Examining the Social Aspects of Pregnancy Tracking Applications

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Pregnancy is a significant but stressful life transition, requiring effort from multiple stakeholders including expectant parents, family members, and friends to navigate. Existing work has primarily focused on understanding and supporting the technology use of pregnant people, neglecting other stakeholders' needs and participation. We therefore consider how pregnancy tracking apps both improve and interfere with the reconfiguration of social relationships caused by pregnancy, drawing on insights from family sociology to examine how these relationships evolve over pregnancy and the transition to parenthood. We reviewed the features of 20 pregnancy tracking apps, and analyzed 4,709 public reviews of them, finding that stakeholders used apps to bond with one another around the excitement of pregnancy, build a prenatal relationship with the fetus, and co-manage pregnancy-related logistical tasks. We find that not accounting for fetal demographics and users' identities, along with socio-cultural norms around gender and parenting roles, often inhibit these collaborative practices. We therefore suggest designing collaborative pregnancy tracking technology that considers both inclusiveness and specificity regarding stakeholders' different roles and relationships to pregnancy.

CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**; Empirical studies in HCI.

Additional Key Words and Phrases: Pregnancy tracking, Personal informatics, Self-tracking, Women's health

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1 INTRODUCTION

Pregnancy is a complex life event that reconfigures and changes the lives and relationships of many people including the pregnant person, non-pregnant partners, family members, siblings, and friends. Pregnancy and the arrival of a newborn are often regarded as a "crisis" for a family since it causes dramatic changes to expectant parents' relationships and roles [21, 34, 60]. Social support therefore becomes crucial for expectant parents to successfully navigate a pregnancy, a significant but stressful life transition period [81, 94]. However, the challenges of pregnancy also often result in changes in social relationships, such as reduced contact with family members and friends. These challenges can impact expectant parents' ability to get necessary support [10, 25, 28, 99], which

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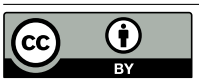

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negatively affects new parents and infants' health & wellbeing [10, 23, 87]. For example, a lack of social support from families and peers can lead a pregnant person to experience poor mental health and high-risk pregnancy behaviors [43, 46, 81].

To cope with pregnancy's complexity and stress, many pregnant persons therefore utilize pregnancy tracking technology, typically apps, to monitor a variety of pregnancy-relevant data (e.g., weight, food, physical activity, blood pressure, mood, belly growth, fetus movement, fetus kicks, and doctor appointments) and interact with others on app's internal social platforms. These apps additionally offer informational support, such as articles and video tutorials about pregnancy and labor relevant knowledge. There is a history of HCI work on understanding and designing pregnancy tracking technology, particularly on supporting healthy pregnancy outcomes for the pregnant parent and the baby. For example, designs have been proposed to monitor fetal growth [12, 50] and pregnant persons' health & wellness (e.g., daily diet, physical activity, and mental wellbeing) [27, 35, 71, 75]. Pregnant people often seek out informational advice and emotional support from others during the pregnancy [43].

However, the bulk of this work has primarily focused on understanding and supporting technology use for a small group of the stakeholders involved in the life transition around pregnancy. Current studies often regard non-pregnant stakeholders (e.g., non-pregnant partners, family members, and friends) as passive recipients of shared data rather than active trackers [14, 50], while in practice they often co-track with pregnant women and there have been a few pregnancy tracking apps explicitly designed for dad-to-bes in the market [45]. Peyton et al. [74–76] also critiqued that existing pregnancy apps often ignored the crucial role of non-pregnant partners.

We therefore consider how pregnancy tracking apps improve and interfere with the reconfiguration of social relationships, drawing on insights from family sociology on how these relationships typically evolve over pregnancy and the transition to parenthood. Understanding the design of current pregnancy tracking apps surfaces how society imagines different stakeholders like non-pregnant partners, friends, and family members will participate in pregnancy and childcare. Further eliciting how people use and experience pregnancy tracking apps to promote social interactions, as well as how these apps detract from social interactions, can offer guidance towards designing pregnancy technology which better supports people's social surroundings. We answer the research questions:

- RQ1: What are different stakeholders' (pregnant people, non-pregnant partners, family members, and friends) social goals and practices when using pregnancy tracking apps?
- RQ2: How do existing pregnancy tracking apps support and inhibit different social goals and practices?

We analyzed 20 pregnancy tracking apps and 4,709 public reviews of them, finding that pregnancy tracking apps are used by various stakeholders while apps are often designed with a specific type of stakeholder in mind. While apps are primarily designed for self-tracking practices, stakeholders utilize pregnancy tracking apps to bond with others, build a prenatal relationship with the fetus(es), co-manage pregnancy or labor relevant logistics, and seek peer support. We also find that socio-cultural factors, such as gender norms, parenting roles, and stereotyped perceptions towards pregnant persons, often inhibit users from achieving social goals or practices. For example, social expectations of parenting roles result in fewer pregnancy tracking apps designed for non-pregnant partners than pregnant persons and these apps often contain less useful features and information than counterpart apps. We suggest designing pregnancy tracking technology towards a more collective experience which supports a full pregnancy support team, having a balance between inclusiveness, which does not presume stakeholders' identities and their relationship to pregnancy, and stakeholders' specific needs based on their roles in pregnancy.

We contribute:

- An empirical understanding of stakeholders' social goals and practices around pregnancy, informed by experiences described in app store reviews for popular pregnancy tracking apps. We find that stakeholders' experiences follow behaviors described in family sociology, using pregnancy tracking apps to bond with other people, build a prenatal relationship with the fetus, and co-manage pregnancy and labor relevant tasks. Stakeholders who are not themselves pregnant often use pregnancy tracking technology not explicitly designed for them to be a part of the pregnancy experience.
- An empirical understanding of how apps support and inhibit stakeholders' social goals and practices based on user reviews and feature analysis of popular apps. Results suggest that apps are able to support some of people's social goals or practices through features like monitoring fetal growth, diet and weight tracking, and information about pregnancy stages. However, apps' lack of inclusiveness and encoding of socio-cultural norms around parental gender and race, body image issues, and stereotyped perceptions of parenting roles often negatively influence people's ability to use these apps to achieve social goals.
- Recommendations for designing pregnancy tracking technology to support collective participation in the pregnancy journey. We discuss the tensions between being agnostic to a stakeholder's identity and role in pregnancy and the ability to provide advice and features specific to their role as a pregnant person, partner, grandparent, or other social connection. We also suggest opportunities for providing greater support for non-parent stakeholders and improving designs of apps explicitly designed for non-pregnant partners.

2 RELATED WORK

2.1 How Pregnancy and the Arrival of a Newborn Impact Social Relationships

In family sociology, a family is perceived as a small social system where adding or removing members forces a reorganization of roles, statuses, values, and needs within the system [60]. Therefore, some scholars argue that pregnancy and the arrival of a newborn presents a "crisis" in the family system since it changes expectant parents' social relationships and brings anxiety and stress to expectant parents [21, 34, 60]. While many prior studies focus on the negative aspects of pregnancy and having a new child, some scholars emphasize pregnancy's positive aspects, such as the gratification of having a new member and positive changes to partnerships [60, 84]. The experience of individual parents going through pregnancy is highly subjective and nuanced, but family sociology offers a framework for considering how pregnancy and the arrival of a child reconfigure social relationships.

Pregnancy is a significant but stressful life transition period, and social support from family members, friends, and other people is vital for expectant parents to successfully cope with difficult life transitions [81, 94]. Prior studies show that receiving social support during pregnancy leads to improved birth outcomes (e.g., smooth labor progress and healthy babies) [19], helps reduce postpartum depression [10, 23, 87], and benefits postnatal parent-child interaction which is important for developing children's health & wellness [10]. Due to pregnancy and childbirth's influences on social relationships, expectant and new parents' social support needs may be affected, which can correspondingly impact parents' and infants' health & wellness.

Overall, pregnancy and the arrival of a newborn child mainly change four types of social relationships: (1) between expectant parents and the fetus, (2) partnership between the expectant parents, (3) kinships between the parents and other family members, and (4) friendships with other social connections [10, 21, 22, 55, 60, 79, 99]. Individuals have unique social relationships, so in

many cases only some will be relevant (e.g., single parents, greater or fewer friends, more or fewer grandparents, more or fewer siblings, multiple children born simultaneously).

Parents often begin developing relationships with their infants before their newborn children's birth. The parental-fetal relationship is largely a unidirectional interaction between expectant parents and fetuses, associated with expectant parents' cognitive and emotional capabilities to conceptualize the unborn child and influenced by their situated socio-cultural contexts [22, 79]. Viewing ultrasound images, attending screening procedures, and feeling fetal movement and position all help form and enhance expectant parents' relationship with fetuses [22, 47]. The strength of the parental-fetal relationship is positively associated with various individual-interpersonal factors, such as expectant parents' emotional health & wellbeing [22], the relationship between partners [88], and the social support people receive [22, 79]. In addition, pregnant people often have more attachment to their fetuses than their non-pregnant partners since non-pregnant partners do not physically experience pregnancy [68, 86, 90]. Ultrasound experiences are especially important for expectant fathers to make them feel the fetus is "real" [88]. Building parental-fetal relationships benefits both expectant parents as well as the infants after childbirth. For example, the level of parent-infant bonding influences children's psychological and physiological development [22, 88], and good maternal-fetal relationships can improve expectant mothers' self-care and health behaviors which help reduce adverse pregnancy outcomes [22].

As for partnership between expecting parents, pregnancy often results in a short period of high satisfaction between partners due to the joy of growing a new life, and it generally decreases after childbirth [99]. However, many studies find that having a new baby, especially the first child, negatively affects couples' relationships [10, 21, 55, 60]. LeMasters [60] further argues that the arrival of a first child can change relatively stable and satisfactory dyadic relationships between partners to more volatile triangle group relationships. However, Kluwer [55] suggests some partners report no change and even improvement in their relationship with one another after childbirth, depending on how couple's interactions with one another and efforts to support one another evolve during and after pregnancy. Tasks around pregnancy and childcare introduce more logistical demands for partners. In heterosexual couples, articles from the 1980's suggest that pregnancy often results in partners doing cross-gender household tasks than previously [21, 42], and fall back to traditional gender roles when dividing household labor due to the burden of childcare [21, 42]. But recent years have seen greater convergence in gender roles in parents, as well as increases in same-sex partners having children [5]. While same-sex partners tend to have equal divisions in household labor [89], Moore [69] finds that the biological mother in lesbian families usually undertakes more household chores to exert control over family organization, such as childrearing and finances. Parents also tend to have less intimate time and give less attention to their partners than nonparents, which negatively affects satisfaction between couples [55, 55, 99].

Family members are often primary sources of social support for expectant and new parents, and couples' contact with family members often increases after childbirth [10]. For some families, grandparents or other family members provide support ranging from emotional to logistical, from celebrating pregnancy and childbirth to sharing pregnancy and childrearing experiences to gifting to helping with housework (e.g., cooking, chores, and child care) [25, 28]. The 2018 American Community Survey found more than 2.5 million grandparents were the primary caregiver for a grandchild [13]. However, discrepancies in expectations and goals around pregnancy and child-rearing between expectant parents and their parents can hurt the parent-grandparent relationship [28]. Pregnancy also influences the relationship between parents and their other children. For example, studies find parents that the reduced attention and care to a firstborn during a later pregnancy often causes the child's anxiety and introduces negative behavioral changes, which in turn inhibits how well the firstborn adapts to the arrival of their siblings [44, 56].

New parents often have less contact with their friends, but increased communication with other people with young children [10, 99]. Studies find that there are often gender differences in how pregnancy and childbirth affect parents' social network sizes and types of received social support. Fathers' social networks with friends and colleagues are less likely to be affected than mothers [94]. However, mothers tend to get more social support from their friends with children and people from antenatal and postanal groups, while fathers tend to lack social support from friends and colleagues [25]. In addition, fathers are often excluded from prepartum appointments and classes [25].

In addition, culture and society often decide who is involved in pregnancy and how people participate, often following narrow gendered norms and expectations of family roles to assign exclusive capability and responsibility for pregnancy to cisgender women [26, 33, 38, 48, 97]. Widarsson et al. [97] found expectant parents valued each other's involvement, but expectant fathers often encountered barriers to participation due to gendered norms around pregnancy, inadequate communication with expectant mothers, and a lack of support from prenatal care which mainly focuses on pregnant people and fetuses. Institutional barriers intertwined with socio-cultural norms around pregnancy further constrain trans parents' abilities to reproduce [26]. For example, gender norms that equate pregnancy with cisgender women, viewing masculine gender identity and pregnancy as incompatible, and some countries' policies requiring sterilization when undergoing gender transformation can create social and legal obstacles to transgender men's pregnancy, limiting their access to receiving antenatal care [33, 48].

2.2 Women's Health and Pregnancy-Related Research in HCI

Recent years have seen a growing number of HCI and CSCW works calling attention to women's health. These works often touch on topics around reproductive, maternal or menstrual health, self-tracking around women's bodies, and intimate care [2, 16, 31, 38, 43]. In addition, researchers often emphasize the need to examine women's health within a broad social and socio-cultural context, since women's lived experiences are heavily shaped by how society perceives women and their bodies [2]. Many cultures often regard discussion of women's bodies as taboo, and do not openly discuss aspects of women's health conditions, creating barriers for women to seek interpersonal, technological, and institutional support [2, 16, 58]. For example, negative societal attitudes towards women's aging make them worry about their relationship with partners [58]. Social norms often constitute what "women's health" means, shaping how technology is designed as well as whom the technology is designed for [54]. For example, Epstein et al.[31] found menstrual tracking apps were predominantly assumed to be designed for women and often contained stereotyped feminine elements, such as pink themes or flower images. Further, women's health data often encompasses a variety of intimate and sensitive data that can reveal things beyond individual-level health, such as their sexual orientation, political views, social relationships, and even data of others (e.g., partners, children, and fetuses) [3, 67]. This has led to critiques of the privacy and data security practices of women's health technology, where many apps collect users' data and share it without user consent or awareness [1, 67]. For example, there is concern that anti-abortion campaigns have or could mine women's menstrual data to flag possible abortions in places where abortion is illegal [1, 3, 67].

Existing HCI works have explored various aspects of pregnancy, such as getting pregnant [38, 49, 67], managing pregnant women's health & wellness for successful pregnancy [12, 27, 35, 50, 71, 74–76], information seeking [40], preventing maternal mortality [91, 92], coping with pregnant loss [7, 57, 82], seeking social support around pregnancy from social media and online communities [43], and preparing for the transition to motherhood [17, 29, 41, 81]. Some of these works illustrate how the broad social and socio-cultural context has shaped people's lived experiences with pregnancy.

For example, pregnant women who are disadvantaged socioeconomically often lack access to technology, social support, and medical resources which results in them facing undesirable pregnancy complications, such as infant mortality [14, 81]. Because medical systems often provide fetal-centric care, pregnant women often face difficulties in getting support from healthcare providers for their own health & wellness, motivating them to actively seek peer support from online communities [43]. Prior work has also highlighted how men who experience fertility issues experience social stigma, with online communities similarly offering spaces for support and information [73]. Peyton et al. similarly found that expectant fathers were neglected in pregnancy tracking apps since the design space primarily focuses on pregnant women and their interactions with doctors [76]. Prior work [6, 8] examining pregnancy tracking apps mainly focused on understanding how apps support or inhibit pregnant women's experiences. We expand on these works by understanding how people perceive this lack of engagement with other stakeholders, as well as analyzing apps specifically targeted at expectant fathers and how people perceive them.

Prior HCI and CSCW works on social interactions during pregnancy usually centers around expectant mothers seeking social support from family members and peers [43, 66, 81]. Comparatively less is understood about how technology could support or inhibit other types of social interactions during pregnancy, such as between partners, siblings, or even parent-fetal bonding, all of which are crucial for ensuring healthy pregnancy outcomes, positive parental-infant interaction after childbirth, and well-adjusted social dynamics following the life transition.

2.3 Social and Socio-Cultural Aspects of Self-Tracking Practices

Self-tracking devices and applications have been increasingly used in everyday life to help people collect personal data for various goals, such as self-improvement, chronic health management, social connection, instrumental recording, curiosity, and external rewards [30, 32, 61]. Though self-tracking technology often focuses on personal practices, how people use tracking technology is largely embedded in its broader social and socio-cultural context [38, 65, 83]. For example, tracked activities are often done with others for meaningful engagement, such as one's regarding walks with the partner as special activities and using technology to journal such events [65]. People often socially share tracked data to sustain tracking [18, 32, 43, 53] or co-track with other stakeholders to manage complex health conditions [11, 70]. The lived informatics model also describes some of people's social interactions during tracking, such as deciding to track in order to see others' data or share with others, getting advice from others about what tools to use, and even stopping tracking when others no longer track [32]. Lu et al. [63] recently extend this model by integrating it with people's use of social technology, showing how data transitions between tracking and social technology to help people gain self- and domain-knowledge crucial for behavior change.

Self-tracking practices are often situated in a broader context beyond interpersonal-level interactions. Some studies surface how individuals' data practices are embedded in an ecosystem containing micro-, exo-, and macro-level of societal structures, from individuals (e.g., partners, family members, friends, peers, colleagues, and healthcare providers) to institutional spaces (e.g., healthcare, workplace, industry, and educational institutions) to socio-cultural factors (e.g., economic, politic, culture's attitudes and ideologies) [38, 70]. For example, organizations such as educational institutions, workplaces, and healthcare facilities often encourage people to participate in self-tracking to enhance performance and maintain health [65]. Social-cultural norms often fundamentally shape people's perspectives towards and uses of self-tracking technology, such as why and what to track as well as how to use the technology. In a study to understand people's self-tracking practices for managing cardiac diseases in India, Bhat and Kumar find the strong gender structures in the culture resulted in female patients often being stigmatized, leading to their difficult interactions around health management with males [9].

Family informatics introduces another set of social circumstances that influence tracking dynamics. For example, some work has highlighted that when families jointly participate in tracking experiences, they are able to better understand each individual's needs and goals and make collective decisions towards health benefits [15, 78, 85]. But, tracking in family settings often creates invisible work for certain family members, often mothers, to manage family tracking systems [52, 72].

In summary, self-tracking, women's health, and pregnancy are entangled with various socio-cultural factors, while existing studies of pregnancy tracking largely center collecting and managing pregnant women's health records towards promoting healthy pregnancy [6, 8, 12, 27, 35, 50, 71, 75]. Less is understood about how pregnant women's lived experiences, such as non-pregnant stakeholders' involvement and situated pregnancy-related socio-cultural norms, shape their pregnancy tracking practices and needs.

3 METHODS

3.1 Preliminary Analysis

To gain some understanding of pregnancy tracking app usage, we first conducted a preliminary analysis of 15 of the most widely-used pregnancy apps. To get a basic understanding of people's uses and perceptions of pregnancy tracking apps, the first author read about 50 to 80 user reviews shown in the app store page's "Ratings and reviews" section, which selectively showed some reviews based on a few criteria defined by the marketplace, such as reviews' usefulness and informativeness [80], for each selected app from the Android store in August 2022. The first author also downloaded these apps, going through all the interfaces in these apps to see what features each app contained and how these features were designed. The first author took the grounded theory approach [20], mainly the open coding and constant comparison principles, to generate themes that help with building an initial codebook. The author first open-coded the selected reviews to identify potential themes, regularly comparing coded themes to merge or nest related topics. When discussing some initial findings with the research team and comparing them with previous studies, we realized that 1) Pregnancy tracking apps were often designed with a specific stakeholder in mind, typically either the pregnant person or a non-pregnant partner (a "dad" in all the apps). 2) Reviews suggested many non-pregnant stakeholders actively used pregnancy tracking apps or viewed tracked data. 3) Reviews showed pregnancy tracking was often a social practice of information-sharing and tracking among these stakeholders. Pregnancy tracking apps also contained some social features, such as data-sharing and internal social platforms. These preliminary results informed our research questions, methodology, and codebook.

3.2 Data Collection

To answer our research questions around what social goals and practices different stakeholders have when using pregnancy tracking apps as well as how apps support or inhibit these social goals and practices, we reviewed 20 pregnancy tracking apps by analyzing user reviews and app features (Table 1). We searched for pregnancy tracking apps in two major app stores, iOS App Store and Google App Store, in Oct 2022. We regarded any apps that monitored and collected pregnancy-related information (e.g., pregnant persons' weight, food, blood pressure, mood, fetal movement, and fetal kicks) as a pregnancy tracking app. Inspired by prior works' search strategy for identifying apps within a health & wellbeing domain [36, 62], we used "pregnancy" as the keyword and selected apps that (Fig. 1): (1) focused on pregnancy and have features to log/track pregnancy-related information (e.g., pregnant women's weight, food, blood pressure, mood, fetus movement, and fetus kicks), (2) had an average rating >= 3 stars, (3) had at least one update since

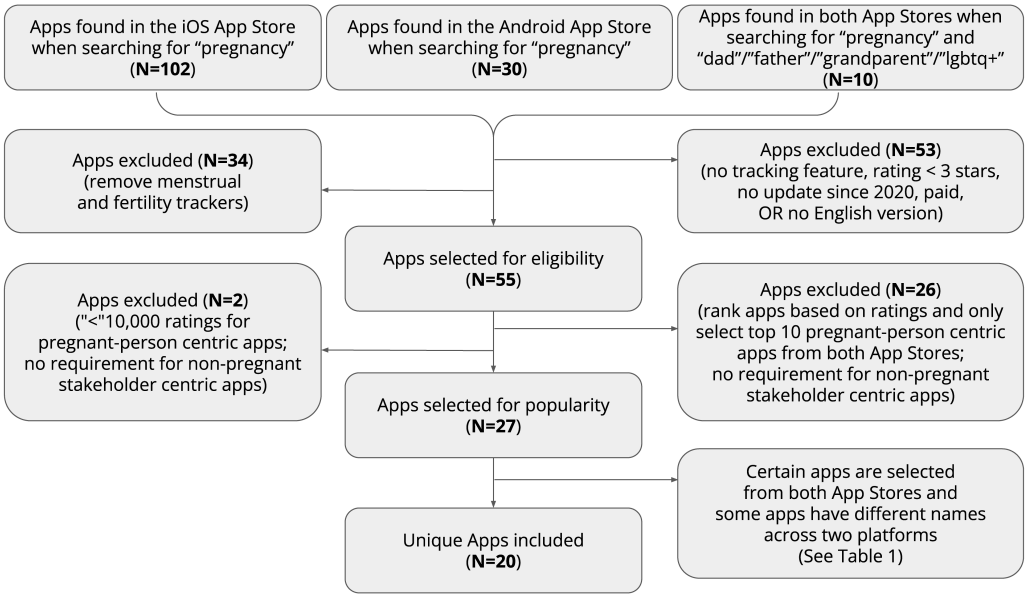

Fig. 1. We selected 20 pregnancy apps to analyze. We searched "pregnancy" in both app stores, and we also explicitly searched "pregnancy" with non-pregnant stakeholders, such as "father" and "grandfather". We removed apps that did not fit the criteria of eligibility and popularity. We did not remove any apps for non-pregnant stakeholders based on popularity.

2020, (4) were free, and (5) had an English version. We also removed apps that support tracking menstruation and fertility alongside pregnancy to avoid user reviews which speak primarily to these topics. We then utilized the number of reviews as a criterion, choosing the 10 most popular eligible apps from both App Stores and removing apps with fewer than 10,000 ratings. During the first step of searching, we also explicitly searched for non-pregnant stakeholders as well as gender and sexual minorities, such as *"pregnancy"* combined with terms like *"father"*, *"dad"*, *"grandparent"*, *"lgbtq+"*, *"gay"*, and *"lesbian"*, to find any pregnancy tracking apps designed for non-pregnant users. All pregnancy tracking apps we identified that were explicitly designed for non-pregnant stakeholders claimed that they were designed for dads-to-be, as indicated by their names and app descriptions. No apps were observed for non-parent stakeholders. As for pregnancy tracking apps centered around non-pregnant stakeholders, exclusively expectant fathers, we included them regardless of their number of ratings (from 12 reviews for "the Big Daddy", to 538 for "DaddyUp") since they were less popular than apps explicitly designed for pregnant persons. Noted, certain apps were chosen from both App Stores, and some apps had different names across the two platforms. We finally included 20 distinct apps (Table 1).

We collected each selected app's App Store pages and user reviews between October and December 2022. For reviews, we downloaded 500 most recent reviews and filtered out reviews with less than 50 characters. We filtered out shorter app reviews because our preliminary analysis highlighted that many short reviews frequently only presented an overall sentiment about the app, (e.g., "this app is great!", "super helpful for tracking my pregnancy."). We therefore decided to focus our qualitative analysis on longer, more in-depth descriptions. In total, we analyzed 4,709 reviews (3,167 for apps targeting pregnant people and 1,542 for apps targeting non-pregnant stakeholders), after which we felt we had reached theoretical saturation towards our research questions. For

Table 1. We analyzed 13 apps primarily targeted at pregnant people and 7 primarily targeted at non-pregnant stakeholders, of which all 7 were explicitly designed for expectant fathers.

Target User Group	Numbers	Apps and Selected App Stores
Pregnant People	13	**iOS**: The Bump, Nurture, Sprout **Android**: Together For Her, Asianparent: Pregnancy & Baby, Timskiy, amma, PregnancyDue Date **Both**: Pregnancy+, Pregnancy & Baby Tracker-WTE, BabyCenter, Ovia, Amila
Non-pregnant Stakeholders	7	**iOS**: The Big Daddy, Pregnant Dad **Android**: Super Dad **Both**: HiDaddy!, Daddyup, ProDaddy (iOS)/Dad's pregnancy app (Android), DadToBe(iOS)/Becoming Dad(Android)

the app feature analysis, we downloaded each selected app, documented its main features, and inputted some typical data as though we were tracking a pregnancy. We also took screenshots of each selected app's major features.

3.3 Data Analysis

Informed by preliminary analysis, our initial codebook focused on exploring users' self-tracking behaviors, social interactions, and socio-cultural factors manifested in people's uses and perceptions of pregnancy tracking apps. The initial codebook contained seven parent codes: tracking goals, tracked data, social interactions, gender norms, pregnant situation, socio-cultural factors, not target user. The first and the second author then used the initial codebook to code 300 app reviews randomly selected from our database respectively. The first author then calculated the inter-rater reliability and discussed the result with the rest collaborators, reaching an initial agreement of 80% across codes and discussing to resolve ambiguities to reach a consensus. For the formal codebook, we added some child codes for some parent themes. For example, we added "online community" under "social interactions" when finding pregnant people frequently commented on their apps' internal social platforms. We also added "pregnancy/labor logistic" under "tracking goals" and "tracked data" when finding some users appreciated how apps helped them deal with different tasks during pregnancy. The first and the second author then used the codebook to code the formal dataset, 4709 reviews in total. The first author coded 200 reviews for each of the non-pregnant stakeholder-centric apps and the iOS pregnant people-centric apps, while the second author separately coded 200 reviews for each of the Android pregnant people-centric apps. Noted, some apps had reviews fewer than 200. At the end of their respective coding, both authors felt they were observing similar takeaways in reviews from the app marketplace they read. When we met to compare and discuss takeaways, we noticed similar themes following from our codebook and neither author had felt it would be beneficial to add new codes. These discussions led us to feel we had reached theoretical saturation [20], and we therefore did not seek out additional reviews. The formal codebook and the number of each app's reviews included in the formal data analysis are attached to the supplemental material.

We further analyzed the features included in each of the apps to better understand what capabilities were being offered to pregnant and non-pregnant parties and what uses of these apps were intended. The first author developed a codebook for app features following the main themes that surfaced in the analysis of the app reviews. For example, some reviewers of apps targeted at non-pregnant stakeholders described some features by using gender-relevant words, such as "manly", "masculine", or "sexist". They also compared some features with similar counterparts they had seen in pregnant people-centric apps, such as choices for objects in fetal size comparison. The codebook therefore contained a "gender norms" theme, following reviewers' examples around how

people perceived gender norms. The second author downloaded and categorized the features of each app, taking screenshots of each feature and noting how many apps included given features. We further analyzed the store page description of the app, what data was featured on the home page, what data each app supported tracking, visualizations of health or wellbeing data (e.g., fetal health, maternal health), social features, and components that mentioned other stakeholders. We also noted informational support provided, design features that perpetuated gender norms, and design features that supported or inhibited socio-cultural status.

Our institution's IRB indicated that our study did not require review, viewing app review data as public information for audiences interested in learning more about these apps and people's perceptions of them. To avoid potential privacy and ethical risks, we took additional measures to ensure user anonymity by removing usernames and editing parts of quotes or paraphrasing them. We also searched for final quotes in our dataset to make sure it was not possible to easily find the original reviews.

3.4 Limitations

While the review analysis offered a chance to get a broad understanding of people's usage and perceptions of pregnancy tracking apps, this method has some limitations.

First, people tend to give a general picture of their user experience. They often do not comment on many features of the apps, which may result in an incomplete understanding of people's experiences and perceptions of app features. For example, we found relatively little discussion about some tracking features, such as monitoring the mood of both partners throughout the pregnancy. App reviews are also limited in that they give the perspective of people who at least somewhat successfully used an app. People frequently try multiple tracking apps until they find one which meets their needs or give up on looking [59], but we suspect they are unlikely to review apps which did not meet their tracking needs. Our understanding of how apps fall short of meeting people's needs might be somewhat incomplete, although these pitfalls were a major component of many of the reviews we examined. User reviews offer a more limited lens into a stakeholders' social practices or goals, since most reviews were from the primary user talking about their collaborative experience. We also observed discrepancies in the number and quality of user reviews for each app. For example, we observed that reviews of the same app often had shorter reviews on the Android Store than on the iOS Store, suggesting platform differences around review quality. This platform difference in review length and quality suggests that our results give somewhat greater insight into the perceptions of iOS users compared to Android users. iOS users tend to have higher incomes than Android users [51], suggesting that our findings may be somewhat biased towards this demographic. While we expect that many practices and desires around social pregnancy tracking persist across demographics, further work is needed to verify and further understand the perspectives of lower socioeconomic groups.

Second, our methods had some limitations in how they represent the people who manage pregnancy and technology opportunities within. We only focused on English-language apps and reviews, which may limit our ability to understand how socio-cultural norms influence pregnancy apps and people's perspectives of them beyond the English-speaking world. Prior work in other health & wellness domains [9, 62] has highlighted how socio-cultural norms around other aspects of women's health differ across cultures, and technologies designed for those cultures reflect those norms. It is therefore worth conducting further examination of socio-cultural norms around pregnancy specifically, and how those manifest in technology.

In spite of these limitations, the prevalence of commentary on social uses of the app offers strong evidence that people often use pregnancy tracking apps in social ways. In the future, building on the insights from this study, we suggest seeking out other qualitative research methods such as

Table 2. Features' prevalence in each selected app, categorized by apps' targeted users. Apps geared at non-pregnant stakeholders included tracking features much less frequently and rarely included social features.

Target User Group	Mood/Emotion Tracking	Nutrition Tips	Diet Tracking	Weight Tracking	Kick Counting	Contraction Timing	Fetal Size Comparison	Fetal Size Metaphors	Online Forums	Sharing Features
Pregnant People (13)	2	11	1	10	10	10	12	5	6	10
Non-Pregnant Stakeholders (7)	2	0	0	0	1	2	5	0	0	5

interviews and co-design workshops to provide an in-depth understanding of stakeholders' usage and perceptions of using pregnancy tracking technology for collaborative practices.

4 RESULTS

Overall, we found stakeholders often used pregnancy tracking apps to attain social goals or complete tasks requiring a collaborative effort: bond with each other, build a prenatal relationship with the fetus, and co-manage pregnancy around logistical and informational tasks (RQ1). We found two major categories of pregnancy tracking apps: apps intended to be designed for pregnant people and apps aimed at non-pregnant stakeholders (Table- 1). Those explicitly designed for non-pregnant stakeholders usually contained "dad" in their names, such as "ProDaddy" and "HiDaddy". We did not observe pregnancy tracking apps explicitly designed for non-parent stakeholders, such as expectant grandparents. While apps were often designed with a specific stakeholder in mind, such as either designed for expectant mother or father, reviews showed other non-target stakeholders (e.g., family members and friends) also used these apps (119 quotes and 94 quotes that mentioned non-target stakeholders' usage for pregnant people-centric apps and non-pregnant stakeholders-centric apps respectively).

We now explain how pregnancy tracking apps supported and inhibited (RQ2) stakeholders' different social goals and collaborative practices (RQ1) according to app reviews.

4.1 Bonding Between and Among Different Stakeholders

Pregnancy often becomes a central topic of conversation among families and close social networks, and therefore increases interactions between different people (e.g., expectant parents and their grandparents) [28, 39, 93]. App reviews indicated that users leveraged pregnancy tracking apps as a way to bond with other stakeholders around the experience by sharing pregnancy-relevant data or articles provided by pregnancy tracking apps.

4.1.1 Support: Sharing Excitement Among Family Members. Data included in pregnancy tracking apps around how pregnancies were progressing such as week of pregnancy, fetal growth measures, and fetal size comparisons helped multiple stakeholders bond with each other around the excitement of a family growing via sharing and commenting on data that they are interested in. Pregnant people often invited family members to directly use apps so they could follow along with the pregnancy journey together. For example, one user of Pregnancy & Baby Tracker said: *"I invited my mother-in-law to use this app and it sparked endless conversations about the growing new life. A wonderful way to bond with her."* The shared experience was especially helpful for connecting people who were unable to see each other in person. An expectant father who had to miss his wife's pregnancy due to the Military appreciated the app for *"It allowed me to easily follow the entire pregnancy and provided answers to all my questions about my son. It was a great tool to stay connected with my wife regardless of the distance between us. (PregnancyPlus)"* Among pregnancy tracking apps' various types of data and information, different stakeholders most often shared fetal-relevant information, finding that it acted as a conversation or interaction starter. One user and her family members competed with each other for who was the first to share the fetal growth data: *"My*

daughter, my mother, and I have a daily race to see who first opens the app in the morning to send a gif to our group message about which item the baby's size is compared to. (The Bump)" Sometimes, inaccurate or confusing fetal size comparisons even served as a fun conversation starter among stakeholders: *"The helpful weekly size comparison served as a delightful way to update my family. We found it to be entertainingly random and had a good laugh over them. (The Bump)*" In addition, expectant parent(s) often appreciated how pregnancy tracking apps helped them explain to their older children how the pregnancy started and developed: *"It's quite helpful if you already have a little one when you're trying to explain to your child that another one is coming! My son loves looking at the pictures and he even thinks it is my baby! (PregnancyPlus)*" Announcement tools in some pregnancy tracking apps also helped expectant parent(s) conveniently share the joyful moment of a new life's arrival: *"[It] features an attractive design like a Christmas card that allows me to share my baby's birth time, weight, height, and photo with others. (DaddyUp)*"

4.1.2 Support: Facilitating Emotional Support for Pregnant People. The information that pregnancy apps include about the pregnant person's health & wellness enabled non-pregnant stakeholders to be aware of what the pregnant person is experiencing and thus provide emotional support. For example, pregnancy tracking apps often provided information about what symptoms that pregnant person might experience for the following week: *"I often tell my husband things like 'This might sound strange, but I feel...' and then describe some bizarre symptom, only to discover the next day (thanks to this app) that it is actually a common symptom of pregnancy! (Pregnancy & Baby Tracker)"* These hints provided non-pregnant stakeholders advice on how to support the pregnant person: "*The app was accurate when it predicted that my wife's morning sickness and nausea would begin to ease up. As my wife is the one physically experiencing the pregnancy, using this app helps me be more engaged and guides me to alleviate her pregnancy symptoms. (BabyCenter)"* Some pregnancy tracking apps also raised non-pregnant stakeholders' awareness or understanding of the pregnancy by allowing pregnant persons to share their health & wellness data with others. For example, one non-pregnant partner appreciated Nurture for updating him with the wife's symptoms so he could take timely action to support her: *"I receive notifications on days when my spouse logs her symptoms, helping me understand when she feels particularly unwell. It also gives hints when she might benefit from a little extra support. (Nurture)"*

4.1.3 Support: Maintaining Intimacy Between Partners. Moreso than facilitating conversations with other stakeholders, pregnancy tracking apps more often emphasized how to enhance or maintain partners' relationships during pregnancy (Fig. 2). Pregnant people-centric apps often included an article section for partnership, offering ideas on promoting intimacy between expectant parents. Apps for non-pregnant partners instead often used tips and notifications to prompt users to take action towards supporting their pregnant partners. One user of DaddyUp thanked the app for reminding him to express love to his pregnant partner: *" There is always a reminder to express your love to your partner. One tip said: Text your partner and tell her why you love her. When I read them, they remind me what truly mattered. HER. (DaddyUp)"* Some pregnant people therefore appreciated non-pregnant partners' actions prompted by apps that made them feel like they were being cared for, creating a positive feedback loop between couples. One user of DaddyUp shared how his wife thanked him and the app: *"The wife appreciates the tips which aim at making her feel more comfortable."*

4.1.4 Inhibit: Stereotypically Masculine and Patronizing Recommendations. Apps geared towards non-pregnant partners often encoded gender norms around masculinity, resulting in some *"sexist"* or *"patronizing"* prompts for how to take care of a pregnant person. Reviewers often suggested that this information interfered with their ability to provide emotional support and some norms

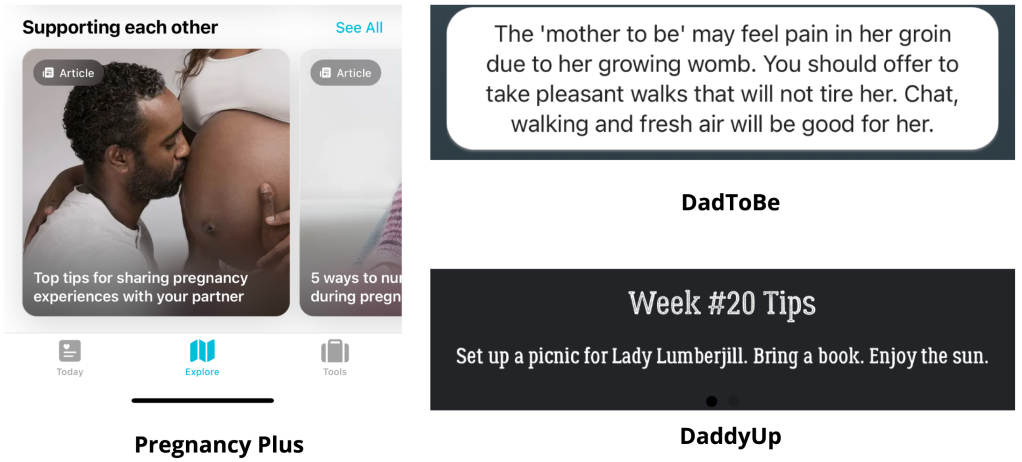

Fig. 2. Apps' gendered recommendations on enhancing partnership, with Pregnancy Plus providing multiple articles about supporting each other and apps for non-pregnant partners (DadToBe and DaddyUp) suggesting tips to have fun, such as taking a walk and having a picnic.

often make both parents-to-be feel uncomfortable: *"I want to rate this app with negative points. It is incredibly misogynistic, sexist, and trashy with daily reminders for men to tell their wives 'to chill' or 'to eat' or 'to use the restroom'. (HiDaddy)"* One user of DaddyUp similarly complained that the app assumed that fathers-to-be would no longer consider their partner physically attractive: *" The number one app to promote toxic masculinity. The first advice I received from the app was to avoid looking at that attractive waitress because my wife is now pregnant."* Apps which centered on non-pregnant stakeholders often contained prompts that encouraged non-pregnant partners to persuade pregnant women to monitor their body shape. One user was disappointed by the outdated advice provided by Dad's Pregnancy: *"Bad app and I had hoped for something better - one doesn't objectify the expectant mother and doesn't depict me as someone stuck in the 1950s, who's more concerned about the partner's body shape than the child's wellbeing. (ProDaddy)"* The app HiDaddy even promoted the idea to non-pregnant partners via mimicking the fetus(es)' tone: *"'I'm glad because I can feel mom is still working out' (implying the baby is upset if the pregnant woman is not doing exercises? Quite subtle gilt trip. (HiDaddy)"* Apps often further promoted social stigmas around hormonal changes making pregnant women overly emotional, which also offended some non-pregnant partners: *" It's frustrating and offensive that this app implies that pregnant women are naturally overly emotional and insecure about their body shape. (Pregnant Dad)"*

4.1.5 Inhibit: Lacking Peer Support for Non-Pregnant Partners. While peer support is important for both expectant parents [10, 25, 99], existing tracking apps tended to ignore that non-pregnant partners might have such a need. Aligned with prior work on pregnancy-related online communities [37, 43], almost half of apps (N=6/13) targeted at pregnant people contained internal social platforms, helping them get desired emotional and informational support from people who were also pregnant: *"The community feature is helpful in letting you know that you are not alone in the symptoms and feelings you're experiencing. (Pregnancy & Baby Tracker)"*. In contrast, no apps centered around non-pregnant stakeholders contained the internal online community feature (Table 2). One user expressed his loneliness and cluelessness as a dad-to-be, therefore hoping for a place that can provide support: *"It would be great to have a section where experienced dads can share their ultimate*

Pregnancy & BabyTracker **Sprout** **BigDaddy**

Fig. 3. Many apps, such as Pregnancy & Baby Tracker, compare to objects like fruit or vegetables, but some use images of the fetus themselves (Srout's 3D model). And some apps geared towards dads promote "manly" size comparisons, such as BigDaddy's comparing the fetus to a poker chip.

wisdom with guys like me who still feel lost. Maybe just an in-app blog where men can communicate and help each other. (DaddyUp) "

4.2 Building a Prenatal Relationship with the Fetus

Overall, pregnancy tracking apps supported different stakeholders in building their relationship with the fetus(es) by raising awareness of the fetus(es)' existence, supporting following fetal development, interacting with the *"virtual"* fetus(es), and documenting pregnancy memories to share with the baby(s) in the future (Fig. 3). Stakeholders varied some in how they used pregnancy apps to bond with the fetus(es). Expectant parents, especially pregnant persons, tended to bond with the fetus(es) in multiple ways, while non-parent stakeholders mainly leveraged apps to monitor fetal development or interact with the fetus(es).

4.2.1 Support: Making pregnancy more "real". Pregnant people often begin forming maternal-fetal relationships when feeling pregnancy is a *"real"* thing, especially during the early pregnancy, since fetal movement usually can only be noticed starting in the second trimester [95]. Apps' cartoon graphics or 3D models used to visualize fetal development therefore helped pregnant persons feel and affirm the presence of the fetus during early pregnancy: *"This app's graphics are amazing - you end up getting attached to the little virtual baby throughout the pregnancy! It's really helpful to see your baby's growth, especially when you don't feel the baby moving yet (PregnancyPlus)."* One user who experienced a miscarriage before also expressed how *"seeing the customized baby everyday"* gave a sense of comfort since *"we cannot see the real one everyday (PregnancyPlus)"*. While most (N=15/20) pregnancy tracking apps only contained the graphical representation of a fetus, the app Bump included a 3D model of a womb with a fetus inside (Fig. 4), helping pregnant women visualize their fetus(es) in relation to their bodies: *"The 3D images of me and the baby are fantastic for getting a clear picture of what your baby really looks like instead of just imagination. (The Bump)"* One user appreciated that The Bump made pregnancy feel *"more real"* than being informed by doctors: *"It makes you feel like this child growing inside you is more real than just being told by the OB that there's a child in your belly!"*

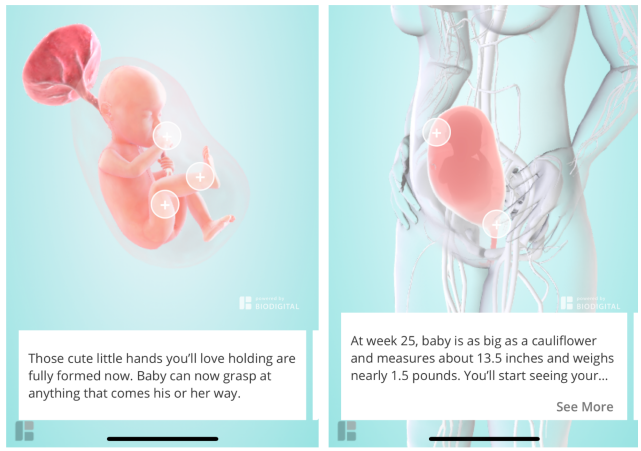

Fig. 4. Some apps, such as the Bump, helped build a maternal-fetal bonding by visualizing how the fetus relates to the expectant mother's body. The left was the fetus' model and the right was the mother's body.

4.2.2 Support: Developing Greater Understanding of Fetal Development. Bonding occurred through stakeholders developing a greater understanding of the pregnancy process as they became more and more familiar with the fetus(es). Both expectant parents and non-parent stakeholders often became more excited about the pregnancy from following the fetal development (e.g., growth of particular body parts, overall size over time): *"I love following my baby's weekly growth! It is incredible to see what happens there and what my little tiny child is developing into. And I will soon have my own adorable child! (Pregnancy & Baby Tracker)"* Pregnancy tracking apps supported this by providing fetal development data based on timing, such as size comparisons and weekly metaphors. For example, one user described how the app helped increase the anticipation of the fetus growing and developing: *"I couldn't resist checking this app several times a day, eagerly anticipating new updates on my baby's development in the womb. It was amazing to track my baby's milestones and discover all the exciting things he was capable of as he grew inside me. (BabyCenter)"* Some non-parent stakeholders similarly downloaded pregnancy tracking apps to keep track of the fetus(es)' growth. One grandfather appreciated the app for allowing him to *"see"* the fetus growing every day: *"First time grandpa, is has been a long-awaited journey since my daughter trying to get pregnant, and we feel incredibly blessed to see this little one finally come and grow day by day. (Sprout)"*

4.2.3 Support: Interacting with the Virtual Baby. Expectant parents used pregnancy tracking apps to build their attachment to the fetus(es) by feeling like they were directly interacting with their babies. Compared with traditional methods such as touching the pregnant belly, talking to the fetus, and attending to kicks or other movements [22, 47, 88], pregnancy tracking apps enabled expectant parent(s) to interact with virtual representations of the fetus(es): *"The app is incredibly interactive to see your baby move and it even has the heartbeat! (Sprout)"* Some apps, such as HiDaddy (Fig. 5), also included text as though it were written by the fetus(es), making expectant parent(s) feel like they were directly talking to the baby(s): *"The app shows the information as if your baby is speaking to you and providing guidance throughout the process. (HiDaddy)"* Reviews suggested that fetal growth data and interactive visualizations within apps also helped form bonds between a family's older children and the fetus(es). One user appreciated that BabyCenter helped them establish the sibling relationship: *"I used the app again after almost 9 years after my first baby. I showed the app to my*

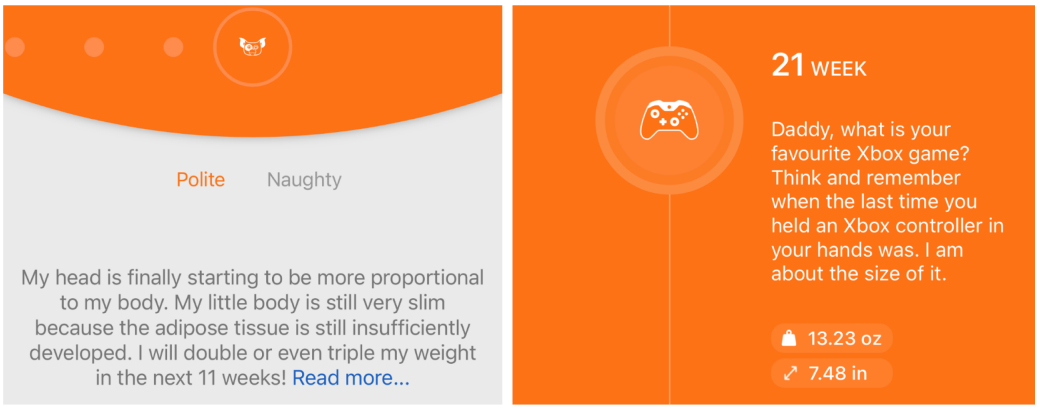

Fig. 5. Personalized description about fetal development, such as manly description about the fetal size via a baby's narrative, helped non-pregnant partners bond with the fetus. The left picture was the fetus' introducing what happened to his or her body; The right picture was the fetus' comparing him/herself to an Xbox controller.

firstborn and taught her all about her little sister. She enjoyed watching the videos repeatedly and was curious about what vegetable or fruit her sister was compared to each week. This app helped foster a beautiful relationship between my daughters. (BabyCenter)"

4.2.4 Support: Setting Up Opportunities for Future Reminiscence. Expectant parents often aimed to bond by setting up opportunities for reminiscence around pregnancy experiences once the child was more grown up. Many parents make baby journals documenting photos and notes during pregnancy so that they can cherish this journey with the child in the future, letting the child know the parents' anticipation for his or her arrival to the family. Some expectant parents similarly leveraged pregnancy tracking apps to keep a record of pregnancy experiences with the intent to share them with their babies in the future: *"I always have a belly book for my children since I believe it is important that they know each one's uniqueness and have a story of them before their arrival. This app also helps me keep track of notes and take belly photos for my belly book. (Ovia)"* The app DaddyUp provided a service to transform logged data into a physical book to create a more tangible and personal experience for future reminiscence. One user was therefore motivated to *"log each day as if speaking to my incoming kid so I can use the information when filling out the baby book."*

4.2.5 Inhibit: Ignoring Fetal Demographics and Stakeholder Identities. While many stakeholders appreciated how pregnancy tracking apps helped them build attachments to their fetus(es), app reviews also showed that some apps interfered with bonding by not considering diversity in fetal demographics and stakeholders' identities, mainly resulting in a lack of inclusiveness towards recognizing all potential races, gender identities, or sexual orientations of the fetus(es) and stakeholders.

Stakeholders often felt that when apps did not account for demographic characteristics of the fetus(es), such as gender, race, and quantity (Fig. 6), it inhibited their ability to bond with the fetus(es). Although apps (N=13/20) often contained different gender options for fetus(es), such as girl, boy, and unknown, some apps contained information geared towards one specific gender regardless of users' options. Users did not appreciate that some apps' insisted on calling the fetus

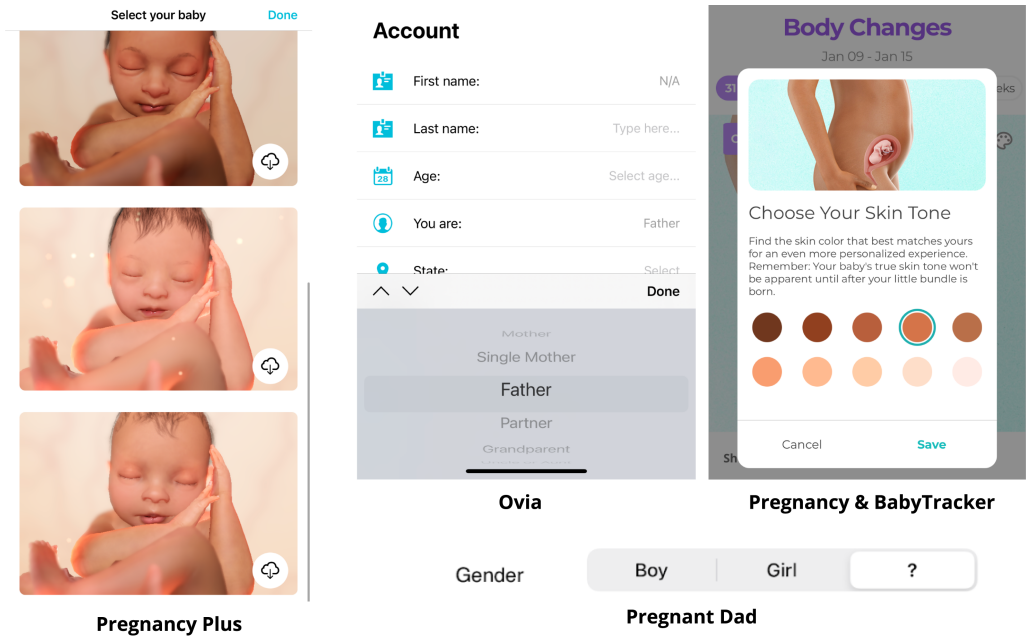

Fig. 6. Some apps did include options for selecting gender or race for the fetus or the user, helping with bonding. But most did not. Most apps did not provide options for users to self-identify their gender. For example, Ovia allowed for choosing the user's identity but had no option for choosing gender.

by a wrong pronoun: *"The app kept referring to all babies as female and used feminine pronouns in every piece of information. It continues to refer to my boy as a girl after I changed the gender setting, which is frustrating and disrespectful (Pregnancy & Baby Tracker)"* or did not provide a gender-neutral option before expectant parents discovered the fetus(es)' sex: *"When you are not able to find the baby's gender, I think the app should use gender-neutral languages, such as 'baby' or 'they/them/their' (Ovia)"*. As for the racial aspect, stakeholders felt disrespected or isolated from their fetus(es) when fetal visualizations contained different skin tones than their own or other incorrect representations of their race. For example, some users were disappointed with apps' biased illustrations of black babies: *"The app never revised how it showed African American babies' hair. I suggest the app include curls and straight hair instead of only portraying kinky hair because that is not how babies' hair shows. (PregnancyPlus)"* One user expressed disappointment when their older children were confused by the virtual fetus not looking like them: *"My young children questioned why the baby didn't resemble them, especially since our skin is very dark. It was disheartening. (PregnancyPlus)"* None of the pregnancy tracking apps we examined supported displaying fetal growth data and visual representations for someone pregnant with multiple fetuses, making those with multiples feel disconnected from the experience: *"I feel left out since there are no apps for twin or multiple pregnancies. I wish to see two babies growing in 3D. I wish to see my babies' genders and everything for them! What a great resource for people with one child, but what about us with more? (PregnancyPlus)"*

App reviews showed that not accounting for stakeholders' identities (e.g., genders, sexual orientations, and races (Fig. 6)) also inhibited their abilities to bond with fetus(es) by making them feel being marginalized during the pregnancy journey. Pregnancy tracking apps often assumed the pregnant person to be a woman or cis woman, offering a reminder that society often ignores

pregnant people of different genders or sexual orientations: *"No option to choose not to be referred to as a mother, or female-specific language. Not only Cisgender women can pregnant. (Ovia)"* One What to Expect user who did not identify as a mom felt excluded by constantly seeing this language emphasized in the app: *"It is not inclusive for pregnant people who don't self-identify as 'mom or mother' like me. There are many 'look at you, mom!' or 'motherhoods are...' sorts of things. (Pregnancy & Baby Tracker)"* Similar to the fetus(es), users also felt disrespected that pregnant women depicted in apps were mainly white females: *"It is disrespectful to my race and sets a negative tone for the app. It only has a white version for mom's belly growth. Why no choice for persons of color. It seems everything is tailored to white people which is totally unfair. (PregnancyPlus)"*

4.3 Co-managing Logistical and Informational Needs Around Pregnancy

Pregnancy requires collaborative effort among different stakeholders to ensure better health & wellbeing outcomes [81, 94]. Pregnancy tracking apps often contained features to help users manage logistical and informational needs such as contraction timers, calendars to record doctor appointments and take notes, and hospital bags. Many reviews suggested that not only pregnant people but also non-pregnant stakeholders, especially partners, were able to share some pregnancy-related responsibilities by using their apps for managing tasks.

4.3.1 Support: Jointly Seeking Information about Pregnancy Care. Expectant parents often jointly performed information-seeking behaviors via pregnancy tracking apps, aiming to enhance both parties' knowledge about things which happened or could happen to pregnant persons and fetuses. This joint behavior was mainly conducted in three ways. Sometimes one person used the app, finding something important or interesting and to share with the other: *"I would share the information with my spouse and he even began reminding me to watch the app's new daily video. It helped begin conversations and we all gained a greater knowledge of the miracle of pregnancy and birth (Pregnancy & Baby Tracker)"* Sometimes couples read things from the apps together: *"We all love it! My husband even reads the information aloud in some lumberjack accents. (DaddyUp)"* Sometimes they both downloaded the same app and shared things with one another when learning interesting information: *"My husband also had the app on his phone and enjoyed sharing interesting facts and articles with me when finding something was fun. (BabyCenter)"* Expectant parents also often used pregnant persons-centric apps and non-pregnant stakeholders-centric apps together to get a more complete understanding of pregnant persons and the fetus(es): *"Used this app the beginning of my wife's pregnancy. She had her more feminine app and I had my masculine app. She even learned things from this app that her app didn't provide! (DaddyUp)"* Apps' information on symptoms that pregnant women experienced helped expectant parents evaluate whether the pregnancy went smoothly or not, which sometimes also alleviated their worries: *"When my wife realized or experienced physical changes accompanied by anxiety, fatigue, and illness, the app helped us calm down and even be happy since it meant our baby was growing in a healthy way. (Amma)"*

4.3.2 Support: Being Better Prepared for Upcoming Events. Pregnancy tracking apps helped non-pregnant partners stay on track with pregnancy-relevant logistics via providing various practical tools. One user valued DaddyUp's checklists for what to do during each trimester since it made him stay organized: *"It assists me in keeping focused on my tasks and staying organized. The list has things that I had not considered"*. Attending doctor appointments and communicating with OB-GYNs is an important part of pregnancy for pregnant people, and apps enabled non-pregnant partners to support their beloveds by managing appointments: *"A place to track my wife's appointments. (Pregnant Dad)"* One user was grateful for the app's helping him be well-prepared for doctor appointments: *"The app empowered me to know what to ask doctors so we could stay up-to-date on controversial facets of birth and postnatal care. It felt nice to have this knowledge without having to*

blindly trust everything. (DaddyUp)" Apps became a vital tool that facilitated non-pregnant partners to take necessary action during the big day. One user appreciated contraction timers for helping him well-communicate with hospital staff during labor: *"I used the app to track her contractions and I was able to tell the medical staff the duration and frequency of her contractions when we got to the hospital. (DaddyUp)"*

4.3.3 Support: Feeling Involved in the Pregnancy. Since non-pregnant partners usually have no bodily experience with pregnancy, pregnancy tracking apps enabled them to feel involved with the process by monitoring what was occurring in the pregnant person's body. While non-pregnant partners cannot monitor as much data as their pregnant partners do (Table 2), apps supported them in monitoring fetal development by taking photos of pregnant persons' bellies, keeping track of ultrasound photos, and counting fetal kicks. For example, One user appreciated PregnantDad for organizing ultrasound photos gained from OB-GYNs (obstetrician-gynecologist): *"It was a good tool to keep our baby's ultrasound photos in one place. (PregnantDad)"* Knowledge gained from apps helped non-pregnant stakeholders, mainly expectant parent(s) and family members, learn important knowledge about pregnancy and labor that enabled them to know when and how to provide necessary support. One Ovia user's husband felt involved by following the app's guidance on nutrition: *"My husband even subscribes to the app's daily emails! It makes him feel engaged. Following the app's nutrition recommendations, he has been going for groceries for me without me having to ask - the app tells him our needs!"*

4.3.4 Inhibit: Feeling Excluded Due to Stereotypes around Parenting Roles. Many pregnancy tracking apps were explicitly designed for pregnant people and assumed that only certain relationships, mainly expectant mothers, would be interested in monitoring, making non-pregnant stakeholders, especially non-pregnant partners, feel overlooked and unsupported. Such perceptions may result in a lack of features for involving non-pregnant stakeholders, such as no collaborative or sync features, creating extra burdens for them to participate: *"Unfortunately, I can only see the pregnancy progress by login in with my wife's information or my account had to mimic the information she put. Pregnancy is a journey that involves two people. It would be beneficial to share the mother's journey with their partners rather than relying on loopholes. (Pregnancy & Baby Tracker)"* Another non-pregnant partner felt annoyed for having to self-identify as pregnant so as to use Ovia: *"A bit frustrating that you must be pregnant or pretend to create accounts. (Ovia) "* In addition, while some apps had options for users to self-identify their relationship with the fetus(es), content within these apps remained geared towards expectant mothers. One user wished The Bump could account for their role as a grandparent, rather than continuing to refer to the fetus as *"your baby"*, which made him disappointed: *"I selected 'someone I love is expecting' rather than 'I was expecting' when registering since my daughter is pregnant. But the app keeps using 'my' when providing daily updates about fetal size and countdown. I really hope mine would say something like 'grandbaby' or give a place to show the relationship. (TheBump)"* Throughout reviews of apps geared towards non-pregnant partners, some male users were glad that there was finally an app "for them", showing information and content in a masculine way: *"The app also makes my wife happy knowing I have one app to their thirty apps. (DadToBe)"*

While some reviewers initially expressed excitement for discovering apps tailored for non-pregnant stakeholders (mostly non-pregnant partners), reviews often expressed that these apps failed to provide useful information and features due to stereotyped perceptions that neglected partners' capabilities to partake in pregnancy. This lack of support then hindered their ability to provide crucial logistical support, seek necessary information, or be involved in pregnancy. One user complained that non-pregnant stakeholder-centric apps focused too much on providing tips about being a supportive partner rather than useful tips about pregnancy-related science: *"This app*

doesn't do pregnancy justice. As a first-time dad, I would like as much information about pregnancy as possible. I don't want advice on how to become a good husband to my unborn child's mother. My wife's app tells her all about the size, comparisons, and what organs are developing. I do not need tips on buying her flowers. (DadtoBe)" Some reviews mentioned that apps portrayed non-pregnant partners as ignorant people incapable of undertaking pregnancy duties, such as going to doctor's visits: *"This app is an insult to expectant fathers. It assumes that no men want to participate in doctor visits. It literally accuses you of this. (HiDaddy)"* The stereotyped design led non-pregnant partners to abandon the app and turn to other apps, often mom-centric apps, because they provided more meaningful information and accurate data: *"The mom-oriented apps provide many things I would want in this app, Perhaps future updates will resolve some, but I will now probably just stick to [a mom-centric app]. (PregnantDad)"*

However, reviews showed that users sometimes anticipated and even appreciated "stereotyped" designs in non-pregnant stakeholder-centric apps, feeling they provided more practical information about pregnancy. Some reviewers chose apps geared towards non-pregnant partners because their simple and *"right"* amount of information fit their expectations of non-pregnant stakeholders' roles in pregnancy. One wife believed the app PregnantDad was a good match for her husband since " *One can easily understand and its information is not too overwhelming. My husband dislikes reading, so the short paragraphs will be ideal for him!"* Some reviewers believed that apps geared towards non-pregnant partners were helpful for bringing up pregnancy topics between parents, whereas apps for pregnant persons were for medical needs: *"This app well serves its purposes. It is not the app to find all the medical things, but you will get enough from your wife like me. This app is cute and good for starting conversations. (DadToBe)"* Interestingly, a few pregnant people viewed the less serious information of non-pregnant stakeholder-centric apps as a way to better manage and cope with pregnancy, since pregnant persons-centric apps often promoted fear-mongering aspect of pregnancy: *" Please make a MommyUp app! This app is way more user-friendly and practical than pregnancy apps filled with articles about health problems. (DaddyUp)"*

While reviews suggested that paternalistic interventions can help relieve pregnant persons' burdens during pregnancy, some pregnancy tracking apps' strong emphasis on partnership sometimes degraded single pregnant persons' abilities by making them feel *"different"* or *"isolated"* from other parents and placing emotional burdens to those who struggled alone. One single expectant mother wished the app could provide information to support people who had to go through pregnancy on their own: *"The only place needs change is to be a choice of being 'with partner' or 'single'. A lot of time the app's pregnancy suggestions mention the partner and how they could/should be helpful. As someone who is experiencing this pregnancy alone, I do not need reminders about how partners could be helpful. I want tips on how to go through the pregnancy on my own. (The Bump)"* One expressed the painfulness and sorrow when having to consistently face information that in turn added emotional burdens: *"It has been consistently frustrating to see the mention of partners when I set my account as a single mother. I am already very emotional. Today's reading is 'Ask your spouse to help daily chores. He'll be quite willing to help you', setting off my tears. Please review your information to ensure that it is not more stress-inducing for those of us without a partner. (PregnancyPlus)"*

5 DISCUSSION

By reviewing features of pregnancy tracking apps and analyzing their public reviews, we find apps are frequently used by non-pregnant stakeholders besides pregnant people. Extending prior work that focused on examining the experiences and use of features by pregnant people [6, 8], we further find that non-pregnant partners, grandparents-to-be, and other family members, and other close ties often use pregnancy tracking apps to stay informed about the pregnancy and connect with the parent(s). However, apps are often designed without these groups in mind, typically catering either

pregnant persons or non-pregnant partners, and often silo the experiences of the stakeholders to their respective apps. User reviews further suggest that stakeholders use pregnancy tracking apps to support social goals beyond self-tracking. Tracked data, crucial information provided by apps, and some social features enable stakeholders to start building a prenatal relationship with the fetus(es), bond with other stakeholders, and co-manage information and logistical needs around pregnancy. However, the lack of inclusiveness regarding who can use pregnancy tracking apps and some socio-cultural norms (e.g., gender norms, body image issues, and stereotyped perceptions of parenting roles) inhibit stakeholders from achieving these social goals.

We now reflect on how pregnancy tracking apps support or interfere with the social reconfiguration that happens around pregnancy, as described in family sociology. We further offer design recommendations for how pregnancy tracking technologies can better support the breadth of social goals and social circumstances under which people are pregnant.

5.1 How Pregnancy Tracking Apps Support and Inhibit Different Social Relationships from Family Sociology

Family sociology literature identifies four types of social relationships which are reconfigured with pregnancy and the arrival of a newborn: the relationship between the parent and the fetus, partnership between expectant parents, kinships between the parents and other family members, and friendships with other social connections. Our results suggest that pregnancy apps both support and inhibit the transition of each of these social relationships, with kinships and friendships having similar characteristics.

5.1.1 Build a Prenatal Relationship with the Fetuses. How pregnancy tracking apps support building a prenatal relationship with the fetus(es) reinforces some of the desirable social principles from family sociology. For example, users' viewing and interacting with apps' 3D models can create a similar experience to expectant parents' viewing ultrasound photos during appointments [47, 88]. However, traditional interventions usually have a time delay for expectant parents to build this relationship with the fetus(es), since they often need to wait until the second month of pregnancy to have their first prenatal appointment. Further, ultrasounds are relatively infrequent during pregnancy, with some guidelines suggesting that many pregnant people only receive one during the term [96]. Pregnancy tracking apps therefore provide early and frequent access for pregnant people, expectant partners, and other stakeholders to interact with the virtual "fetus", offsetting time and frequency constraints surrounding traditional interventions.

While family sociology tends to focus on the prenatal relationship between expectant parents and the fetus(es) [22, 68, 86, 88, 90], pregnancy tracking apps provide opportunities for non-parent stakeholders to build attachments with the fetus(es) as well. Traditional interventions, such as feeling fetal movement and attending appointments, often marginalize non-parent stakeholders since they are either bodily experiences or require in-person participation. Prior studies show non-pregnant partners often find it more difficult to build relationships with the fetus(es) than pregnant persons [88, 90], not to mention non-parent stakeholders' challenges to build such bonds with the fetus(es). Data sharing features in pregnancy tracking apps, and the ability to follow along with the experience, open access to everyone therefore enabling non-parent stakeholders to make progress towards bonding with the fetus(es) before childbirth. Considering the benefits of interacting with fetus(es)' virtual representations identified in this study, there is a potential opportunity to apply virtual (VR) or augmented reality (AR) to pregnancy tracking apps since they can provide an immersive experience of "being there" [24, 77]. For example, AR can "project" fetus(es)' virtual representations into users' real-world environment, creating co-located playful experiences [24] between people and virtual babies. Such playful experiences might be particularly

valuable in family settings, such as with older children, where a more immersive and "like real" interaction might help promote deeper attachment to the child-to-be.

However, pregnancy tracking apps mainly hinder stakeholders' ability to build a prenatal relationship with the fetus(es) when they do not align with fetal demographics and stakeholders' identities. While it may not be possible to know exactly how each fetus will look and incorporate that into an app, our findings suggest that having no or limited options for choosing characteristics like a fetus' race can interfere with people's ability to imagine that the virtual fetus "is" the unborn child. Further, a lack of support for options regarding race and gender for the pregnant person can reinforce stereotypical or arcane notions around who should, or is allowed, to be pregnant. Epstein et al. [31] identified similar issues for menstrual tracking apps that they tended to assume that only women used these apps or that users' partners were men, making gender and sexual minorities feel excluded.

5.1.2 Partnership. Family sociology studies find that pregnancy influences partnership in various aspects, such as changing couples' division of household work, sharing the joy of a new life's arrival, and breaking a stable dyadic relationship into a fragile triangular one [10, 21, 22, 55, 60, 79, 99]. We find that pregnancy tracking apps enable partners to cope with these changes by providing tips on sustaining partnership, raising non-pregnant partners' awareness of what a pregnant person is experiencing, and facilitating both partners to stay organized around pregnancy and labor-relevant tasks and informational needs. Some apps further allow pregnant partners to send their mood to their partners' counterpart app, or link accounts with pregnant persons' profiles.

While pregnancy tracking apps provide different ways to cope with changes in partnerships, user reviews show that apps often encode some socio-cultural norms surrounding healthy pregnancies and gender roles in parenthood. For example, apps targeted at non-pregnant partners often encode stereotyped perceptions that non-pregnant partners have or want to have no or little involvement in pregnancy. As a technology that partners adopt during a point of major transition, where new familial roles have not yet been established, embedding these stereotypes into technology runs the risk of further perpetuating these stereotypes. Stereotyped designs, that primarily incorporate everything for pregnant people while no or few features for non-pregnant partners, can reinforce an inequity between partners and also put more burden on pregnant people than their companions. Joint participation is crucial when tracking an event that matters for a family, since family members' health & wellbeing are mutually dependent and collective behaviors can help diffuse tracking burdens [78]. In addition, these encodings often interfere with non-pregnant partners' ability to provide logistical support, since apps for them focus more on providing tips for pleasing their pregnant partners rather than giving practical guidance on logistical tasks as well as providing necessary knowledge for how to navigate pregnancy.

However, user reviews also show that people have different perceptions of the presence of these socio-cultural norms in pregnancy tracking apps. While many users expressed their disappointment or disagreement with designs which enacted socio-cultural norms, some people felt like their experiences were better recognized and understood by their presence. For example, many non-pregnant partners enjoyed "cheesy" dad jokes contained in apps for expectant fathers. In a few cases, pregnant partners sought out "dad" apps because they disliked that apps targeted at them contained overly serious and even fear-mongering information about pregnancy. Overall, we largely see people's perspectives on pregnancy tracking apps and the design of them reflecting the nuances and challenges surrounding establishing partnerships in broader socio-cultural conversations around the pregnancy transition, with conflicting and varied opinions on how the topic should be framed.

5.1.3 Kinship, Friendship, and Peer Support. Family sociology suggests family members, especially grandparents, are major sources of social support for expectant parents and they tend to provide a

range of emotional, informational, and logistical help [28, 98]. User reviews suggest that pregnancy tracking apps can assist these family members in providing emotional support, since information within apps helps raise their awareness of what the pregnant person is experiencing and what they need at a given moment. Information within apps can also promote successful communication between expectant parents and grandparents by reducing discrepancies and conflicts in pregnancy and child-rearing. A few grandparents appreciated how apps refreshed their memory of the experience of pregnancy, such as highlighting how the pregnant person felt, which enabled them to take appropriate actions towards caring for pregnant people. However, pregnancy tracking apps tend to neglect the participation of these family members in pregnancy-relevant logistical tasks. For example, we did not observe any pregnancy tracking apps tailored to family members who live with and care for pregnant persons and the infant after childbirth. While user review data did show that some grandparents utilized pregnancy tracking apps targeted at pregnant persons or non-pregnant partners, the general lack of acknowledgment of these stakeholders led them to feel excluded from the experience.

Expectant parents usually turn to their friends, colleagues, and peers for emotional and information support [10, 94, 99]. Pregnancy tracking apps support interaction with friends and peers via data sharing features and internal social platforms. However, both feature analysis and user reviews show that social support from family members, friends, and peers tends to focus on pregnant persons and the fetus(es) while ignoring the needs of non-pregnant partners, aligning with findings from family sociology that suggest that non-pregnant partners are less likely to get support from friends and peers [25]. For example, almost all the pregnant persons-centric apps had internal social platforms but no apps explicitly for pregnant partners had this feature. User reviews and app features suggest that non-pregnant partners are primarily regarded as support givers rather than takers. Our data show that non-pregnant partners often express stress and anxiety around pregnancy and the unknown fatherhood. Prior HCI studies on online communities for fatherhood suggest that fathers are hesitant to use social media platforms for privacy concerns and impression management, perhaps leading to a paucity of online communities explicitly to support fatherhood, paralleling our findings [4, 5].

While pregnancy requires collective efforts across stakeholders, we observed fewer apps for non-pregnant partners in the app stores, and them having fewer reviews, compared with apps for pregnant people. We also did not identify any apps geared towards non-parent stakeholders. While it is possible that non-pregnant stakeholders may have little interest in using apps geared towards their role in pregnancy, user reviews suggest that non-pregnant stakeholders, especially partners, instead turn to apps targeting pregnant people since the state of technology support for non-pregnant stakeholders is rather poor. More fundamentally, parallelling fertility tracking [38], our findings suggest that designs are perpetuating the socio-cultural norm that pregnancy monitoring is primarily the job of the pregnant person, and the pregnant person alone. We therefore think there's an opportunity to design pregnancy tracking technology to be more inclusive, and involve more stakeholders, to broaden out the responsibility. Breaking this norm is particularly critical given that pregnancy is a transition point for most families, where familial social roles are actively being redefined and are therefore up for negotiation. Encouraging other stakeholders to participate in pregnancy monitoring therefore could facilitate them taking a more active role in later child-rearing.

5.2 Design Opportunities

As a baseline, our findings point to the value in improving the representation and inclusivity of pregnancy tracking apps. Similar to other health & wellbeing domains [31], our work suggests that offering greater demographic options (e.g., gender, race, sexual orientation) in pregnancy tracking

apps for fetuses and their parents can make stakeholders feel more included in the experience. But further, these options also improve opportunities for apps to support bonding, particularly with the fetus prior to birth. We also find that if apps allowed for more ambiguity about a person's role in monitoring a pregnancy, they would be more inclusive of different stakeholders including grandparents, siblings, friends, and other family members. We therefore suggest that apps could use terms like "the baby you are watching", "the pregnancy you are monitoring", and "the people you are caring for" to refer to the pregnancy, without presuming a particular relationship.

Beyond tweaking the framing of relationships and including greater customization options, our work suggests that it might be valuable to radically rethink the design of pregnancy tracking technology towards a more collective experience which supports a full pregnancy support team. Such a rethinking would allow for individuals regardless of role to observe and contribute to the pregnancy process, and would avoid presumptions around the presence of specific stakeholders and how they might be able to be involved. However, we further surface that stakeholders have goals and needs for using pregnancy tracking apps, suggesting a tension between designing such technology for a more collective and stakeholder-agnostic style with experiences more tailored to the specific needs of different stakeholders.

Towards designing more collaborative technology for pregnancy support, a single app or technology could be intended for use by all stakeholders interested in a particular pregnancy, following the journey of a specific fetus and family. Such an app could give all stakeholders access to the same information about how a fetus is developing, as well as tracking capabilities for monitoring aspects of the health & wellbeing of the fetus and the pregnant person. An advantage of this structure is that all stakeholders receive the same information presented the same way, which has the potential to enable better communication across the stakeholders, whether in-app or out-of-app. Drawing from family informatics [78], such a system could allow individuals to jointly participate in tracking, perhaps spreading the burden of tracking and managing pregnancy across stakeholders. In addition, stakeholders' unique roles and interests may lead to their different levels of participation in tracking, which could make someone feel tracking too much or too little. Therefore, a need to help stakeholders control and negotiate over what tracking activity each one is interested in or what updates about pregnancy each one wants to receive.

However, an inclusive but general approach has weaknesses in that the features and information are no longer tailored to stakeholders' unique roles and needs surrounding pregnancy. Some user reviews expressed that people can react negatively to receiving too much or overly serious information about pregnancy, suggesting that a one-size-fits-all approach might be rejected by some stakeholders. In addition, prior work suggests that people often seek out support around pregnancy on role-specific online platforms [5, 43, 64], which a collective and universal approach would effectively eliminate. However, it could also be argued that such a collective experience is needed to help break social stigmas and taboos regarding pregnancy, and ensure all stakeholders are participating. To strike a balance between a collective experience's universality and individuals' specific needs, one option is to provide choices in the app ecosystem marketplace. Essentially, let people choose whether they want the tailored but identity-specific version, or a more identity-agnostic version. But ensuring that some baseline collective features exist across all apps, such as using identity-agnostic terms when mentioning the fetus to support any relationships between users and the fetus, which can help de-stigmatize participation in pregnancy. The collective approach also needs to carefully balance pregnant people's bodily autonomy with the collective benefits of tracking. Turning pregnancy tracking into a collaborative activity may limit pregnant people's sense of ownership over their own bodies. In more patriarchal or conservative environments, where the reproductive rights and choices of cisgender women and/or transgender people are being regulated, collective pregnancy tracking has the potential to invoke feelings of a lack of choice

around pregnancy-related decisions. When designing for collective pregnancy tracking, there is a need to give pregnant people a choice to monitor pregnancy on their own and prioritize their needs while also enabling others to help with tracking and positively participate in the experience.

Therefore, we suggest that care needs to be taken to balance support for inclusiveness with support for a stakeholder's specific needs based on their identity and relationship to the pregnancy. We now discuss some specific design opportunities for supporting different stakeholders independent of format.

5.2.1 Provide Support for Non-Parent Stakeholders in Pregnancy. While many non-parent stakeholders are involved in pregnancy to provide emotional, informational, and/or logistical support, we did not observe any pregnancy tracking apps explicitly for non-parent stakeholders, such as grandparents or a family's older children. While reviews show that non-parent stakeholders are able to use apps either for pregnant people or non-pregnant partners, we recommend apps include some specific features based on people's non-parent roles. For example, grandparents at a distance might not be able to help with monitoring tasks, but are still interested in following along with the pregnancy. Apps therefore can therefore enable following along with fetal development, replicating many of the "size comparison" and virtual fetuses common in pregnancy apps targeted at the pregnant person. Apps could also contain information on how advice on pregnancy and newborn care has changed since they became parents. As for a family's older children, studies suggest that parents' lack of interaction with older children during pregnancy often results in children's being anxious, misbehaving, and having difficulties in adapting to the arrival of a new life [44, 56]. We therefore suggest pregnancy tracking apps could leverage different types of tracked data as well as pregnancy-relevant information to prompt joint tracking or information-seeking behaviors between parents and older children.

5.2.2 Improve Designs of Apps Targeting Non-Pregnant Partners. Our study surfaces that non-pregnant partners have varied perceptions of the use of masculine design characteristics in the apps tailored for them. We see tradeoffs around the use of these stereotypically masculine aspects. For example, while some apps specifically for dads-to-be emphasize humor and playfulness over science and seriousness, some users, including a few pregnant people, appreciated that these apps added some levity to pregnancy rather than perpetuating fear around negative health consequences or guilt around decision-making. However, designs which embody these characteristics may also create some content which both partners find offensive or lacking. We encourage designers of apps geared towards non-pregnant partners to consider how to support a balance between humor and information. Given that all of the apps for non-pregnant partners included these masculine tonal elements, we believe that there is an opportunity for apps to do more in this space. But regardless, our results point to the utility of including more of the tracking and socializing features which are commonplace on mom-centric apps, at least to provide the option in case dads want to take advantage.

6 CONCLUSION

In examining the design of and people's experiences with 20 pregnancy tracking apps, we find that pregnancy tracking is a collaborative process, yet pregnancy apps primarily center the experiences and needs of one stakeholder, most often the person who is pregnant. Apps' lack of acknowledgment of other stakeholder identities such as partners, grandparents, and siblings often prevents stakeholders from attaining their social goals. This lack of support is further perpetuated by tracking apps encoding some socio-cultural norms around pregnancy, such as expectations around gendered parenting roles and norms around the identity of pregnant people. This study suggests the value of building pregnancy tracking technologies for collective use, supporting stakeholders without

presuming their identities and social relationships, while also considering stakeholders' specific needs based on their identity and role in pregnancy.

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