

A Scoping Review of Smartphone-Based Interventions for Improving Nutrition Literacy and Preventing Anemia During Pregnancy

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ABSTRACT

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Anemia in pregnancy remains a major public health challenge in developing countries due to its harmful effects on mothers and fetuses. Smartphone technology offers new opportunities to deliver nutrition education and reduce this burden. This scoping review mapped and appraised evidence on smartphone-based interventions to improve nutrition literacy and prevent anemia among pregnant women. This review adapted the Joanna Briggs Institute (JBI) framework for scoping reviews. Literature searches were undertaken across major databases, including PubMed, Scopus, Web of Science, CINAHL, ProQuest, and relevant regional databases, focusing on publications from January 2015 through 2024. Eligible studies comprised experimental and observational research evaluating smartphone-based nutrition or anemia-related interventions among pregnant populations. Extracted data covered study design, intervention characteristics, outcomes, and contextual factors, which were subsequently analyzed thematically to synthesize findings and identify determinants of intervention success. Of 5,120 records identified, 11 studies met inclusion criteria. Interventions mainly used mobile apps, SMS reminders, and multimedia educational modules, with varying duration and intensity. Most studies reported positive outcomes: better adherence to iron supplementation, higher hemoglobin levels, and improved knowledge and self-care behaviors. However, effect sizes varied according to user engagement, digital literacy, content personalization, and integration with existing health services. Smartphone-based interventions show considerable promise for closing maternal nutrition-literacy gaps and preventing anemia, especially in

resource-limited settings. Nevertheless, their effectiveness depends on cultural appropriateness, technological accessibility, and alignment with health systems. Future efforts should prioritize user-centered design, context-specific adaptation, and strategies that ensure long-term sustainability and equitable access.

1. Introduction

Maternal anemia represents a critical global health challenge with profound implications for both maternal and neonatal outcomes. This hematological disorder, characterized by insufficient healthy red blood cells, significantly increases risks of premature delivery, low birth weight, and maternal-infant mortality (Engidaw, Eyayu, & Tiruneh, 2022; Wirawan & Nurrika, 2022). Indonesia faces a particularly acute burden, with national health surveillance data revealing anemia prevalence of 48.9% among pregnant women, affecting nearly half of all expectant mothers nationwide (Riset Dinas Kesehatan, 2018). Traditional intervention frameworks for maternal anemia have encompassed iron supplementation protocols (Tiwari, Mahdi, Mishra, Parveen, & Fatima, 2020), structured nutritional education programs (Ahmad et al., 2022), and integrated disease prevention initiatives (Konje et al., 2022). Urban healthcare settings typically implement these strategies through formalized antenatal classes (Kare & Gujo, 2021), Professional Nutritional Consultations (Dewidar et al., 2023), and systematic distribution of educational resources (Wulandari, Octaviani, & Fajrin, 2023). While these conventional approaches demonstrate efficacy in enhancing nutritional knowledge and behavioral modification, their effectiveness remains constrained by accessibility barriers and variable healthcare provider-patient interaction quality (Widyawati, Jans, Utomo, van Dillen, & Janssen, 2015).

The persistent urban-rural healthcare disparity creates substantial gaps in maternal health education access, contributing significantly to differential maternal outcomes (Haruna, Dandeebo, & Galaa, 2019). Geographic isolation, inadequate health infrastructure, and unequal healthcare workforce distribution exacerbate these inequalities. However, rapid technological advancement and expanding internet connectivity, particularly smartphone penetration into previously underserved regions, present unprecedented opportunities to bridge these healthcare access gaps. Smartphone-based health interventions have emerged as promising solutions for anemia prevention and management in pregnancy (Rukmaini, Lipoeto, Masrul, & Effendi, 2019). These mobile health (mHealth) platforms offer universal accessibility, cost-effectiveness, and geographic independence, enabling continuous health support delivery without traditional temporal or spatial constraints. Research evidence regarding smartphone intervention effectiveness presents mixed findings. Several studies demonstrate significant improvements in iron supplementation adherence and hemoglobin level enhancement among intervention participants, while others report statistically insignificant impacts on maternal anemia status.

This heterogeneity in intervention outcomes likely stems from multiple determinant factors including application design architecture, educational content quality, target population demographic characteristics, usage intensity patterns, and intervention sustainability mechanisms. Socioeconomic variables such as educational attainment, income levels, digital literacy competency, and technological access significantly influence intervention success rates. Research indicates that culturally contextualized

and socially appropriate interventions demonstrate superior effectiveness compared to generic approaches (Aarons, Sklar, Mustanski, Benbow, & Brown, 2017). Implementation challenges in developing nations include technological infrastructure limitations, digital literacy disparities, and varying healthcare system integration capabilities. User-centered design principles that incorporate local contexts, cultural preferences, and existing healthcare frameworks are essential for maximizing intervention impact and sustainability.

Contemporary smartphone-based interventions require multidimensional functionality beyond basic information dissemination, including medication adherence reminders, dietary intake monitoring, symptom tracking systems, and healthcare provider communication platforms. This comprehensive approach facilitates sustained behavioral modification while providing personalized, real-time support tailored to individual maternal needs. Current scientific literature lacks systematic synthesis regarding smartphone-based nutritional education interventions for anemia prevention in pregnant women, particularly within developing country contexts. This scoping review aims to systematically map and analyze diverse smartphone-based health and nutrition education interventions targeting pregnant women in developing nations, with a specific focus on evaluating intervention effectiveness in enhancing nutritional literacy and preventing maternal anemia.

Following the Joanna Briggs Institute framework for systematic reviews, this study will comprehensively identify and analyze various intervention types and research methodologies, mapping available evidence on intervention effectiveness, success determinants, and research gaps requiring future investigation. The findings will establish an evidence foundation for developing contextually appropriate and effective smartphone-based interventions to address maternal anemia in resource-limited settings.

1.1. Research Objectives

This scoping review was designed to address critical gaps in maternal nutrition by leveraging the growing accessibility of mobile technology. Specifically, the study aimed to:

- i. To systematically map the characteristics and types of smartphone-based interventions targeting nutrition literacy and anemia prevention among pregnant women.
- ii. To appraise the reported effectiveness of these smartphone-based interventions on outcomes such as iron-supplementation adherence, hemoglobin levels, nutrition knowledge, and self-care behaviors, and to identify contextual factors influencing their success.

1.2. Research Questions

To guide the mapping and appraisal of mobile health strategies for maternal anemia prevention, this review was structured around the following research questions:

- i. What types and characteristics of smartphone-based interventions have been used to improve nutrition literacy and prevent anemia among pregnant women?

- ii. How effective are these smartphone-based interventions in improving outcomes such as iron-supplementation adherence, hemoglobin levels, nutrition knowledge, and self-care behaviors among pregnant women?
- iii. What contextual factors (e.g., user engagement, digital literacy, content personalization, and health-system integration) influence the success of smartphone-based nutrition and anemia interventions for pregnant women?

2. Literature Review

2.1. Anemia Prevention and Nutrition Literacy in Pregnancy

Anemia during pregnancy remains a major public-health concern because it is associated with increased risks of maternal morbidity, poor birth outcomes, low birth weight, preterm birth, and reduced maternal well-being. Iron deficiency is a leading cause of anemia among pregnant women; however, anemia is multifactorial and may also be influenced by infections, inherited hemoglobin disorders, chronic diseases, inadequate dietary intake, and poor utilization of antenatal services. The World Health Organization (WHO) recommends daily oral iron and folic acid supplementation during pregnancy—30–60 mg of elemental iron and 400 µg of folic acid—to reduce maternal anemia, iron deficiency, low birth weight, and preterm birth. In settings where anemia is a severe public-health problem, the higher 60-mg daily iron dose is recommended (Arifah, 2023).

Although iron–folic acid supplementation is a central preventive strategy, supplying tablets alone does not necessarily ensure their regular use. Pregnant women may miss doses because of forgetfulness, nausea, constipation, concerns about side effects, limited awareness of anemia-related risks, misconceptions about iron tablets, or inadequate family and health-provider support. Nutrition literacy is therefore essential because it involves more than simply receiving dietary information. In the context of pregnancy anemia prevention, it includes the ability to access, understand, appraise, and apply nutrition information to choose iron-rich foods, combine iron sources with enhancers such as vitamin C, avoid inhibitors of iron absorption around meals or supplements, recognize anemia risks, and adhere to iron–folic acid supplementation.

Evidence suggests that educational interventions can improve anemia-related knowledge and promote preventive practices among pregnant women. However, conventional counseling is often limited by short antenatal consultations, uneven access to nutrition professionals, geographic barriers, and the inability to reinforce information between clinic visits. Smartphone-based interventions offer a potential solution by allowing educational content, reminders, monitoring, and supportive communication to be delivered repeatedly and at a time convenient for the user. This approach is particularly relevant in antenatal care, where sustained dietary and supplementation behaviors are required over several months.

2.2. Smartphone-Based Health Education

Mobile health, commonly termed **mHealth**, refers to the use of mobile and wireless technologies to support health-care delivery, health education, behavior change, monitoring, and communication. Smartphone-based interventions may use short message service (SMS), WhatsApp messages, voice calls, videos, interactive mobile applications, push notifications, digital monitoring tools, online questionnaires, and

teleconsultation. Their key advantage is the ability to provide tailored and repeated support beyond a single face-to-face counseling session (Rahman et al., 2022).

For anemia prevention in pregnancy, smartphone interventions can address several components of nutrition literacy. First, they can provide understandable education about the causes, signs, consequences, and prevention of anemia. Second, they can deliver practical nutrition guidance, including information on locally available iron-rich foods, vitamin C-rich foods that improve iron absorption, and foods or drinks such as tea and coffee that may inhibit iron absorption when consumed close to iron intake. Third, digital reminders can support regular iron-folic acid tablet consumption and help women overcome forgetfulness, which is frequently reported as a barrier to adherence. Finally, interactive content, feedback, and communication with health providers may improve motivation, perceived self-efficacy, and sustained engagement with anemia-prevention behaviors (Fatthy & Ezzat, 2020).

The effectiveness of digital interventions may depend not only on the technology used, but also on the educational content, frequency of contact, usability, language, cultural relevance, access to internet connectivity, and integration with routine antenatal care. Interventions that merely remind women to take supplements may improve adherence; however, interventions that combine reminders with education, motivational messages, behavioral theory, and opportunities for interaction may be more likely to improve nutrition literacy and clinical outcomes.

2.3. Evidence on Digital Interventions

Recent intervention studies provide promising evidence that smartphone and mobile-phone approaches can improve knowledge, iron-supplement adherence, dietary practices, and hemoglobin outcomes among pregnant women. In Indonesia, Arifah et al. (2023) conducted a pilot randomized controlled trial among 44 pregnant women who received daily visual educational and motivational messages through WhatsApp for seven weeks. The messages addressed anemia prevention, iron-folic acid consumption, diet, and the consequences of anemia. Compared with standard care, the intervention significantly improved anemia-prevention knowledge and cumulative iron-folic acid tablet consumption over 42 days. Mean tablet consumption was 39.54 in the intervention group compared with 34.86 in the control group, with an adjusted mean difference of 4.68 ($p = .003$). However, the intervention did not produce a significant difference in anemia-prevention dietary behavior, indicating that education and reminders alone may be insufficient to change food practices that are also shaped by food availability, household resources, and social support.

A more intensive theory-based intervention was evaluated by (Rahman et al., 2022) in Malaysia. The MyPinkMom program delivered six infographic video clips via WhatsApp to pregnant women with anemia. The content was developed using the Health Belief Model and included information about anemia, its risks, dietary iron, vitamin C, iron supplementation, and management of tablet side effects. In this cluster-assignment randomized controlled trial, the intervention group demonstrated significant improvements in hemoglobin level, anemia knowledge, dietary iron intake, vitamin C intake, attitudes, subjective norms, and perceived behavioral control related to iron-supplement adherence. At week 6, mean hemoglobin was 10.75 g/dL in the intervention group and 10.08 g/dL in the control group, while the effect of the intervention on knowledge was substantial ($\eta_p^2 = 0.62$). By week 12, hemoglobin increased to 11.48

g/dL in the intervention group compared with 10.41 g/dL in the control group. These findings suggest that theory-informed smartphone education may improve both nutrition literacy and clinically relevant anemia outcomes.

Similarly, Sontakke et al. (2022) examined mobile phone call reminders in antenatal women with iron-deficiency anemia in India. Women receiving standard iron therapy plus fortnightly calls had higher adherence to iron supplementation than women receiving standard therapy alone. The intervention group also had a larger mean increase in hemoglobin from recruitment to delivery: 0.96 g/dL compared with 0.59 g/dL in the control group ($p = .00001$). The findings highlight that even relatively simple mobile interventions can support adherence, especially when calls provide an opportunity to identify barriers such as forgetfulness, constipation, heartburn, or fatigue with daily tablet use.

Evidence from Ethiopia further supports the value of combining counseling with mobile messaging. A cluster randomized controlled trial by Wakwoya et al. (2023) used trimester-based nutrition education and counseling guided by the Health Belief Model, weekly SMS messages, and printed dietary materials. The intervention produced a significant increase in hemoglobin and improved intake of iron-rich foods. Mean hemoglobin in the intervention group increased from 12.08 g/dL at baseline to 12.53 g/dL after the intervention, while anemia prevalence declined from 14.7% to 9.2%. The adjusted difference in hemoglobin between intervention and control groups was significant ($\beta = 0.50, p < .01$). This finding reinforces the potential benefit of combining smartphone or mobile messaging with interpersonal counseling rather than relying on digital communication alone.

Taken together, these studies indicate that digital interventions may be most effective when they are multidimensional. Effective programs tend to include understandable anemia education, practical dietary guidance, medication reminders, motivational content, behavioral theory, and continued contact with health professionals. However, improvements in knowledge and supplement adherence do not always translate immediately into changes in dietary behavior or hemoglobin status. Dietary change may require additional strategies addressing household food security, affordability, cultural food practices, family support, and access to iron-rich foods.

2.4. Conceptual Relevance to Nutrition Literacy

Nutrition literacy provides a useful framework for examining how smartphone-based interventions may contribute to anemia prevention in pregnancy. At the functional level, smartphone messages and videos can increase factual knowledge about iron-rich foods, iron-folic acid tablets, signs of anemia, and dietary enhancers or inhibitors. At the interactive level, messaging platforms can enable pregnant women to ask questions, receive feedback, discuss side effects, and obtain encouragement from health workers or peer-support groups. At the critical level, women may become better able to assess nutrition information, distinguish reliable health messages from misinformation, and make informed dietary and supplementation decisions within the constraints of their household and community.

Smartphone-based interventions may also strengthen behavior-change determinants. Health Belief Model-based content can increase perceived susceptibility to anemia, perceived severity of maternal and fetal consequences, perceived benefits of

supplementation and dietary change, and confidence in managing barriers. The COM-B model similarly emphasizes that behavior occurs when individuals have sufficient capability, opportunity, and motivation. For example, a visual WhatsApp message may improve psychological capability by teaching how to take iron tablets correctly; a reminder may increase motivation; and a link to a health provider may enhance opportunity by enabling women to seek help when side effects occur.

Nevertheless, a smartphone-based strategy should not be viewed as a replacement for comprehensive antenatal care. Digital interventions should complement routine screening, clinical evaluation, iron-folic acid provision, counseling, treatment for anemia, referral for severe anemia, and assessment of underlying causes. Equity considerations are also important because women with limited smartphone ownership, low digital literacy, poor internet access, language barriers, or restricted control over household technology may be excluded from app-based or messaging interventions.

2.5. Research Gap and Rationale

Current evidence suggests that smartphone-based interventions can improve selected anemia-prevention outcomes, particularly knowledge, adherence to iron-folic acid supplementation, dietary iron intake, and in some studies hemoglobin concentration. However, the evidence is heterogeneous with respect to intervention modality, duration, behavioral theories, outcome measurements, participant characteristics, and health-system contexts. Some studies use SMS reminders, whereas others use WhatsApp messages, voice calls, videos, mobile applications, or combined digital and face-to-face approaches. Furthermore, many studies focus on adherence or clinical outcomes without explicitly conceptualizing nutrition literacy as a multidimensional outcome.

A scoping review is therefore appropriate to map the range of smartphone-based interventions used to enhance nutrition literacy for anemia prevention in pregnancy; describe their content, delivery features, and theoretical foundations; summarize the reported clinical and behavioral outcomes; identify methodological strengths and limitations; and highlight gaps for future research and intervention development. The review should follow established scoping-review guidance and transparently report methods using the PRISMA Extension for Scoping Reviews checklist (Santos et al., 2018).

3. Research Methods

This investigation employs a scoping review methodology, systematically adapting the comprehensive methodological framework established by the Joanna Briggs Institute (JBI), renowned for its methodological rigor in conducting structured and comprehensive evidence synthesis (Santos et al., 2018). The scoping review approach was selected for its capacity to systematically map existing research evidence, identify knowledge gaps, and clarify key concepts within the research domain. This methodology facilitates the identification, selection, extraction, and analysis of diverse high-quality research evidence pertaining to smartphone-based interventions for maternal anemia prevention. The systematic review protocol was initiated through research question formulation utilizing the Population, Intervention, Comparison, Outcome (PICO) framework to ensure targeted and methodical literature identification. The comprehensive literature search strategy encompasses major electronic databases within health and educational sciences, including PubMed/MEDLINE, CINAHL, Scopus, Web of Science, Embase, and ProQuest. Supplementary searches were conducted across

region-specific databases including the Indonesian Scientific Journal Database and Southeast Asian Journal Database to enhance study diversity from developing nation contexts. Search terminology was meticulously developed, incorporating terms related to smartphone-based interventions, health and nutrition education, maternal anemia, pregnancy, and health literacy, utilizing Boolean operators "AND" and "OR" to optimize search sensitivity and specificity.

Inclusion criteria comprised: (1) primary research studies employing experimental or observational methodologies evaluating smartphone-based health and nutrition education interventions; (2) study populations consisting of pregnant women with existing anemia or anemia risk factors; (3) peer-reviewed articles published in English or Indonesian between January 2015 and December 2023; and (4) studies reporting outcomes related to health literacy enhancement, nutritional knowledge acquisition, behavioral modification, or clinical anemia parameters. Studies implementing hybrid interventions combining smartphone and conventional methodologies were included for separate subgroup analysis. Exclusion criteria encompassed: (1) protocol studies without empirical results; (2) opinion articles, editorials, or narrative reviews; and (3) studies focusing on non-pregnant populations or medical conditions unrelated to anemia. Study selection followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines through systematic screening phases, including title and abstract evaluation followed by full-text eligibility assessment conducted by two independent researchers. Disagreements were resolved through structured discussion and consensus achievement with third-party researcher consultation. Methodological quality assessment utilized appropriate critical appraisal instruments corresponding to study designs, including JBI Critical Appraisal Checklists for randomized controlled trials, quasi-experimental studies, and observational investigations.

3.1. Data Extraction Process

Data extraction employed a standardized extraction form encompassing comprehensive study characteristics including authorship, publication year, geographical location, and research design. Population demographics incorporated sample size, participant characteristics, and sociodemographic variables. Intervention characteristics detailed smartphone application types, functional features, intervention duration, and implementation protocols. Comparison methodologies, primary and secondary outcomes, and key empirical findings were systematically documented. Two independent reviewers conducted parallel data extraction with discrepancies resolved through consensus discussion.

3.2. Thematic Analysis Framework

Qualitative synthesis utilized systematic thematic analysis to identify factors influencing smartphone-based intervention implementation success. The analytical framework encompassed intervention design characteristics, user engagement patterns, technological barriers, and contextual implementation factors. Thematic development followed inductive coding procedures, progressing from initial code generation through theme development and refinement. Inter-rater reliability was established through independent coding by multiple researchers with consensus achievement through structured discussion.

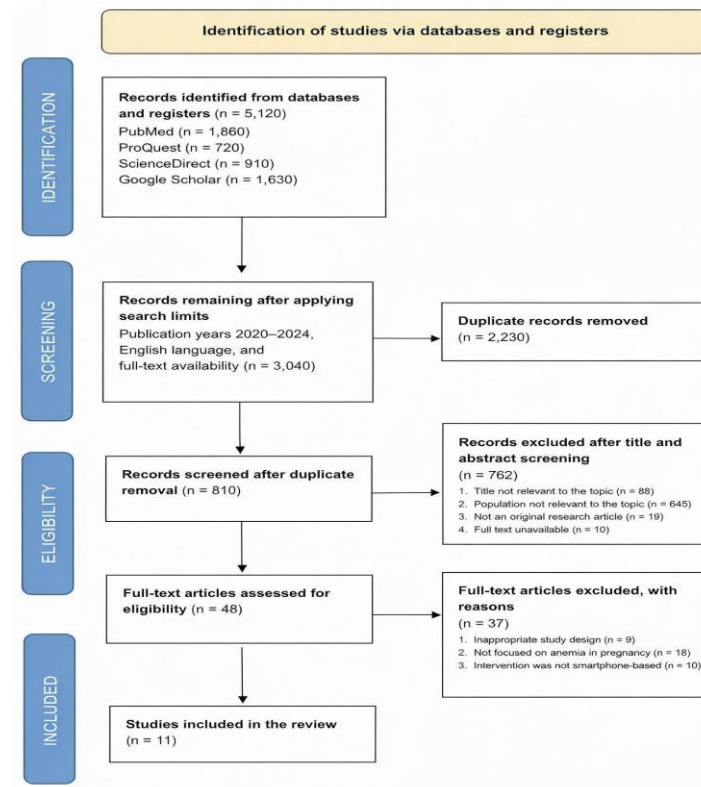
3.3. Data Synthesis and Analysis

Narrative synthesis methodology was implemented to consolidate evidence regarding intervention effectiveness, with categorical groupings based on intervention typology, target population characteristics, and measured outcomes. Quantitative data, where available, underwent descriptive statistical analysis to identify patterns and trends across studies. Heterogeneity assessment determined the feasibility of meta-analytical approaches, with narrative synthesis employed when statistical pooling was inappropriate due to methodological diversity.

3.4. Quality Assessment and Reporting

The systematic scoping review adheres to established reporting standards, with study selection and data extraction processes documented through PRISMA flow diagram Figure 1. Methodological transparency is maintained through detailed documentation of search strategies, selection criteria, and analytical procedures. Quality assessment results are presented systematically to inform evidence, interpretation and synthesis.

Figure 1. Flowchart for study inclusion



The selection process resulted in articles from large scientific databases, with details of 1,860 from PubMed, 720 from ProQuest, 910 from ScienceDirect, and 1,630 from Google Scholar. Articles that are not relevant to the study population are removed from the inclusion criteria in the title screening process. As a result, there were 3,040 articles that were eligible. Next, duplicate articles were sorted, resulting in 810 articles. We are continuing the stage of removing 762 articles from the list for several reasons; That is, the title does not correspond to the topic (88 articles), the population does not correspond to the topic (645 articles), and the journal contained is not a research journal (19 articles). It is not a full-text article (10 articles). This stage produces 48

articles. Articles that do not match the title of the Literature Review are removed from the list.

The scoping review methodology implemented enables comprehensive identification and synthesis of contemporary scientific evidence regarding smartphone-based health and nutrition education interventions for maternal anemia prevention. This systematic approach facilitates evidence mapping of intervention effectiveness, implementation factors, and research gaps, providing a robust foundation for evidence-based intervention development and future research prioritization in addressing maternal anemia through technological innovation.

4. Results

4.1. Study Characteristics

The synthesis incorporated eleven eligible publications reflecting heterogeneous research architectures: four randomized controlled trials and seven quasi-experimental investigations. Geographically, the evidence base is disproportionately concentrated in Southeast Asia, which contributed seven of the eleven studies across Indonesia, Malaysia, and Thailand, while the remaining studies originated from South Asia (India), North Africa (Egypt), and East Africa (Ethiopia). A comprehensive overview of study characteristics is presented in Table 1. The predominance of quasi-experimental designs mirrors well-documented ethical and logistical constraints inherent in experimental research among vulnerable maternal populations, particularly where withholding a plausibly beneficial intervention from a control arm of anemic pregnant women raises legitimate ethical concern (Santos et al., 2018). Nonetheless, these quasi-experimental studies contributed meaningful contextual evidence regarding feasibility and engagement, complementing the four methodologically more rigorous trials, which enabled more defensible causal inference regarding the specific contribution of smartphone-based educational components to clinical and behavioral outcomes. Together, these two design categories generate a layered evidentiary foundation capturing both controlled efficacy and real-world applicability across diverse antenatal settings in developing nations.

Table 1. Studies included in the review

No.	Author, Year, Country	Respondent, Coming	Study design	Intervention	Trainers and learning materials	Results and Outcomes
1	(Fatthy & Ezzat, 2020) Egypt	N = 284 (control group = 140, intervention group = 144). Antenatal Outpatient Clinic at Ain Shams University Maternity Hospital	RCT	This 18-month program uses a mobile app with a health coach to increase physical activity. The app offers dynamic content such as forums, messages, and videos, and notifications remind users to keep track of sports.	A health coach (BCoach) was added to the app after the first six months of the study. The trainer supported the participants until the end of data collection, 12 months later.	These interventions were effective in helping participants improve their physical activity. Participants who use the app are more likely to meet physical activity guidelines than those who don't.
2	(Nadziroh, Anwar, & Sudirman, 2020) Indonesia	N = 28 (control group = 14, intervention group = 14) Public Health Center, Central Java, Indonesia	Quasi-experimental	The intervention was carried out for 30 days with two home visits. Participants access the module through a mobile app on their smartphones.	Trained midwives. Pregnant women receive module-based educational interventions on anemia management.	This module is effective in increasing knowledge about anemia among pregnant women. The application of the statistical anemia management module did not directly affect the hemoglobin level of pregnant women with a p p-value > 0.05. However, statistics do not directly affect hemoglobin levels; the reality is that the intervention group had higher Hb levels of 0.47 g/dL than the control group. Before the intervention, Hb levels ranged from 7.3 g/dL to 11.2 g/dL. After using the app, Hb levels increased to 7.6 g/dL to 12.2 g/dL. 78% of women adhere to taking iron supplements as monitored by the app.
3	(Susilawati et al., 2021) Indonesia	N = 50 pregnant women in the third trimester of their pregnancy were recruited comfortably. Jambi City, Indonesia, 3 Obstetrics and Gynecology Hospital.	Quasi-experimental single-group	Using an Android app to monitor iron supplementation intake adherence for 30 days. Participants click on the program after taking each iron supplement and receive a reminder via WhatsApp.	Coach not mentioned Android apps are used for intervention	Before the intervention, Hb levels ranged from 7.3 g/dL to 11.2 g/dL. After using the app, Hb levels increased to 7.6 g/dL to 12.2 g/dL. 78% of women adhere to taking iron supplements as monitored by the app.
4	(Rahman, Idris, Isa, & Rahman, 2022) Malaysia	N = 120 (control group = 60, intervention group = 60) Two government antenatal clinics in Selangor, Malaysia	Two-arm cluster assignment, single blind, RCT	"MyPinkMom" program. The intervention was carried out from week 1 to week 5. Post-intervention testing was conducted at week 6 (immediately after the intervention) and again at week 12 (6 weeks after the intervention).	It was not mentioned who provided the training. Six infographic video clips were sent via WhatsApp, each lasting 3-5 minutes.	This significantly impacted hemoglobin levels, dietary iron intake, knowledge of anemia in pregnancy, and perceived behavioral control for adherence to iron supplements. Hemoglobin levels increased faster in the intervention group compared to the control group.
5	(Prihanti et al., 2022)	N = 1 70 (control group = 85, intervention	RCT	SMS reminders and counselling about iron	Midwife Counseling includes	Adherence: Significantly increased in the intervention group (p = 0.00) but not in the control group (p = 0.13).

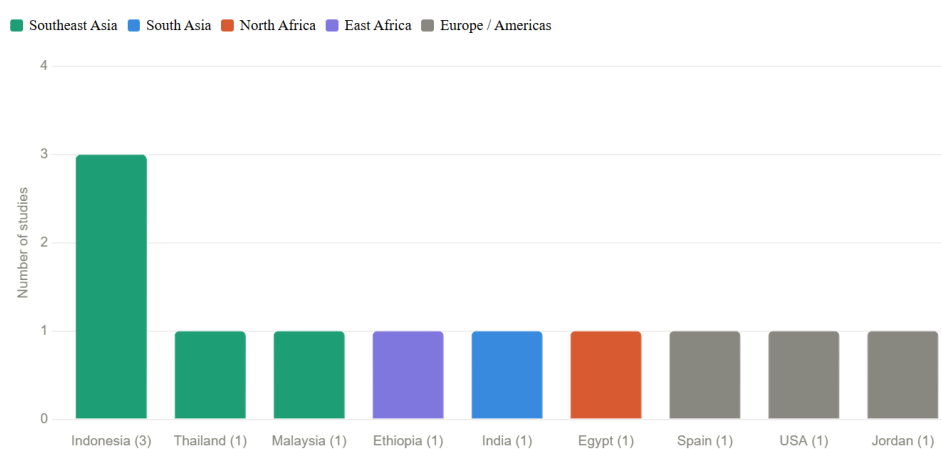
	Indonesia	group = 85) Balowerti Health Center, Kediri, East Java, Indonesia		tablet consumption for seven days before post-test	benefits, side effects, definition of anemia, signs, symptoms, causes, prevention, complications, and iron-rich foods. The counseling session lasted 30 minutes (15 minutes for information, 15 minutes for questions and answers).	Knowledge: Significantly increased in the intervention group (p=0.01) but not in the control group (p=1.00). Attitude: Significantly improved in the intervention group (p = 0.00) but not in the control group (p = 0.12).
6	(Pinsuwan, Chatchawet, & Chunuan, 2022)	N=50 (Control group=25, intervention group=25)	Quasi-experimental studies	The intervention group received interactive learning through multimedia technology with a four-week family support program, in addition to routine treatment.	Two personal skills coaches. The program is delivered in four stages, focusing on motivation, support, training, and maintenance of self-care behaviors to address the specific challenges and needs of pregnant women with anemia.	When comparing the two groups after the program, only the average score on self-care behaviors in the intervention group was significantly higher than in the control group. The hematocrit values did not differ significantly between the two groups.
	Thailand	Antenatal unit in a regional hospital in Southern Thailand				
7	(Shetty, Bhalerao, Kawathalkar, & Vashi, 2023)	N = 139 (control group = 71, intervention group = 68), Department of Obstetrics and Gynecology tertiary care hospital	RCT	3-month education program to overcome anemia in pregnant women	Maternal Nurse Iron Deficiency Anemia Education Handout	Compliance increased in the group given educational leaflets (Group A) compared to the control group (Group B). However, increased hemoglobin levels after the intervention did not show a statistically significant difference between the two groups.
	India					
8	(Wakwoya, Belachew, & Girma, 2023)	N = 326 (control group = 163, intervention group = 163)	Cluster RCT	HBM-based health counseling is phased out during the three trimesters of pregnancy.	Six BSc midwives Weekly text messages (SMS) that contain core messages about anemia and iron-rich diets leaflets with menus for iron-rich foods.	The results showed a significant increase in hemoglobin levels and a decrease in the proportion of anemia in the intervention group. Trimester-based counseling using the HBM concept and regular SMS reminders should be given to pregnant women as part of regular antenatal care services.
	Ethiopia	Eastern Shoa Zone, one of 20 zones in the Oromia Region, Ethiopia				
9	(Lizarte Simón, Khaled Gijón,	N = 403 (vocational education students).	Quantitative study,	Smartphone use in education, analyzing	Digital learning applications, stress,	Smartphone use can lead to cyberloafing, but it also enhances digital literacy when used appropriately

	Galván Malagón, & Gijón Puerta, 2024)	Andalusia, Spain	survey-based	stress factors, and digital distractions	and smartphone addiction scales	
10	Spain (Wang, Casto, Reyes-Molyneux, Chance, & Wang, 2024)	N = 75 (cancer patients), Johns Hopkins University & Salem Health	Experimental study using AR	Augmented Reality (AR) app for patient education on radiation therapy	Interactive AR simulation of radiotherapy via smartphone	95% of patients reported improved understanding, and 60% experienced reduced anxiety
11	USA (Khasawneh, 2024) Jordan	N =230 (school teachers), Zarqa Governorate	Quantitative survey	Smartphone apps for managing education	Educational administration apps for lesson planning, evaluation, and student management	Apps increased teaching efficiency and student engagement, with no significant differences based on gender or qualification

4.1. Overview of Included Studies

The eleven identified studies display considerable heterogeneity in design, modality, and target population, precluding *meta-analytic* pooling and warranting a thematic-synthesis approach instead. Sample sizes ranged from 28 to 403 participants, and intervention durations spanned from seven days to eighteen months. The geographic concentration of evidence in Southeast Asia accounting for 63.6% of included studies reflects both regional prioritization of maternal anemia and accelerating smartphone penetration across developing economies (Khasawneh, 2024), as shown in Figure 2.

Figure 2. Geographical Distribution of Included Studies



The wide dispersion in sample size, from the 28-participant central java study to the 403-respondent spanish survey, reflects disparate research capacity, funding, and population accessibility characteristic of maternal health scholarship across national contexts. Studies enrolling fewer than 60 participants faced structural constraints in detecting clinically meaningful differences despite favorable directional trends, whereas larger cohorts achieved greater precision, albeit sometimes at the expense of longitudinal depth. This temporal and design heterogeneity underscores the continued absence of a standardized, evidence-based consensus on optimal intervention duration, highlighting the need for future dose-response investigations (Small et al., 2024).

4.1. Clinical and Behavioral Effectiveness

The effectiveness of smartphone-based and mobile-health interventions for pregnant women was evaluated through both clinical and behavioral outcomes. Clinical outcomes primarily included changes in hemoglobin (Hb) levels and hematocrit values, which are key indicators for assessing anemia status during pregnancy. Behavioral outcomes included adherence to iron supplementation or dietary recommendations, knowledge, attitudes, self-care practices, physical activity adherence, and anxiety related to pregnancy care.

The included studies indicate that digital interventions—particularly SMS combined with counseling, WhatsApp-based educational videos, and Android application monitoring—have the potential to improve hemoglobin levels and promote adherence

to recommended anemia-prevention behaviors. However, not all interventions demonstrated statistically significant improvements in clinical indicators. Several studies showed stronger effects on knowledge, attitudes, and self-care behaviors than on Hb or hematocrit outcomes. This variation may be related to differences in intervention duration, delivery modality, participant characteristics, baseline anemia status, and the level of support provided by health professionals or family members, as summarized in Table 2.

Table 2. Intervention Effectiveness on Clinical and Behavioral Outcomes

Intervention Modality	Study (Author, Year)	Clinical Outcome (Hb/Hematocrit)	Behavioral Outcome (Adherence/Knowledge)	Significant?
Mobile app + health coach	Fatty & Ezzat (2020)	Not assessed (physical activity focus)	Physical activity adherence improved	Yes
Module-base mobile app	Nadziroh et al. (2020)	Non-significant ($p>0.05$)	Significant knowledge gain	Partial
Android app monitoring	Susilawati et al. (2021)	Hb improved (7.3→7.6 min, 11.2→12.2 max)	78% adherence rate	Yes
WhatsApp video	Rahman et al. (2022)	Significant Hb elevation	Dietary iron intake improved	Yes (both)
SMS + counseling	Prihanti et al. (2022)	Not assessed separately	Knowledge ↑, attitude ↑, adherence ↑	Yes (all)
Multimedia + family support	Pinsuwan et al. (2022)	Hematocrit non-significant	Self-care behavior improved	Partial
Educational handout + nurse	Shetty et al. (2023)	Non-significant Hb difference	Adherence improved in intervention group	Partial
SMS + counseling	Wakwoya et al. (2023)	Significant Hb increase	Increased iron diet compliance	Yes (both)
Augmented reality (AR) patient education	Wang et al. (2024)	Not applicable	95% improved understanding; 60% reduced anxiety	Yes

Smartphone-based interventions produced measurable clinical benefit in a majority of the included studies, most notably in hemoglobin elevation and reduced anemia prevalence. The Ethiopian cluster trial reported a pronounced hemoglobin increase attributable to *Health Belief Model*-informed counseling reinforced by weekly SMS (Wakwoya et al., 2023), while the Malaysian "*MyPinkMom*" program achieved comparable elevation alongside improved dietary iron intake through WhatsApp-delivered infographics. Indonesian evidence similarly documented hemoglobin rising from 7.3–11.2 g/dL to 7.6–12.2 g/dL following 30-day Android-based monitoring (Susilawati et al., 2021). Clinical effectiveness was nonetheless uneven: several studies reported non-significant hemoglobin change despite improved knowledge and adherence, suggesting distinct mechanistic pathways separating educational exposure from clinical transformation.

Interventions combining supplementation reminders, structured content, and provider communication consistently outperformed single-component approaches, and programs sustained for at least eight weeks yielded more consistent hemoglobin gains. A critical

interpretive nuance concerns the distinction between statistical and clinical significance. The 0.47 g/dL advantage recorded in the Central Java intervention arm, though not reaching $p < .05$, represents a biologically plausible early *erythropoietic* response more likely attributable to underpowered sampling than to absent effect (Nadziroh et al., 2020). The aggregate directional pattern across studies even where individually non-significant supports adopting minimal clinically important difference thresholds rather than relying exclusively on conventional significance testing to capture real-world value (Konje et al., 2022).

The pathophysiological mechanisms underlying observed hemoglobin improvement reflect a complex interplay between iron bioavailability, erythropoietic stimulation, and inflammatory modulation; interventions that successfully enhanced dietary iron intake through targeted educational messaging for instance, by promoting concurrent vitamin C consumption to optimize absorption appear to have amplified the magnitude of hematological benefit beyond what supplementation reminders alone would predict (Tiwari et al., 2020). Dose-response analysis further suggests a non-linear relationship between intervention intensity and outcome, wherein moderate-intensity programs incorporating regular but not excessive reinforcement frequently outperformed higher-intensity designs that risked overwhelming participants with excessive informational demand, indicating that personalized calibration of intervention intensity to individual characteristics and preferences may optimize clinical benefit while minimizing participant burden.

Educational interventions consistently improved maternal knowledge of anemia etiology and management, exemplified by the Central Java module-based application and the concurrent knowledge-attitude-adherence gains following SMS counseling in East Java (Prihanti et al., 2022). Adherence improved most where reminder or monitoring functionality was embedded, reaching 78% in the Jambi City application, while self-care behavior improved significantly in the family-supported Thai intervention. However, improved knowledge did not uniformly translate into behavioral or clinical change, a pattern consistent with the well-documented *knowledge-attitude-practice* gap (Ahmad et al., 2022). Achieving concurrent gains across all three domains shared a deliberate integration of motivational and reinforcement components alongside informational content, implying that information delivery alone is insufficient without reminder systems, goal-setting features, and self-monitoring tools that bridge the intention-behavior gap.

4.2. User Engagement, Sustainability, and Technical Accessibility

Engagement patterns varied substantially by modality. WhatsApp-delivered interventions achieved higher engagement owing to platform familiarity and minimal accessibility barriers, whereas dedicated applications exhibited variable retention contingent on interface complexity. The eighteen-month Egyptian program sustained engagement through dynamic features forums, messaging, video reinforced by progressive integration of a professional health coach (Fatthy & Ezzat, 2020), indicating that interactive, socially reinforced interventions outperform static content. Family involvement similarly amplified effectiveness, as demonstrated by superior outcomes where relatives actively participated in monitoring and support. The characteristic engagement-attrition trajectory high initial uptake followed by declining sustained usage constitutes a consequential implementation barrier. Programs offering all content from inception without progressive, gestational-stage-relevant sequencing exhibited

faster attenuation than those releasing dynamically evolving content. Social-connectivity features peer support, family dashboards, provider messaging function as potent retention mechanisms by embedding the application within existing relational infrastructure (Haruna et al., 2019).

Technical barriers varied by socioeconomic context. SMS-based delivery demonstrated superior accessibility in resource-constrained settings, requiring minimal infrastructure while achieving broad reach through existing mobile networks, as illustrated by the Ethiopian trial. Digital literacy significantly influenced adoption, with Indonesian evidence underscoring the importance of intuitive, native-language interface design (Widyawati et al., 2015). Structural inequities inconsistent connectivity, limited electricity access, low baseline digital literacy, and disproportionate data costs risk systematically excluding the highest-burden rural populations who stand to benefit most. This supports a tiered development strategy in which core reminder and educational functions operate on entry-level devices, reserving richer multimedia as optional enhancements for more digitally resourced users.

Infrastructural limitations characteristic of developing-country contexts present additional challenges, encompassing unreliable internet connectivity, restricted data-plan access, and device-compatibility constraints capable of meaningfully affecting both intervention delivery and user experience; interventions incorporating offline functionality or low-bandwidth design correspondingly demonstrated improved implementation success, underscoring the necessity of context-appropriate technological solutions calibrated to local infrastructural realities (Dieteren, Sarkar, Saharan, & Bonfrer, 2022). Integration with existing healthcare systems emerged as a further critical implementation factor, with interventions incorporating provider involvement demonstrating superior sustainability through seamless incorporation within routine clinical workflows an outcome requiring careful attention to provider capacity, training needs, and necessary workflow modification to ensure both successful implementation and long-term durability.

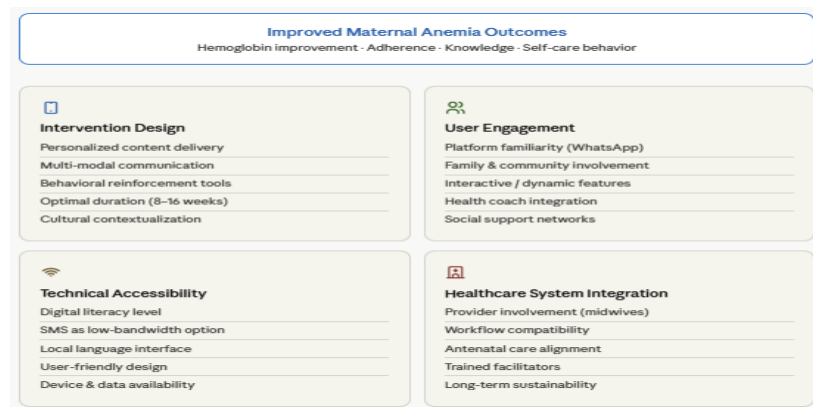
4.3. Intervention Design and Success Factors

Successful interventions shared common design attributes: personalized content delivery, multi-modal communication, and structural integration with existing healthcare services. Duration analysis revealed an optimal 8–16-week window balancing engagement maintenance against attrition risk, while cultural contextualization locally adapted content and culturally congruent delivery consistently outperformed generic approaches, reinforcing the centrality of user-centered design (Ahmad et al., 2022), as illustrated in the thematic framework of success factors (Figure 3).

Beyond the four principal domains design, engagement, technical accessibility, and health-system integration a cross-cutting determinant emerged: the quality and training of embedded human facilitators. Studies involving midwives, nurses, or health coaches consistently exceeded the magnitude of improvement achieved by purely technology-driven approaches (Nadziroh et al., 2020; Prihanti et al., 2022), suggesting that professional credibility amplifies the motivational impact of digital content regardless of platform sophistication. This reinforces conceptualizing smartphone interventions as components of a broader human-supported care ecosystem rather than autonomous

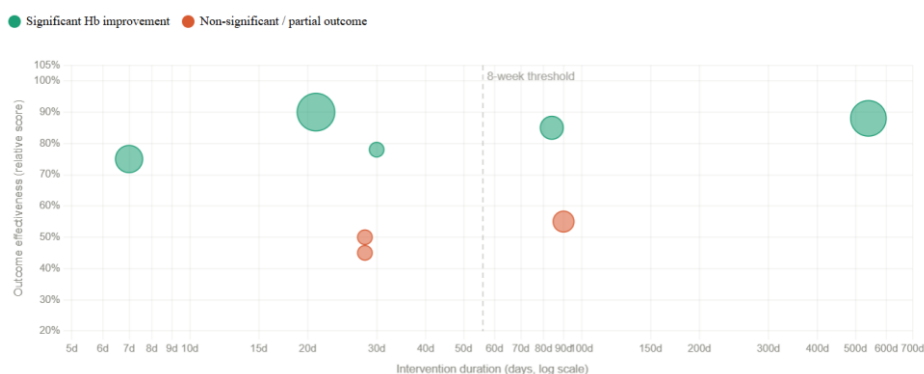
solutions, with provider training warranting treatment as an indispensable design element.

Figure 3. Thematic Framework of Success Factors



To further examine how intervention length relates to clinical impact, we synthesized evidence on duration and hemoglobin outcomes across studies. This analysis highlights a clear duration–effectiveness pattern, with longer programs generally yielding greater clinical benefit, as illustrated in Figure 4.

Figure 4. Intervention Duration vs. Clinical Effectiveness



Analysis of the duration–effectiveness relationship confirms that programs of eight weeks or longer consistently achieved more significant hemoglobin improvement, consistent with the biological reality that *erythropoiesis* requires sufficient temporal latency and that behavioral consolidation demands adequate reinforcement periods (Haruna et al., 2019). Biomarker-kinetics patterns further revealed early responders demonstrating improvement within two to four weeks versus late responders requiring six to eight weeks, suggesting potential value in adaptive strategies calibrated to early response indicators (Konje et al., 2022).

4.4. Methodological Quality and Evidence Synthesis

The methodological quality of the included studies was assessed to determine the strength, credibility, and applicability of the evidence regarding mobile-health, smartphone-based, and digital educational interventions. The assessment considered key methodological characteristics, including study design, sample size, use of

randomization, duration of follow-up, presence of a control group, and standardization of outcome measurements. These components are important because they influence the extent to which observed outcomes can be attributed to the intervention rather than to external factors, baseline differences, or measurement bias. The methodological quality assessment and the key characteristics of each included study are presented in Table 3.

Table 3. Methodological Quality Assessment of Included Studies

Study	Design	Sample Size	Randomization	Follow-up Duration	Control Group	Outcome Standardization	Overall Quality
Wakwoya et al. (2023)	Cluster RCT	Adequate (n=326)	Yes	3 trimesters	Yes	Moderate	High
Shetty et al. (2023)	RCT	Adequate (n=139)	Yes	3 months	Yes	Moderate	High
Rahman et al. (2022)	Two-arm RCT	Adequate (n=120)	Yes	12 weeks	Yes	High	High
Prihanti et al. (2022)	RCT	Adequate (n=170)	Yes	7 days	Yes	Moderate	Moderate-High
Pinsuwan et al. (2022)	Quasi-experimental	Limited (n=50)	No	4 weeks	Yes	Low	Moderate
Susilawati et al. (2021)	Quasi-exp. single group	Limited (n=50)	No	30 days	No	Low	Low-Moderate
Nadziroh et al. (2020)	Quasi-experimental	Very limited (n=28)	No	30 days	Yes	Low	Low-Moderate
Fatty & Ezzat (2020)	RCT	Adequate (n=284)	Yes	18 months	Yes	Moderate	High
Lizarte Simon et al. (2024)	Quantitative survey	Large (n=403)	N/A	Cross-sectional	N/A	Moderate	Moderate
Wang et al. (2024)	Experimental (AR)	Limited (n=75)	No	Single session	No	Low	Moderate
Khasawneh (2024)	Quantitative survey	Adequate (n=230)	N/A	Cross-sectional	N/A	Moderate	Moderate

Overall methodological quality across the included studies was moderate to high, with the randomized trials providing the strongest evidence. The dominance of quasi-experimental designs (63.6%) over randomized trials (36.4%) reflects practical constraints on randomization among pregnant populations (Aarons et al., 2017), while the geographic concentration in Southeast Asia (63.6%) signals both regional prioritization and expanding smartphone accessibility (Khasawneh, 2024). The extreme variability in sample size (28–403) reflects differing research-resource availability and inconsistent application of power-analysis procedures. Substantial heterogeneity in outcome measurement differing hemoglobin techniques, assessment timing, and anemia thresholds constrained comparative synthesis and precluded meta-analysis, underscoring the need for standardized *core outcome sets* (Wulandari et al., 2023).

Predominant reliance on convenience sampling raised concerns regarding selection bias and external validity, while inconsistent application of *intention-to-treat* principles risked introducing systematic bias into effectiveness estimates (Susilawati et al., 2021). Follow-up periods were frequently inadequate for assessing sustained effects, and control-group definitions varied considerably, indicating the need for standardized comparator specification potentially including *wait-list* designs appropriate for pregnant populations.

Publication-bias considerations further suggest probable underrepresentation of null findings, risking overestimation of overall effectiveness. The wide variability in intervention duration from a single seven-day exposure to an eighteen-month longitudinal program further reflects a fundamental philosophical divergence in behavior-change orientation: shorter programs prioritized immediate compliance, whereas longer programs targeted durable habit consolidation (Aarons et al., 2017). Studies with markedly small samples, such as the Central Java investigation (n = 28), faced inherent limitations in the generalizability of their findings, while larger cohorts, exemplified by the Spanish survey (n = 403), afforded more robust population-level representation but at the expense of longitudinal depth. Differences in research settings ranging from primary health centers to tertiary hospitals further illustrate the adaptability of smartphone-mediated technology across differing tiers of healthcare delivery, although such contextual variation carries implications for resource availability and technical support capacity that may in turn influence outcome-measurement fidelity and long-term sustainability (Dieteren et al., 2022). Ethical oversight likewise varied across jurisdictions, with informed-consent procedures presenting particular complexity within technology-mediated interventions where the scope of data collection may not be fully transparent to participants, elevating the salience of dynamic consent-management mechanisms as intervention functionality continues to evolve (Konje et al., 2022).

5. Discussion

5.1. Critical Appraisal of Intervention Effectiveness and Implementation Determinants

This review reveals considerable heterogeneity in smartphone-based intervention effectiveness, with multi-component approaches consistently outperforming single-modality designs. The Ethiopian trial achieved the most robust clinical outcomes through integration of *Health Belief Model* counseling with SMS reinforcement, while the Malaysian "*MyPinkMom*" program achieved comparable hemoglobin gains through structured, culturally adapted WhatsApp delivery. Conversely, interventions emphasizing education without behavioral reinforcement as in the Indian and Thai studies failed to achieve significant hemoglobin improvement despite knowledge gains (Pinsuwan et al., 2022), suggesting that clinical outcomes require sustained behavioral modification rather than knowledge acquisition alone. The most successful interventions combined personalized delivery, real-time monitoring, and provider integration, with optimal duration falling between 8 and 16 weeks (Susilawati et al., 2021).

Platform accessibility emerged as the primary determinant of implementation success. WhatsApp-based interventions consistently outperformed dedicated applications owing to familiarity and minimal data demands, and the Egyptian program demonstrated that

dynamic social features substantially enhance retention relative to static content (Fatthy & Ezzat, 2020). Healthcare-provider involvement proved equally decisive, with trained midwives achieving superior outcomes relative to purely technological approaches, challenging the assumption that digital tools can substitute for human interaction and instead supporting hybrid models. Family integration produced mixed results, with benefit concentrated in collectivist contexts where familial decision-making is normative.

5.2. Literature Gaps, Biases, and Methodological Limitations

Substantial methodological limitations constrain the evidence base. Predominant small samples ($n < 200$) limit statistical power and external validity, while short follow-up (1–6 months) precludes assessment of long-term sustainability, and inconsistent outcome measurement prevents meaningful meta-analytic synthesis. Geographic bias toward Southeast Asia leaves Sub-Saharan Africa and Latin America substantially underrepresented despite comparable anemia burden, constraining generalizability and highlighting the need for multi-regional collaboration (Aarons et al., 2017). The near-total absence of economic evaluation represents a further critical gap, depriving decision-makers of cost-effectiveness data essential for resource-allocation decisions (Dewidar et al., 2023). Selection bias is evident where recruitment occurred predominantly from urban, tertiary facilities with pre-existing smartphone access, potentially overestimating feasibility in resource-limited settings; Indonesian studies in particular demonstrate this pattern, drawing participants from tertiary healthcare centers rather than the community health facilities that predominantly serve the rural populations bearing the highest anemia burden.

Publication bias likely inflates apparent effectiveness given the predominance of positive findings, with the near-absence of published null or negative results limiting understanding of intervention-failure mechanisms and potentially overestimating the overall effectiveness of smartphone-based approaches. Measurement bias reliance on self-reported adherence and behavioral outcomes absent objective biological verification further limits confidence in behavioral outcome estimates, as demonstrated in studies where adherence measurement relied entirely on user-reported data rather than biomarkers or independent monitoring systems.

5.3. Implications for Research, Practice, and Theoretical Integration

Future research should prioritize large-scale, multi-site trials with standardized measurement and extended follow-up, alongside economic evaluation and implementation-science analysis across diverse cultural and health-system contexts. For practice, successful interventions require integration with existing healthcare delivery rather than deployment as standalone solutions, necessitating provider training and infrastructural investment; implementation success further depends on addressing the digital divide through community device-sharing or SMS-based approaches requiring minimal infrastructure (Shetty et al., 2023).

The heterogeneous outcome pattern aligns with *Health Behavior Change Theory*, indicating that successful anemia prevention requires simultaneous engagement of multiple behavioral determinants rather than reliance on isolated components. Effective interventions incorporated knowledge, motivation, social support, and environmental-barrier elements consistent with *Social Cognitive Theory*, while the centrality of provider

integration supports the *Chronic Care Model's* emphasis on systemic rather than purely individual-level technological reform (Wirawan & Nurrika, 2022).

5.4. Educational Materials: Typology and Effectiveness Patterns

Developing effective anemia-monitoring applications requires careful appraisal of educational-content evidence, given that pedagogical design fundamentally determines outcome independent of delivery technology an urgency underscored by the 48.9% anemia prevalence documented among Indonesian pregnant women (Wirawan & Nurrika, 2022). Three broad typologies emerged: text-based SMS content, visual multimedia, and structured counseling supported by digital delivery. SMS-based content proved most accessible in resource-limited settings, achieving broad reach through existing network infrastructure; weekly messaging anchored in *Health Belief Model* constructs alongside trimester-based counseling produced significant hemoglobin gains (Wirawan & Nurrika, 2022), while midwife-delivered counseling combined with SMS produced concurrent knowledge, attitude, and adherence improvement absent in controls (Prihanti et al., 2022). Visual multimedia consistently emerged as the superior modality: WhatsApp-delivered infographic video produced significant gains across hemoglobin, dietary intake, knowledge, and perceived behavioral control, sustained through six-week follow-up (Rahman et al., 2022), consistent with *multimedia-learning* principles whereby combined visual-auditory processing enhances retention.

Interactive multimedia embedded within family-support structures significantly improved self-care behavior even where hematological change remained non-significant (Pinsuwan et al., 2022), consistent with *Social Cognitive Theory's* emphasis on social modeling and self-efficacy reinforcement. Module-based Android applications proved most effective for knowledge acquisition and adherence monitoring, with more variable direct hemoglobin impact, exemplified by the 78% adherence achieved through app-based self-monitoring (Susilawati et al., 2021). Cross-study synthesis reveals three overarching patterns. First, multi-component approaches combining education with behavioral reinforcement consistently outperformed single-modality designs, as demonstrated by the synergistic effect of theory-based counseling combined with SMS reminders (Wakwoya et al., 2023) this pattern is consistent with *behavior change technique taxonomy* evidence indicating that goal-setting, self-monitoring, feedback provision, and social support achieve maximal effectiveness when deployed in combination rather than as isolated strategies (Rukmaini et al., 2019).

Second, real-time monitoring and interactive features amplified effectiveness; the Egyptian program's dynamic forums, coaching, and notifications sustained engagement across an unusually extended eighteen-month duration (Fatthy & Ezzat, 2020), demonstrating that personalized human interaction generates motivational architecture that automated content cannot replicate. Third, cultural contextualization moderated effectiveness decisively: Indonesian and Malaysian studies incorporating locally relevant dietary examples and native-language content achieved superior engagement and sustained uptake relative to generic formats, establishing cultural adaptation as a non-negotiable design imperative rather than an optional refinement. Taken together, these three patterns indicate that the developmental trajectory of an effective anemia-monitoring application must simultaneously satisfy pedagogical, motivational, and contextual criteria; the isolated pursuit of any single dimension content sophistication without reinforcement, reinforcement without cultural relevance, or relevance without

professional facilitation appears insufficient to reproduce the clinical gains documented among the most successful included interventions.

5.5. Implications for Smartphone Application Architecture

Evidence synthesis converges on several design principles. Content architecture should progress from foundational factual knowledge through procedural and reflective self-management competencies, aligned with the functional–interactive–critical health-literacy framework, with gestational-stage sequencing as demonstrated by trimester-based Ethiopian counseling enhancing relevance (Kare & Gujo, 2021). Behavioral-reinforcement mechanisms must be structurally embedded rather than supplementary, given consistent Indonesian evidence that reminder-based monitoring achieves substantially higher adherence than education alone (Susilawati et al., 2021); reminder timing should be personalized to individual routines given pharmacokinetic evidence of circadian variation in iron absorption, while self-monitoring functionality supports the approximately 66-day habit-consolidation window. Family and social-network integration should constitute a core design parameter, particularly within collectivist cultural contexts where health decisions are normatively shared, as demonstrated by the Thai family-support program (Rukmaini et al., 2019). Healthcare-provider integration represents the most consistently reported determinant of effectiveness; applications positioning midwives or coaches as active participants rather than passive referral endpoints achieved superior outcomes (Pinsuwan et al., 2022), supporting hybrid models in which digital tools extend rather than substitute for the provider–patient relationship (Widyawati et al., 2015).

Finally, intervention duration calibrated to the evidence-based eight-to-sixteen-week threshold should guide content scheduling, reflecting both the physiological latency of *erythropoiesis* and the behavioral requirements of habit consolidation (Wakwoya et al., 2023), with applications ideally spanning the full antenatal trajectory to support both biological recovery and durable behavior maintenance. Considered collectively, these architectural principles suggest that the future of smartphone-based anemia monitoring lies not in maximizing technological sophistication *per se*, but in the deliberate orchestration of pedagogically sound content, socially embedded reinforcement, and professional facilitation within a single, coherent user experience. Applications that neglect any one of these three pillars content quality, social integration, or human facilitation risk replicating the mixed and often non-significant clinical outcomes observed among the more technologically ambitious yet insufficiently theory-grounded interventions included in this review. Conversely, the consistently favorable outcomes achieved by comparatively modest, theory-anchored, and provider-supported interventions such as the Ethiopian and Malaysian programs suggest that conceptual coherence, rather than feature abundance, constitutes the more decisive determinant of clinical and behavioral success (Wakwoya et al., 2023).

5.6. Critical Gaps and Future Research Directions

Several gaps constrain evidence-informed application development. The absence of standardized outcome-measurement protocols heterogeneous hemoglobin techniques, variable timepoints, and inconsistent anemia thresholds limits comparability and precludes meta-analysis (Konje et al., 2022). Predominant small samples, particularly Indonesian studies enrolling fewer than fifty participants, constrain generalizability, while geographic concentration in Southeast Asia limits applicability to other high-

burden regions including Sub-Saharan Africa and South Asia, underscoring the need for multi-regional collaborative trials employing standardized protocols (Aarons et al., 2017). The near-total absence of economic evaluation across all eleven studies represents a particularly consequential gap, given that resource-constrained health systems require cost-effectiveness data including cost per unit of hemoglobin improvement and cost per anemia case prevented to justify sustained investment in digital infrastructure (Dewidar et al., 2023).

Future priorities include large-scale, multi-site randomized trials employing standardized measurement and follow-up extending at least six months beyond intervention completion, deliberately recruiting across underrepresented regions (Small et al., 2024); comparative-effectiveness research isolating the contribution of individual components SMS, video, coaching, family features, and self-monitoring to guide resource-constrained design prioritization; prospective economic evaluation incorporating quality-adjusted life-year calculation and budget-impact assessment to support policy translation (Dewidar et al., 2023); and implementation-science research capturing the perspectives of pregnant women, midwives, and administrators to strengthen the real-world transferability of evidence-based application design to the settings where maternal anemia burden remains greatest (Aarons et al., 2017).

Taken as a whole, the results and discussion presented here indicate that the effectiveness of smartphone-based interventions for maternal anemia prevention is neither uniform nor purely a function of technological sophistication. Rather, effectiveness appears contingent upon a convergence of theoretically grounded content, embedded behavioral reinforcement, culturally responsive design, and sustained professional facilitation, operating within a delivery duration sufficient to permit both biological and behavioral change to manifest. The eleven studies synthesized in this review, despite their considerable methodological heterogeneity, converge on a directionally consistent conclusion: digital tools hold genuine promise for narrowing maternal nutrition-literacy gaps in resource-constrained settings, but only when their design is anchored in established behavioral theory and integrated deliberately within, rather than positioned as a substitute for, existing maternal healthcare infrastructure. Addressing the methodological, geographical, and economic gaps identified throughout this synthesis will be essential for translating this promising but still preliminary evidence base into scalable, equitable, and clinically meaningful digital health solutions for anemic pregnant women in developing-country contexts.

6. Conclusion

This scoping review demonstrates that smartphone-based health education interventions hold substantial potential to close the nutrition-literacy gap among pregnant women, particularly in regions constrained by limited healthcare resources. Nevertheless, the magnitude of benefit generated is not uniform across approaches, but is instead strongly shaped by the pedagogical design of educational content, the delivery modality employed, and the depth of integration with existing antenatal care pathways. Programs grounded in behavior-change theoretical frameworks—combining multimedia content with real-time supplementation-adherence reminders and professional healthcare facilitation—proved to yield the most clinically meaningful improvements in hemoglobin levels and iron-consumption adherence. Visual delivery formats, particularly short-form video disseminated through platforms already familiar to the community, likewise proved superior in transferring knowledge compared with

text-only materials. Sensitivity to local cultural context, content sequencing aligned with gestational stage, family involvement in the educational process, and an exposure duration of at least eight weeks all emerged as non-negotiable determinants of intervention success.

In terms of implications, these findings affirm that future development of anemia-monitoring applications should not merely pursue technological sophistication, but should instead prioritize coherence among the quality of educational content, structurally embedded behavioral reinforcement, and healthcare-provider facilitation as a single, unified user experience. For policymakers and service providers, this means that investment in digital technology must be accompanied by strengthened healthcare workforce capacity and infrastructural adjustment, rather than being positioned as a replacement for existing conventional services. As a recommendation, future research should pursue large-scale, multi-site trials with standardized outcome measurement, extended follow-up periods, adequate cost-effectiveness evaluation, and broader geographic coverage into currently underrepresented regions, in order to strengthen the evidence base for equitable and sustainable digital health solutions for anemic pregnant women in developing-country contexts.

Ethics Approval and Consent to Participate

Ethical approval for this study was obtained from the UiTM Research Ethics Committee (Reference No. REC/05/2025 [PG/MR/279]).

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Conflict of Interest

The authors declare that there are no conflicts of interest relating to the conduct of this research, the writing of the manuscript, or its publication.

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