school cluster-randomized trial with hemoglobin and verified tablet-consumption outcomes is warranted.

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Ethical Permissions: The study was approved by the Health Research Ethics Committee of the Health Polytechnic of the Ministry of Health, Jambi, Indonesia (approval number: LB.02.06/2/1974/2025; approval date: July 22, 2025) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants and their parents or guardians.

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