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MODESTUM

Study Protocol **OPEN ACCESS**

Protocol for pre-pregnancy care mobile health app: Development, validation and usability testing with a human-centered design approach

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ABSTRACT

Despite decades of healthcare initiatives, Malaysia's maternal mortality ratio has plateaued at concerning levels, partly due to underutilized pre-pregnancy care (PPC) services. This study aims to develop, validate, and evaluate a PPC checklist mobile health (mHealth) app for Malaysian women. Using a three-phase, human-centered design (HCD), phase 1 employs a qualitative study to develop a culturally adapted PPC checklist through nominal group techniques with women (n = 8) and experts (n = 9), followed by content validation (n = 7). Phase 2 creates a prototype based on self-determination theory (SDT) and the Wheel of Sukr, integrating gamification features, and conducting face validation with users (n = 10). Phase 3 employs a cross-sectional survey to evaluate usability through the validated Malay version of the mHealth app usability questionnaire with 117 female outpatients across government clinics in Selangor. The HCD approach guides iterative development through continuous user feedback, ensuring contextual relevance, while SDT informs the design of gamification features by supporting autonomy, competence, and relatedness. Expected outcomes include a culturally validated PPC checklist prototype with good usability. This study offers a novel, theory-driven digital tool to enhance PPC service engagement and utilization in Malaysia and other similar healthcare settings.

Keywords: gamification, human-centered design, mobile applications, mobile health, preconception care, self-determination theory

INTRODUCTION

Background

Maternal mortality remains a pressing global health issue, with many countries falling short of achieving the sustainable development goal (SDG) targets related to maternal health. Although significant strides have been made in countries like Malaysia, where the maternal mortality ratio (MMR) has decreased from 540 deaths per 100,000 live births in 1950 to 26 in 2010 [1], progress has stalled in the past decade. Achieving the SDG target of reducing the MMR to 8.7 per 100,000 live births by 2030 is a considerable challenge in Malaysia [2]. One of the leading causes of maternal mortality is pre-existing maternal medical conditions, which are often left unaddressed due to a lack of early interventions. Globally, this issue is compounded by the high prevalence of unplanned pregnancies–60% of pregnancies worldwide are unplanned, and 45% of those ends in unsafe abortions [3]. These alarming figures highlight the urgent need for more effective and accessible pre-pregnancy interventions on both a national and global scale.

Pre-pregnancy care (PPC) is a critical health intervention aimed at improving maternal and perinatal outcomes by addressing health risks before conception and optimize the timing for pregnancy. PPC services offer biomedical, behavioral, and social interventions that modify risk factors, enhance the health of prospective parents, and minimize factors that might lead to adverse maternal and child health outcomes [4]. Research shows that PPC can significantly reduce maternal and perinatal mortality and morbidity, particularly for women with pre-existing health conditions like obesity, diabetes, and hypertension [5]. Despite its benefits, the global utilization of PPC services remains low. For instance, China reports a PPC uptake rate of 42%, the United States 36%, and Ethiopia 14.5% [6-8]. In Malaysia, the situation is no different, with various studies indicating low PPC utilization, especially in rural areas, ranging from 23% to 44% across different regions, such as Kedah, Perak and Kelantan [2, 9, 10].

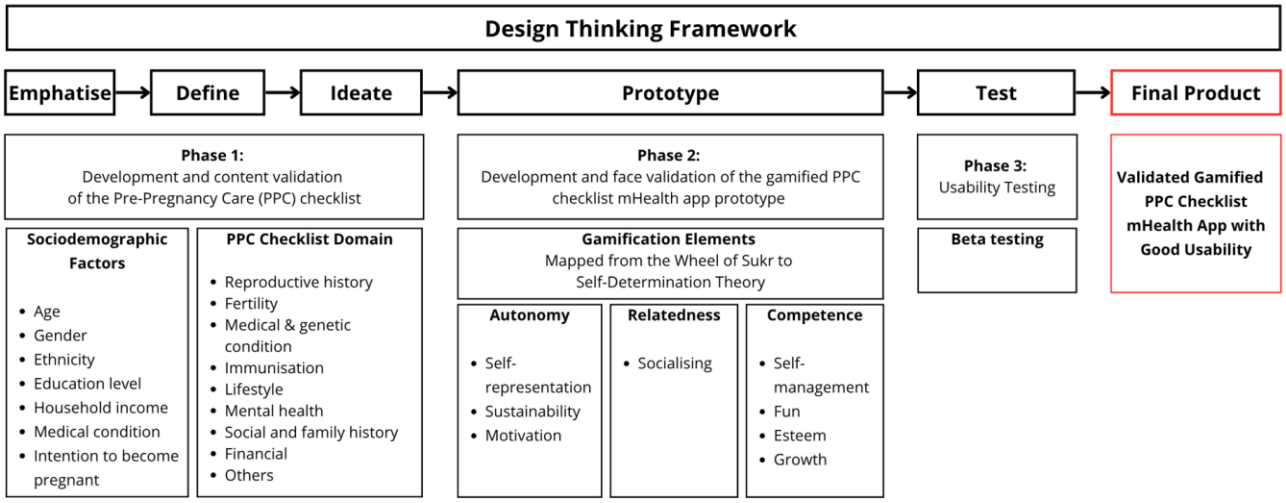

Figure 1. Conceptual framework of this study (Source: Authors' own elaboration)

Table 1. Design thinking process

Phase 1			Phase 2	Phase 3
Empathize	**Define**	**Ideate**	**Prototype**	**Test**
NGT will be conducted with reproductive-aged women (n = 7) to understand their pre-pregnancy planning needs and mHealth preferences. These sessions will focus on gathering user perspectives to inform culturally appropriate content development.	The findings will be organized and analyzed. The target end users will be defined based on the sociodemographic profile to guide tailored solution based on the core challenges in the Malaysian context.	Multidisciplinary experts (n = 9) will review NGT findings to conceptualize culturally adapted app content. The proposed solutions will undergo expert validation (n = 7) to ensure clinical appropriateness and technical usability.	Two mobile app developers will create a minimum viable product incorporating the validated PPC checklist with gamification elements based on SDT and Wheel of Sukr model. Alpha testing and face validation will be conducted with end-users (n = 10).	Beta testing will evaluate app usability among female outpatients (n = 117) using the M-MAUQ .

Multiple barriers hinder the uptake of PPC services, including a lack of awareness about the availability and benefits of these services, societal norms that promote early pregnancy following marriage, and misconceptions about PPC. Additionally, certain religious beliefs discourage the use of PPC, while accessibility issues such as long distances to healthcare facilities, long wait times, and transportation limitations further complicate access. Socioeconomic factors, including work commitments and financial constraints, also contribute to the underutilization of PPC [11, 12]. In the Malaysian context, several cultural and social factors contribute to the underutilization of PPC services. Decisions about seeking care are often shaped by patriarchal family dynamics, where reproductive choices may depend on the support or permission of husbands. Religious sensitivities surrounding reproductive health, language barriers, and limited health literacy, especially in rural communities, along with stigma associated with seeking PPC, particularly among unmarried women, further inhibit women's engagement with available services [11, 12]. A culturally adapted approach, as highlighted in the principles of culturally safe healthcare, is critical for addressing mistrust and health inequities, particularly in underserved populations [13]. These challenges necessitate innovative solutions to make PPC services more accessible and acceptable to women in Malaysia.

Opportunities to enhance communication in healthcare, streamline healthcare delivery, and improve the dissemination of medical information have paved the way for innovative solutions. Among these, one promising approach is the use of mobile health (mHealth) applications to deliver PPC services [14, 15]. While existing mHealth apps primarily focus on pregnancy care, few are designed to address the pre-pregnancy phase, and even fewer are tailored to the cultural and social context of Malaysian women, as previously discussed. To address this gap, this study proposes the development of a gamified PPC checklist mHealth application. This app will be designed with a human-centered design (HCD) approach and guided by self-determination theory (SDT) to enhance user engagement [16, 17]. By integrating gamification elements such as rewards, progress tracking, and social sharing, the app aims to overcome access barriers through a convenient mHealth platform, making these services more engaging and accessible to women in Malaysia [18].

Hence, this study is to develop, validate and test the usability of a "gamified PPC checklist mHealth app" aimed at enhancing women's motivation and engagement to utilize PPC service in Malaysia in the future.

Conceptual Framework

This study will employ a HCD approach following a structured design thinking process, as illustrated in the conceptual framework shown in **Figure 1**. This process comprises five key iterative steps: empathize, define, ideate, prototype, and test (**Table 1**). We adapted this framework from [19] to develop and validate the gamified PPC checklist mHealth app and test for its usability among female outpatients from government health clinics in Selangor. This methodology focuses on iterative testing and revisions, continuously integrating user feedback to improve the final product's usability, functionality, and relevance [16].

Research Objectives

The general objective is to develop and validate the "gamified PPC checklist" mHealth app and evaluate its

usability among female outpatients from government health clinics in Selangor. Specific objectives include:

1. to develop and validate an evidence-based, culturally adapted PPC checklist content,
2. to develop and validate the gamified PPC checklist mHealth app prototype, and
3. to evaluate the usability of the gamified PPC checklist mHealth app among female outpatients from government health clinics in Selangor.

METHOD

Study Phases

The study will be conducted in three phases:

Phase 1. Development and content validation of the PPC checklist

Phase 2. Development of the gamified PPC checklist mHealth app prototype and its face validation

Phase 3. Usability testing of the app

Phase 1. Development and content validation of the PPC checklist

Phase 1a. Development of PPC checklist

Study design and setting: The development of the PPC checklist will utilize the nominal group technique (NGT), a systematic consensus-building approach [20]. The NGT was selected for its structured methodology, which ensures equal participation from all group members. Two sequential NGT sessions will take place at a local institution in Selangor, Malaysia, selected for its centralized location and equipped facilities for qualitative research. This phase is expected to take approximately three months to complete.

Participant selection and sample size: The first session, we will recruit eight female community members from Selangor through purposive sampling. We will select participants from diverse backgrounds to ensure generalizability across social status, age, education level, and ethnicity. While the number of participants can vary, traditional groups have around four to seven participants but may have up to fourteen [21]. Inclusion criteria require participants to be Malaysian citizens, female, aged 18-49, with prior PPC service experience from local government health clinics or hospitals, and smartphone proficiency. We will exclude individuals unable to communicate independently in Malay language, as this could impede full participation in the discussion process.

The second session will involve nine multidisciplinary experts selected from a public university in Selangor, comprising eight healthcare experts and one mHealth app developer expert. The expert panel composition has been carefully determined to include: one public health specialist, two family medicine specialists, two obstetrician-gynecologist, one psychiatrist, one dietitian, one dentist and one mHealth app developer with gamification expertise. All healthcare experts must possess academic qualifications with a minimum of two years of relevant experience in PPC to ensure a meaningful contribution to the discussion. For the mHealth app developer expert, inclusion will require experience in mHealth application development with gamification expertise, and exclusion will apply to those with less than two years of relevant experience. This sample size aligns with established NGT guidelines for optimal discussion and consensus-building [21].

Data collection method: Each session will begin with a clear explanation of the NGT process and research objectives. The NGT process follows four distinct stages:

1. **Silent generation:** Participants will independently generate checklist items in response to structured prompts.
2. **Round robin:** Each participant will share their ideas one at a time while a facilitator records them on a whiteboard visible to all participants. This process will continue until all ideas are recorded.
3. **Clarification discussion:** The group will examine each item for relevance and clarity, with the facilitator ensuring focused discussion
4. **Voting and ranking:** Participants will independently rank each item based on 7-point Likert scale assessed each item (1 = not at all important, 7 = extremely important). Lastly, the scores for each idea will be summed and converted to percentage form, ranked, and presented to the group for final discussion and consensus.

The results from the community NGT session will inform the subsequent expert NGT session. The expert panel will review and refine the community-generated items through the same four-stage process. This sequential approach will ensure the final checklist incorporates both community needs and clinical expertise.

Statistical analysis plan: Qualitative input will first be generated during the NGT sessions, as described in the data collection procedure. Checklist items proposed by participants will then be quantitatively rated using a 7-point Likert scale. For each item, scores will be summed and converted into percentage values to standardize comparisons and enable ranking. Items reaching a consensus threshold of 70% or higher will be considered relevant and retained [22]. As the NGT process yields structured and quantifiable outputs, thematic coding and qualitative analysis software (e.g., NVivo) will not be used, as they are not applicable in this context.

Phase 1b. Content validation of PPC checklist

Validation process: Following the development phase, we will conduct online content validation over three months using a different panel of seven experts. These experts will be purposively selected and match the specialty distribution of Phase 1a, maintaining inclusion and exclusion criteria but consisting of different individuals to ensure independent validation. This approach will provide fresh perspectives while maintaining the necessary subject matter expertise. This sample size aligns with established content validation requirements [23].

Data collection method: We will distribute online content validation forms with clear instructions to facilitate the process. Experts will evaluate the checklist using a structured online validation instrument [23]. Each item will be rated on a 4-point Likert scale (1 = not relevant to 4 = very relevant), with space provided for qualitative feedback.

Statistical analysis plan: We will calculate the content validity index (CVI) to guide item retention and modification. In accordance with established guidelines, a CVI cut-off value of 0.83 will be applied for a panel of seven experts to indicate acceptable content validity [23]. Items below this threshold will

Table 2. Technical components and features of the PPC checklist mHealth app

Component	Specifications	Features
User iterface (visual and interactive elements through which users interact with and navigate an application, serving as the point of contact between the user and the digital system) [53].	1. Login screens 2. Home screen 3. Tools screen	1. The authentication interface will provide secure signups and login forms along with user profile management capabilities. 2. The main navigation system will include a tab bar that enables easy access to key sections including home, articles, and tools, with a welcome orientation for new users. 3. The interface will incorporate simple tools featuring progress displays, achievement badges, and appointment reminders for a user-friendly experience.
Core features	1. PPC checklist 2. Educational content 3. Appointment reminder 4. Service provider directory 5. Report generation	1. The interactive PPC tools will offer digital checklists and educational content to support pre-pregnancy planning 2. The appointment feature will include a simple scheduling tool with reminders and a list of nearby healthcare providers. 3. Users can track their progress through basic health summaries and a downloadable progress report that they can share with their healthcare providers.
Gamification	1. Progress bar 2. Badges and rewards 3. Points and leader boards 4. Social integration	1. The features will include a simple progress bar, achievement badges, and points to encourage regular app usage. 2. Social elements will allow users to optionally share achievements and view community progress, creating a supportive environment while maintaining privacy preferences.
Security & privacy	1. User authentication 2. Local data encryption 3. Privacy controls 4. Compliance with personal data protection act	1. Secure login via email and password with hashed credentials; session timeout after inactivity. 2. All user information saved on the device is protected with encryption to prevent unauthorized access. 3. Users can choose which features to enable, such as social sharing. No personal health data is shared without consent. 4. The app follows Malaysian privacy laws, including user consent and protection of personal information.

be reviewed for possible revision or removal, depending on expert feedback.

Phase 2. Development and face validation of the gamified PPC checklist mHealth app prototype

Phase 2a. Development of the gamified PPC checklist mHealth app prototype

Study design: Once the PPC checklist is validated, it will be integrated into an mHealth application prototype. The app development follows HCD principles, emphasizing iterative testing and refinement based on continuous user feedback. Two mHealth app developers with expertise in gamification will develop the intended prototype. This phase of translating specifications into a functional cross-platform minimum viable product through iterative build-test refinement is expected to take approximately four months to complete.

The development process will integrate established gamification frameworks, specifically “The Wheel of Sukr” model [24], and quality assurance metrics from the validated “adapted mobile application rating scale” [25]. To promote motivation and meaningful engagement, the eight core components of the Wheel of Sukr (self-management, self-representation, fun, growth, motivation, sustainability, socializing, and esteem) will be mapped onto the three core constructs of SDT (autonomy, competence, and relatedness).

Developmental frameworks: The mobile app will be developed using two Google frameworks–Flutter and Firebase. Flutter allows for cross-platform development from a single codebase. This saves time and cost compared to developing native apps separately for Android and iOS [26]. Flutter employs the Dart programming language, which enhances crash prevention capabilities essential for positive user experience [27]. Firebase provides backend services like user authentication (password/username or Google login) and Cloud Firestore Database [28], with customizable security rules compliant with the personal data protection act. The Google backing of both frameworks provides reliability and security.

App architecture: The app is intended to follow clean architecture principles, organizing the code according to the ‘separation of concern’ principle [29]. This approach facilitates efficient testing and ensures the app’s scalability for seamless addition of new features in future. Whenever feasible, a test-driven development (TDD) approach will be employed. TDD involves testing the codes before writing the actual app codes, helping prevent the inclusion of problematic codes that could lead to app crashes. This proactive testing method ensures a robust and stable app.

To ensure the app provides a quality user experience, **Table 2** specifies the essential technical components and their corresponding features.

Deployment: The app shall be released in multiple versions according to completion status which are:

(1) internal version–comprehensive functionality testing by development team,

(2) alpha version–controlled testing with selected users for face validation,

(3) beta version–extended user testing to eligible users for usability testing, and

(4) production release–final version incorporating all feedback.

Once the app has been released, it will be maintained and updated as needed. User error reports and feedback will be used as guidance for future updates.

Phase 2b. Face validation of the gamified PPC checklist mHealth app prototype

Validation process: Phase 2b focuses on validating the gamified PPC checklist mHealth app prototype through face validation and alpha testing. This phase is expected to take approximately one month to complete.

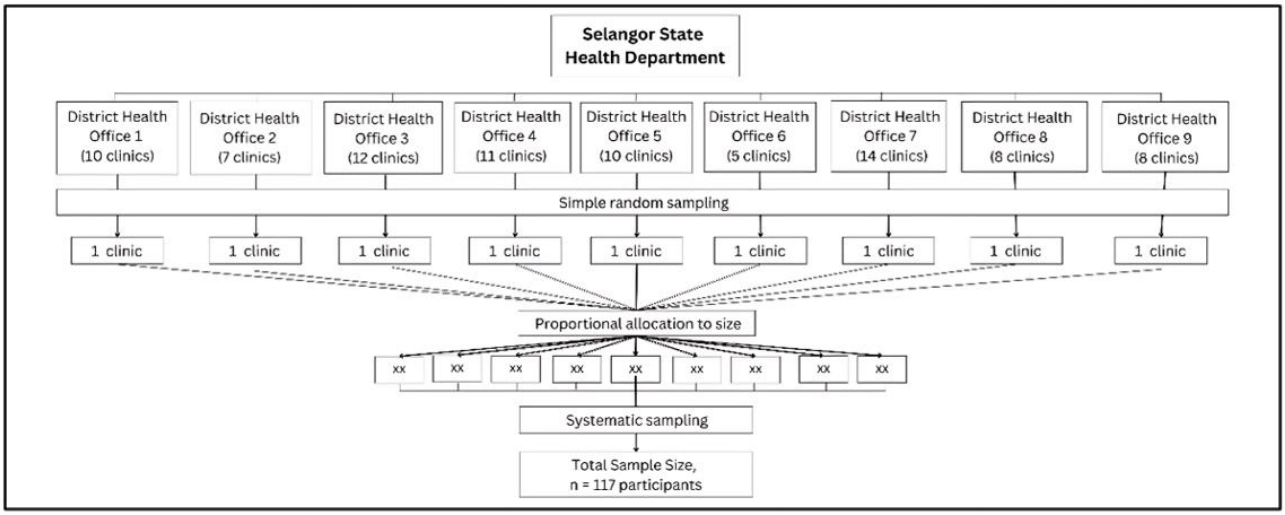

Figure 2. Sampling method of this study (Source: Authors' own elaboration)

Participant selection and sample size: Ten female community members from Selangor will be purposively sampled to participate in this phase. Previous research indicates that ten users suffice for medical app validation [30]. For inclusion in this phase, participants must be Malaysian citizens, female, aged 18-49 years, own a smartphone with internet access, and have basic knowledge of smartphone usage. Participants will be excluded if they are unable to read and understand Malay language independently, do not use Android as their mobile operating system, or have participated in Phase 1a.

Data collection method: Participants meeting our inclusion criteria will engage in a two-week testing period. We will distribute online content validation forms with clear instructions. Participants will need to download the mobile app from the Google Play Store and use it for two weeks, after which they will complete an online face validation form. The validation requires scoring according to a 4-point Likert scale (1 = not clear and not understandable to 4 = very clear and understandable) as well as feedback to improve clarity and comprehension.

Statistical analysis plan: We will calculate the face validity index (FVI) to guide item retention and modification. Based on prior research involving 10 medical app users, an FVI cut-off value of 0.83 will be applied to determine acceptable face validity. Items that fall below this threshold will be reviewed and revised accordingly, incorporating participants' qualitative feedback to enhance clarity [30].

Phase 3. Usability Testing

Study design and setting: In Phase 3, a cross-sectional survey will be employed to evaluate the usability of the app. This phase is expected to take approximately three months to complete. The study encompasses all government health clinics in Selangor, spanning nine districts under the Selangor Health State Department, totaling 85 clinics.

Participant selection and sample size: The study population will comprise female outpatients from all government health clinics in Selangor. For inclusion in this phase, participants must be Malaysian citizens, aged 18-49 years, own a smartphone with internet access, and intend to conceive within one year. Participants will be excluded if they are pregnant, unable to read and understand Malay language independently, or do not use Android as their mobile operating system.

We will employ a sample-to-item ratio of 5:1 for sample size calculation [31]. Since the instrument consist of 18 items, a total of 90 participants will be needed. With a potential 30% non-response rate, 117 participants will be invited. A 30% non-response adjustment was applied to the minimum required sample size as a general estimate to account for participant drop-out and incomplete submissions, which are common in self-administered, online surveys. This approach is consistent with standard recommendations for medical survey research, particularly in digital health contexts, where non-response can range from 20% to 50% depending on the mode of administration [32].

Sampling strategy: The sampling frame comprises female outpatients from all government health clinics in Selangor based on the yearly outpatient attendance census from each health clinic. A multistage sampling technique will be employed as illustrated in **Figure 2**.

1. **Primary stage:** Random selection of one health clinic from each of Selangor's nine district health offices
2. **Secondary stage:** Proportionate allocation of sample size across selected clinics based on annual outpatient census.
3. **Final stage:** Systematic random sampling of eligible participants from each clinic's patient registry.

Data collection method: Participants will download the app, use it for two weeks, and then complete an online, self-administered Malay validated questionnaire.

Study tool: A structured questionnaire will be used to evaluate the mobile app's usability across three key dimensions: ease of use (5 items), interface and satisfaction (7 items), and usefulness (6 items). This evaluation will utilize the Malay version of the mHealth app usability questionnaire (M-MAUQ), which consists of 18 items distributed across the three domains [33]. Each item will be rated on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree). The tool has excellent psychometric properties with a CVI of 0.983, FVI of 0.961, and Cronbach's alpha of 0.946.

The questionnaire will consist of 2 sections.

1. Sociodemographic questionnaire

2. M-MAUQ

Statistical analysis plan: Data analysis will be conducted using IBM SPSS version 25.0. Descriptive statistics will summarise categorical variables as frequencies and percentages, and continuous variables as means and standard deviations or medians and interquartile ranges, depending on distribution.

Usability testing will generate quantitative data through the M-MAUQ. The total usability score will be calculated as the sum of the 18 item scores, with a maximum possible score of 126. A total score of 72 or above will indicate good usability. Additionally, mean item scores of 4 or higher in each domain will reflect good domain-level usability [33]. Independent t-tests and one-way ANOVA will compare usability scores between groups. Non-parametric alternatives (Mann-Whitney U and Kruskal-Wallis tests) will be used if assumptions for parametric tests are violated. Statistical significance will be set at $p < 0.05$.

Methods of Data Management

We will employ a systematic data cleaning using Excel before transferring to IBM SPSS version 25.0 for analysis. All data will remain password-protected with access restricted to the primary research team. We will implement strict confidentiality measures throughout the study. Database will be backed up regularly and stored via multiple secured locations including pen drive. Upon study completion, we will deactivate the Google Forms link and schedule data for deletion five years after final publication, in accordance with institutional data retention policies.

EXPECTED RESULTS

Phase 1

The NGT discussions will likely generate several key topics for the PPC checklist including:

1. risk screening adapted from the perinatal care manual [34],
2. nutrition assessment adapted from the FIGO nutrition checklist [35],
3. physical activity evaluation adapted from the Malay international physical activity questionnaire [36],
4. social and family history documentation adapted from the perinatal care manual [34],
5. immunization status adapted from the perinatal care manual [34],
6. fertility awareness adapted from pregnancy planner [37],
7. mental health screening adapted from the perinatal care manual [34],
8. financial preparation guideline adapted from “7-point financial checklist for new parents” [38], and
9. additional components that will align with current pregnancy planning best practices [37].

It is anticipated that most checklist items will achieve a CVI greater than 0.8, indicating excellent content validity [23].

Phase 2

The development phase will produce a mobile app prototype in Malay language that is user-friendly, culturally appropriate for Malaysian women, and available in the Android Google Play Store with free access for all users.

Phase 3

The gamified PPC checklist mHealth application is anticipated to demonstrate good overall usability, as assessed using the M-MAUQ. It is expected that the total usability score will meet or exceed the threshold of 72, indicating a positive user experience. Furthermore, each of the three usability domains–ease of use, usefulness, and interface and satisfaction–is projected to yield average item scores of 4 or higher, consistent with established usability standards [33].

DISCUSSION

The proposed mHealth intervention aims to address gaps in PPC service utilization among Malaysian women through the development of a user-friendly, culturally relevant mobile application. The app is designed to leverage the growing penetration of mobile technology in low- and middle-income countries to provide health education, reminders, and support, ultimately empowering users to make informed decisions about their healthcare and access essential services aligning with global efforts to reduce maternal mortality and improve maternal and perinatal outcomes [39-41].

A key strength of this study is its systematic, human-centered approach to app development, validation and usability testing which emphasizes user engagement throughout the design and testing phases to ensure the app aligns with the needs, preferences, and contexts of its intended users [42]. Culturally tailored mHealth tools have been shown to improve user acceptability, trust, and engagement, particularly in settings where sociocultural beliefs strongly influence health behaviors [43]. Moreover, the study’s emphasis on cultural adaptation and HCD sets it apart from generic mHealth interventions, increasing its potential for adoption and impact [44-46].

Recent evidence highlights that the failure of many mHealth systems stems from limited attention to users’ sociocultural context during design. Culturally grounded approaches such as HCD are essential for fostering user engagement, particularly in diverse populations, as they integrate users’ values, norms, and lived experiences into the design process, moving beyond techno-centric frameworks that often overlook social realities [47]. Successful applications of HCD in mHealth include the development of culturally responsive reproductive health tools for refugee and migrant women, and large-scale mobile communication programs that addressed gender norms, literacy barriers, and digital access inequities in low-resource settings [43, 48]. These examples highlight the relevance and effectiveness of our chosen approach. Building on this foundation, the present study adopts an iterative process that incorporates end-user feedback at each stage of development.

This study’s iterative process will involve rigorous content development using NGT to integrate insights from end-users and experts into the PPC checklist. Subsequent steps will involve content and face validation to ensure the app’s

relevance. Usability testing will employ the M-MAUQ to evaluate factors such as ease of use, navigation, interface design, and overall user satisfaction. This approach is critical to addressing potential challenges posed by varying levels of digital literacy among users. Feedback from initial testing will guide further refinements, ensuring that the app effectively meets the needs and expectations of its target audience.

The integration of gamification elements, guided by SDT, represents a novel approach to promoting sustained user engagement and behavior change. By addressing core psychological needs for autonomy, competence, and relatedness, users are able to take control of their health decisions (autonomy), offering feedback and challenges to build confidence (competence), and fostering a sense of community (relatedness), the app supports sustained engagement and behavior change [49]. Evidence supports gamified health applications as effective tools for sustaining user engagement, showing significant increases in adherence to health recommendations [18]. These features, combined with a culturally tailored approach, position the app as a novel tool to meet the specific needs of Malaysian women, addressing critical gaps in the availability of localized digital health solutions.

While the primary focus of this study is on development and validation, some key challenges and limitations have been identified. Ensuring usability across a wide demographic, given varying levels of digital literacy, will be crucial. Additionally, the focus on the Selangor Region may limit the generalizability of the findings to other parts of Malaysia, where access to digital health tools and literacy levels could differ. As the app expands, however, challenges related to data privacy, security, and infrastructure must be addressed to ensure scalability and adoption.

Future research should prioritize evaluating the app's effectiveness through rigorous randomized controlled trials, as recent meta-analyses of similar interventions in Asian contexts have highlighted the need for robust evidence to support wider implementation [50]. Exploring the potential for integration with existing healthcare systems could also enhance the app's utility in clinical settings, improving patient-provider communication and access to maternal health resources [51]. Lessons from physician-led social media advocacy underscore the value of strategic communication frameworks, which can be adapted for digital healthcare tools like mHealth applications [52]. Additionally, investigating adaptations for different cultural and language contexts could extend the app's reach to underserved populations, addressing documented disparities in maternal health resource access [53].

CONCLUSION

In conclusion, the proposed mHealth intervention represents a promising approach to increasing PPC service **utilization** among Malaysian women. The study's systematic, human-**centered** development process, grounded in a theory-driven framework and incorporating gamification elements position the app as a novel and potentially impactful tool for addressing critical gaps in maternal healthcare. By building on this foundational work and addressing the identified challenges, future research can further strengthen the evidence base and support the wider implementation of this intervention, ultimately contributing to improved maternal and perinatal outcomes.

Author contributions: NDSMR: oversaw conceptualisation, research strategy, study design, and primary writing; **NNA:** contributed to conceptualisation, research strategy, study design, and writing; & **SD & MSAS:** contributed to research strategy, study design, and writing. All authors have agreed with the results and conclusions.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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