**WINDA-E School-Based Digital Model for Anemia Prevention in Adolescents**

**ABSTRACT**

**Background:** School-based iron supplementation requires educational and behavioral support. Digital education may help, but changes in questionnaire scores do not establish improvements in anemia status.

Objective: To describe development of WINDA-E and explore four-week changes in anemia-related knowledge, attitudes, and self-reported behavior in two schools.

**Methods:** ADDIE-guided development and a usability pilot preceded a four-week quasi-experimental comparison in two purposively selected schools in Jambi City, Indonesia. One school received WINDA-E and one received conventional education, with 45 participants documented per group. Outcomes were questionnaire-based knowledge, attitudes, and preventive behavior. Analysis was descriptive because school identity was inseparable from intervention condition.

**Results:** Knowledge scores changed from 56.4 to 78.9 in the intervention school and from 55.8 to 60.3 in the control school. Attitude scores changed 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. Differences in mean change were 18.0, 11.8, and 17.6 reported-score units, respectively. Score transformations and assessment-specific analysis denominators were not documented sufficiently to verify these descriptive estimates.

**Conclusion:** Larger short-term questionnaire-score increases were reported in the WINDA-E school. The findings remain descriptive and provisional because scoring requires verification and intervention cannot be separated from school context. No reduction in anemia was established.

**Keywords:** Adolescent girls; anemia; digital education; iron supplementation; exploratory study

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## INTRODUCTION

The development of high-quality human resources constitutes a fundamental pillar in achieving the vision of Indonesia Emas 2045. A healthy, productive, and globally competitive generation must be prepared from adolescence, as this period represents a critical phase of physical growth, cognitive development, and the establishment of long-term health behaviors. One important indicator of adolescent health quality is micronutrient status, particularly iron adequacy, which plays a vital role in hemoglobin formation and oxygen transport throughout body tissues [1,2]. Iron deficiency leading to anemia not only results in fatigue and reduced concentration but also has broader implications for decreased learning capacity, productivity, and future reproductive readiness. Therefore, anemia prevention among adolescent girls represents a strategic life-course investment to break the intergenerational cycle of nutritional problems [3].

Conceptually, 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 due to monthly menstruation. An imbalance between iron requirements and intake, low consumption of animal-source foods, unhealthy dieting practices, intake of iron absorption inhibitors, and limited knowledge regarding the importance of supplementation constitute major determinants of anemia. From a behavioral change perspective, anemia prevention interventions require a comprehensive theory-based approach capable of improving knowledge, shaping positive attitudes, and promoting sustained adherence to iron tablet supplementation [6].

Globally, the World Health Organization has reported that approximately 29.9% of women aged 15–49 years experience anemia, making it a priority target in global nutrition reduction efforts [7]. The WHO global target for 2025 aims to reduce anemia prevalence among women of reproductive age by 50% [8]. At the national level, the 2018 Basic Health Research (Riskesdas) indicated that anemia prevalence among adolescents reached 32%, while the 2023 Indonesian Health Survey reported that approximately 18% of adolescent girls aged 14–24 years were affected by anemia. Although the government has implemented a school-based iron supplementation program [3], adherence remains substantially low; only a small proportion of adolescents consume

≥52 tablets per year as recommended. This condition suggests that existing interventions have not been fully effective in consistently changing iron tablet consumption behavior.

At the local level, this issue is also evident in Jambi City. Data from the Jambi City Health Office in 2023 indicated that anemia prevalence among adolescent girls reached 33.7%. Several primary healthcare service areas reported relatively high incidence rates, including Simpang IV Sipin and Aur Duri. Although administrative coverage of iron tablet distribution was reported to be high, actual consumption adherence remained low. Preliminary surveys conducted in several senior high schools revealed that many adolescent girls did not complete their iron tablets due to forgetfulness, perceived side effects, unpleasant taste, and the perception that anemia was not a serious health concern. Furthermore, educational efforts were often incidental and not integrated with technology-based monitoring systems aligned with the characteristics of the digital generation.

These findings highlight a gap between program coverage and implementation effectiveness in the field. Administratively, iron tablet distribution has been nearly universal; however, behaviorally, it has not resulted in significant improvements in adherence. Educational strategies have tended to be one-directional, non-sustained, and insufficient in addressing perceived risk, barriers, self-efficacy, and adolescents' need for interactive learning media. Moreover, reminder and digital monitoring systems to support consistent behavioral change remain limited. This gap underscores the need for an innovative educational model that is not only informative but also adaptive to the characteristics of contemporary adolescents [4,9].

From a research perspective, previous studies have examined anemia prevention using single-theory approaches such as the Theory of Planned Behavior, the Health Belief Model, or media-based interventions including games and educational videos [10,11]. However, most studies have focused on the influence of a single behavioral theory or a single media format without multi-theory integration or the development of a comprehensive model through a systematic development cycle. Few studies have integrated the Health Belief Model, Social Cognitive Theory, Technology Acceptance Model, and Innovation Diffusion Theory within a unified conceptual framework developed through a Research and Development (R&D) design. Therefore, a research gap exists in the development of a conceptually and procedurally integrated digital education model.

The urgency of this research is further reinforced by the long-term consequences of anemia among adolescent girls, including adverse reproductive health outcomes, increased risk of pregnancy complications, low birth weight, and stunting in subsequent generations. Preventing anemia during adolescence represents an upstream life-course strategy to improve maternal and child health outcomes in the future [3,8]. Digital-based interventions are particularly relevant, as most adolescents actively use smartphones and social media as primary sources of information. The utilization of technology enables more engaging and flexible health communication, complemented by monitoring and reminder features that support sustained healthy behaviors.

The novelty of this study lies in the development of the WINDA-E Educational Model (Warning, Information, Need, Diagnosis, Alarm, Evaluation), a web-based digital education model that integrates multiple behavioral change theories into a single conceptual and procedural framework. The model was developed using the ADDIE approach (Analysis, Design, Development, Implementation, Evaluation) [12], resulting in an expert-validated, empirically tested educational product equipped with reminder and behavioral evaluation features for iron tablet consumption. The integration of conceptual (multi-theory integration) and technological (digital-based intervention) components distinguishes this study from previous research.

Based on this background, this study aimed to describe the development of the WINDA-E digital educational model and 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. The comparison was exploratory and descriptive because each study condition was represented by one school, preventing separation of intervention-associated differences from school-specific factors. The study assessed questionnaire-based outcomes rather than biological anemia outcomes.

## METHODS

### Study overview

The project was conducted from February to December 2025 and comprised three sequential phases: ADDIE-guided model development, pilot testing and usability assessment, and an exploratory quasi-experimental school comparison. The development phase involved the design and refinement of the

WINDA-E platform through expert review, while the pilot phase focused on evaluating initial user feedback and improving interface navigation and notification features. The exploratory quasi-experimental comparison was subsequently conducted in two purposively selected senior high schools within the Simpang IV Sipin Primary Health Center service area in Jambi City, Indonesia. A total of 90 adolescent girls participated in the school comparison, comprising 45 students in the WINDA-E intervention school and 45 students in the conventional education control school.

Phase 1 ADDIE development

The development of WINDA-E followed the ADDIE framework [12], comprising analysis, design, development, implementation, and evaluation. The analysis phase identified gaps in school-based anemia education and support for iron supplementation among adolescent girls. During the design phase, six components of WINDA-E—Warning, Information, Need, Diagnosis, Alarm, and Evaluation—were mapped to anemia risk awareness, educational information, perceived needs and benefits, self-assessment, reminders, and feedback. The development phase resulted in a web-based platform incorporating educational modules, interactive quizzes, automated notifications, self-assessment, and monitoring features. The platform content and interface were reviewed by experts in health promotion, nutrition, and educational technology. Feedback from the review process informed revisions to the language, visual presentation, and navigation to improve the platform's clarity and usability.

The original development assessment reported item-level content validity index (I-CVI) values ranging from 0.83 to 1.00 and a scale-level content validity index (S-CVI) of 0.94. However, the available documentation did not provide sufficient details on the expert rating procedures and calculation methods to independently verify these estimates. Therefore, these values are reported as originally documented rather than as independently confirmed evidence of instrument validity.

Phase 2 Pilot and usability assessment

A pilot and usability assessment was conducted before the exploratory school comparison to obtain initial user feedback and identify areas requiring improvement. Feedback from the pilot informed refinements to interface navigation and notification timing. Participants reportedly considered the reminders helpful and the interactive quizzes engaging. These observations were used to improve the platform's presentation and user experience before its implementation in the school comparison. However, quantitative usability scores, formal platform-adherence measurements, and detailed pilot participant characteristics were not available. Accordingly, the pilot findings were interpreted as preliminary user feedback rather than evidence of intervention effectiveness.

Phase 3 School comparison and recruitment

The exploratory quasi-experimental comparison was conducted in two purposively selected senior high schools within the Simpang IV Sipin Primary Health Center service area in Jambi City, Indonesia. The schools were selected based on the availability of an iron supplementation program, reported concerns regarding adolescent anemia, and access to information technology facilities. One school received the WINDA-E intervention, while the other received conventional school-based health education. A total of 90 adolescent girls participated, comprising 45 students in the intervention group and 45 students in the control group. Participants were recruited separately from the two schools, and individual random allocation was not performed. The use of separate schools was intended to minimize potential contamination between study groups; however, school identity was consequently 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. Written informed consent was required for participation. Students with diagnosed chronic diseases, hematological disorders, or who were receiving treatment for severe anemia were excluded. The original sampling procedure described random selection of students within each school, although detailed information regarding the sampling frame and selection process was unavailable.

The study included 90 participants, with 45 students allocated to each school group. The original sample-size calculation was based on an anticipated standardized difference of 0.6–0.7, 80% statistical power, and a two-sided significance level of 0.05. The initial estimated sample of approximately 36 participants per group was increased to 45 per group. This calculation was based on individual-level assumptions and did not account for school-level clustering. Because only one school represented each study condition, the sample size should be interpreted as supporting an

exploratory individual-level comparison rather than a definitive evaluation of intervention effectiveness.

Intervention and comparison education

The WINDA-E intervention was implemented over four weeks using a web-based educational platform designed to support anemia prevention among adolescent girls. The intervention integrated six components: Warning, Information, Need, Diagnosis, Alarm, and Evaluation. The Warning component introduced the risks and potential consequences of anemia during adolescence. The Information component provided educational materials covering the causes, signs and symptoms, health consequences, prevention strategies, and 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 improve students' awareness of anemia-related risks without establishing a clinical diagnosis. The Alarm component incorporated automated reminders to encourage engagement with anemia-prevention activities, while the Evaluation component provided interactive quizzes, activity monitoring, and feedback to reinforce the educational content.

Students in the intervention school received access to the WINDA-E platform throughout the four-week intervention period. The platform provided digital educational materials and interactive learning features that students could access through internet-enabled devices. The intervention focused on improving anemia-related knowledge, attitudes, and preventive behaviors, particularly awareness of iron supplementation and anemia prevention.

The control group consisted of 45 students from a separate senior high school who received conventional school-based health education without access to WINDA-E. This group served as the comparison condition for evaluating changes in questionnaire-based outcomes over the same four-week assessment period. The school-based comparison was intended to examine differences in short-term outcomes between students exposed to the digital educational model and those receiving conventional education.

Platform exposure and behavioral outcomes were considered separate aspects of the intervention. Although WINDA-E incorporated reminders, quizzes, and monitoring features, objective platform utilization records, including login frequency, module completion, reminder delivery, and duration of platform use, were unavailable. Similarly, verified records of iron-tablet consumption and intervention adherence were not available for quantitative analysis. Therefore, intervention engagement and actual iron-tablet consumption could not be independently established. The analysis consequently focused on changes in self-reported knowledge, attitudes, and anemia-prevention behaviors rather than objectively verified platform use or iron-supplementation adherence.

Table 1. Intervention timeline and available documentation

| Stage | Timing | Documented activity |
|---|---|---|
| Development | Within February–December 2025 | Needs assessment, platform design, and expert review; exact phase dates not documented |
| Pilot | Before school comparison | Navigation and notification refinements; sample size and duration not documented |
| Baseline | Before intervention | Questionnaire assessment in both schools; assessment-specific n not separately documented |
| Intervention | Four weeks | WINDA-E access versus conventional school education; detailed delivered dose not documented |
| Posttest | At four weeks | Questionnaire reassessment; losses and outcome-specific analysis denominators not separately documented |

Outcomes and measurement

The study assessed three primary outcomes: anemia-related knowledge, attitudes toward anemia prevention, and self-reported anemia-prevention behaviors, including reported iron-tablet consumption. These outcomes were assessed at baseline and four weeks after the intervention in both study groups. The assessment focused on changes in questionnaire-based outcomes. Hemoglobin concentration, serum ferritin, and anemia prevalence were not measured; therefore, the study did not evaluate changes in the participants' biological iron status or anemia incidence.

Knowledge was assessed using a 20-item questionnaire, with each item scored dichotomously (0 = incorrect and 1 = correct), yielding a raw total score ranging from 0 to 20. Attitudes were measured

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using 15 items with a four-point response scale, producing a raw total score ranging from 15 to 60. Anemia-prevention behaviors were assessed using 15 frequency-based items with a four-point response scale, also yielding a raw total score ranging from 15 to 60. The behavioral questionnaire covered broader anemia-prevention practices, including reported iron-tablet consumption, and was therefore interpreted as a measure of self-reported preventive behavior rather than a direct measure of tablet-count adherence.

The original instrument documentation reported corrected item-total correlations ranging from 0.372 to 0.784. Cronbach's alpha coefficients were 0.812 for knowledge, 0.876 for attitudes, and 0.854 for preventive behaviors, indicating the reported internal consistency of the three instruments. These reliability estimates were retained from the original study documentation.

Data collection and missing data

Data were collected using online questionnaires administered at baseline and four weeks after the intervention, following the same assessment schedule in both study groups. The source documentation reported that enumerators received training and that standard operating procedures were used to guide data collection. The same questionnaire-based assessment procedures were applied to students in the WINDA-E intervention school and the conventional education control school.

As the outcomes were self-reported and collected online, the measurements were potentially susceptible to recall bias, social desirability bias, repeated-testing effects, and differences in participant engagement between schools. Information regarding blinding of participants, data collectors, or outcome assessors was not available in the study documentation.

The available records did not provide sufficient details to establish the procedures for participant identification and linkage between baseline and follow-up responses, duplicate-response prevention, data validation, or the management of missing questionnaire items. The number of participants completing each assessment, losses to follow-up and their reasons by study group, the final analysis population, and the use of any missing-data imputation procedure could not be independently verified. Accordingly, no assumption was made regarding complete follow-up or the absence of missing data.

Exploratory statistical analysis

Data were analyzed descriptively using means, standard deviations (SDs), and changes in mean scores between baseline and the four-week assessment. Change scores (Δ) were calculated as post-intervention minus baseline scores, and the difference in mean changes was calculated as Δintervention − Δcontrol.

Because each study group was represented by only one school, intervention condition was completely confounded with school identity. Therefore, differences between groups could not be attributed independently to the intervention. Individual-level hypothesis tests and covariate adjustments could not resolve this limitation. Accordingly, the findings were interpreted as exploratory descriptive comparisons, without claiming a causal intervention effect or cluster-valid confidence intervals and p-values.

For descriptive standardization, the difference in mean changes was divided by the pooled baseline SD. This statistic was interpreted as a baseline-standardized descriptive difference in change, rather than an adjusted intervention effect. No confidence interval was calculated because the required repeated-measures covariance information and an appropriate cluster-level sampling framework were unavailable.

Ethics

This study has obtained ethical approval from the Health Research Ethics Committee of Kementerian Kesehatan, Poltekkes Jambi, under ethical clearance number No. LB.02.06 / 2 / 1974 2025. The research was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

**RESULTS**

Model development and pilot findings

The ADDIE-guided development process produced a web-based WINDA-E platform comprising six components: Warning, Information, Need, Diagnosis, Alarm, and Evaluation. These components incorporated anemia education, interactive quizzes, self-assessment, automated reminders, activity monitoring, and feedback. Expert review informed revisions to language, visual presentation, and

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navigation. The development records reported I-CVI values of 0.83–1.00 and an S-CVI of 0.94; however, the rating procedures and calculation methods could not be independently verified. Pilot feedback described reminders as helpful and quizzes as engaging, and informed refinements to navigation and notification timing. The pilot sample characteristics and quantitative usability results were unavailable; therefore, these findings represent preliminary development feedback rather than validated feasibility or effectiveness outcomes.

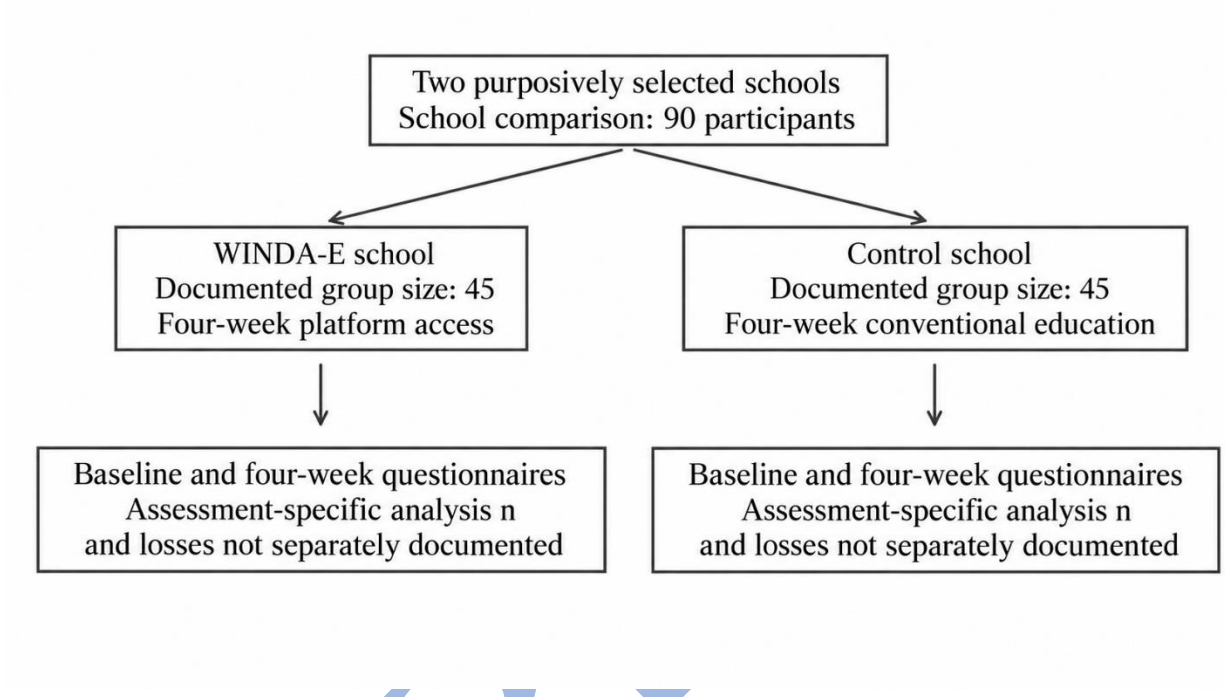



**Figure 1. Participant flow for the exploratory school comparison**

Participant characteristics and available assessments

The school comparison included 90 adolescent girls, with 45 participants in the WINDA-E school and 45 in the conventional education school (Figure 1). Recruitment totals, reasons for exclusion, losses to follow-up, and the numbers contributing to each baseline, follow-up, and paired analysis were not documented separately. Accordingly, the stated group sizes should not be interpreted as verified outcome-specific analysis denominators. Baseline characteristics are summarized in Table 2. 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 for 13 (28.9%) and 12 (26.7%) participants, respectively; previous iron-tablet consumption was reported for 14 (31.1%) and 15 (33.3%). Baseline distributions were described without significance testing, and no equivalence between schools was inferred.

Table 2. Reported baseline characteristics

| Characteristic | Intervention n=45 | Control 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, mean ± SD | 65.4 ± 7.2 | 66.1 ± 6.9 |
| Parental support, mean ± SD | 70.3 ± 8.1 | 69.8 ± 7.9 |

Values are mean ± SD or n (%). SD, standard deviation. Group sizes are those documented for the school comparison. Categorical counts were reconstructed from the reported percentages and group size of 45. The scale ranges and score units for digital literacy and parental support were not documented. No baseline equivalence tests were performed in the revised descriptive analysis.

Changes in questionnaire outcomes at four weeks

Knowledge scores increased from 56.4 ± 8.7 to 78.9 ± 7.5 in the intervention school and from 55.8 ± 9.1 to 60.3 ± 8.4 in the control school. The corresponding mean changes were 22.5 and 4.5 reported-score units. Attitude scores increased from 48.2 ± 6.3 to 62.7 ± 5.8 in the intervention school and from 47.9 ± 6.5 to 50.6 ± 6.1 in the control school, corresponding to changes of 14.5 and 2.7 units. Self-reported preventive-behavior scores increased from 44.6 ± 7.2 to 66.3 ± 6.9 and from 45.1 ± 7.0 to 49.2 ± 7.3, respectively, corresponding to changes of 21.7 and 4.1 units (Table 3).

Table 3. Reported baseline and four-week questionnaire scores

| Outcome and school | Baseline mean ± SD | Week 4 mean ± SD | Δ mean |
|---|---|---|---|
| Knowledge intervention | 56.4 ± 8.7 | 78.9 ± 7.5 | 22.5 |
| Knowledge control | 55.8 ± 9.1 | 60.3 ± 8.4 | 4.5 |
| Attitude intervention | 48.2 ± 6.3 | 62.7 ± 5.8 | 14.5 |
| Attitude control | 47.9 ± 6.5 | 50.6 ± 6.1 | 2.7 |
| Behavior intervention | 44.6 ± 7.2 | 66.3 ± 6.9 | 21.7 |
| Behavior control | 45.1 ± 7.0 | 49.2 ± 7.3 | 4.1 |

Values are mean ± SD. Δ = four-week mean minus baseline mean. The documented group size was 45 per school; baseline, four-week, and paired analysis denominators were not separately available. Results use the score units recorded in the source tables. These units cannot be interpreted as raw scores or percentages because the transformation algorithm was unavailable and the values exceed the stated raw ranges of 0–20 for knowledge and 15–60 for attitudes and behavior. All outcomes are questionnaire-based; the behavior score is not a verified tablet-consumption count.

Table 4. Descriptive differences in mean change between schools

| Outcome | Difference in Δ | Baseline-standardized difference in change | 95% CI |
|---|---|---|---|
| Knowledge | 18.0 | 2.02 | Not calculated |
| Attitudes | 11.8 | 1.84 | Not calculated |
| Behavior | 17.6 | 2.48 | Not calculated |

Difference in Δ = mean change in the WINDA-E school minus mean change in the control school, in reported-score units. Baseline-standardized difference in change (d) = difference in Δ divided by the pooled baseline SD, with $SD_{pooled} = \sqrt{\{[(nI - 1)SDI^2 + (nC - 1)SDC^2]/(nI + nC - 2)\}}$. Values were calculated from the reported summary statistics using nI = nC = 45. This descriptive statistic is neither a paired-sample effect size nor an adjusted intervention effect. CI, confidence interval. Confidence intervals were not calculated because repeated-measures covariance was unavailable and the one-school-per-arm design did not support cluster-valid intervention inference. Interpretation remains conditional on the documented scores.

Descriptive between-school comparisons

The difference in mean change between the intervention and control schools was 18.0 reported-score units for knowledge, 11.8 for attitudes, and 17.6 for preventive behavior. Using the pooled baseline SD as the denominator, the corresponding baseline-standardized descriptive differences in change were 2.02, 1.84, and 2.48 (Table 4). These values describe the observed contrasts between the two schools and do not establish an independent intervention effect. Consistent with the revised exploratory methods, no hypothesis-test p-values, adjusted ANCOVA estimates, or cluster-valid confidence intervals are presented.

Platform engagement and biological outcomes

Quantitative platform-use records, including login frequency, module completion, reminder delivery, and duration of use, were unavailable. Verified iron-tablet consumption records were also unavailable; therefore, actual platform adherence and supplementation adherence could not be quantified. Hemoglobin concentration, serum ferritin, and anemia prevalence were not assessed. The reported changes consequently concern questionnaire-based educational and preventive-behavior outcomes only.

## DISCUSSION

The intervention school showed larger four-week increases in reported knowledge, attitude, and behavior scores than the comparison school. The findings are consistent with a short-term association between WINDA-E exposure and questionnaire outcomes. They do not demonstrate definitive effectiveness, improved iron status, or reduced anemia. Clinical evidence concerning iron supplementation addresses anemia and iron deficiency as outcomes distinct from educational

questionnaire scores [13]. Furthermore, because only one school represented each condition, intervention assignment was inseparable from school identity. Individual-level comparisons therefore cannot establish whether the observed differences reflect the intervention or school-specific characteristics, highlighting the importance of distinguishing the units of allocation and analysis in studies involving clusters [14]. Unverified scoring further limits quantitative interpretation.

Jaga Diri is a close comparator because it used digital education and reminders over four weeks among Indonesian schoolgirls [9]. Unlike the present study, it defined adherence using tablet consumption and included hemoglobin assessment. Its two-school design nevertheless shares the difficulty of separating intervention and school context. Differences in platforms, adherence definitions, instruments, and clinical measurements prevent direct comparison of numerical effects. 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 being assessed and considering the validity and limitations of the selected instrument [15].

The animated-video study supports the possibility that digital educational content can improve adolescent anemia knowledge [10], but knowledge outcomes are narrower than objectively verified adherence or anemia reduction. The supplementation-adherence review documents heterogeneous measurement and multiple barriers [4]. Together, these sources support further evaluation of educational support while underscoring the need to distinguish questionnaire responses from sustained tablet intake and biological outcomes. Accordingly, the present findings provide preliminary information about educational and self-reported behavioral changes rather than evidence that WINDA-E improved physiological iron status.

Several mechanisms could explain score changes: reminders may reduce forgetting, quizzes may reinforce learning, and risk information may influence motivation. A meta-analysis of medication-adherence interventions found that mobile text messaging could support adherence among adults with chronic diseases; however, this evidence is indirect and should not be assumed to apply equally to adolescent iron supplementation or WINDA-E [16]. Research on learning techniques also identifies practice testing as a potentially useful strategy for strengthening retention, offering a plausible explanation for improvements in questionnaire-based knowledge [17]. Reminders, feedback, and self-monitoring can be described as distinct behavior change techniques, but their presence in a platform does not establish that each technique was delivered as intended or caused the observed changes [18]. These explanations therefore remain hypotheses. Perceived susceptibility, self-efficacy, perceived usefulness, technology acceptance, and diffusion processes were not evaluated as mediators. Pilot comments cannot establish that a particular feature caused the observed change, and the contribution of each WINDA-E component was not isolated.

The very large descriptive standardized contrasts require caution. Methodological work on pretest–posttest control-group designs shows that the definition of the effect-size numerator and the choice of standardizing SD are important for interpretation [19]. Guidance on effect-size reporting similarly emphasizes that different standardizers produce statistics with different meanings and that the calculation must correspond to the study design [20]. In the present study, the standardized contrasts describe differences in mean change relative to the pooled baseline SD; they do not represent independently identified causal intervention effects. Repeated exposure to the same questions and alignment of teaching content with test items may contribute to knowledge-score gains, while self-report expectations may influence reported behavior [15,18]. Differential educator attention, school leadership, supplementation supervision, prior education, and digital resources may also contribute to differences between schools. A uniform linear score transformation applied consistently to both groups and measurement occasions would not change the standardized contrast, but incorrect scoring or inconsistent units would invalidate it. The original d values were not reproducible from a clearly stated formula; the revised descriptive values use one explicit denominator and remain provisional pending scoring verification.

The principal limitation is perfect confounding of intervention with school. Neither a large student sample nor ANCOVA removes this problem, and conventional individual-level precision can be misleading. Purposive school selection and smartphone/internet eligibility limit generalizability. Recruitment and missing-data documentation are incomplete, and four-week follow-up cannot establish durability. Online questionnaires may be influenced by recall, social desirability, and test familiarity. Lack of verified usage logs prevents evaluation of dose–response relationships; lack of

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hemoglobin and ferritin prevents assessment of biological benefit. No independent parental-support or digital-literacy association is asserted because the original adjusted output is inconsistent.

Future evaluation should recruit multiple schools per arm, preferably with randomized allocation and a prespecified cluster-aware analysis. It should verify scoring before recruitment, document allocation and participant flow, measure actual platform exposure and tablet consumption, and include longer follow-up and appropriate hemoglobin/iron-status outcomes. Development and usability results should be reported with their own denominators and instruments. These steps would test whether the observed score changes generalize beyond the participating schools.

**CONCLUSION**

Larger short-term increases in questionnaire-based knowledge, attitudes, and preventive behavior were reported in the WINDA-E school. These descriptive findings remain provisional pending verification of scoring and analysis denominators. One school per arm prevents separation of intervention and school effects, and no biological anemia outcome was assessed. The study does not establish definitive effectiveness or reduced anemia.

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