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Fostering Sustainable Female Participation in STEM Through Ecological Systems Theory: A Comparative Study in Three African Countries

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Abstract: This study explores factors influencing female engagement in STEM (Science, Technology, Engineering, and Mathematics) fields in Mozambique, Nigeria, and Uganda through Urie Bronfenbrenner's Ecological Systems Theory. The research collected qualitative data from 81 women across these countries through open-ended surveys. Using content analysis, the results demonstrate the critical role of personal interests nurtured by family, showing how direct interactions with family influence STEM engagement at a microsystem level. The mesosystem level reveals the supportive influence of community and school interactions, emphasizing the importance of relationships between different microsystems, such as family–school collaborations, in fostering female participation in STEM. The exosystem level identifies the impact of positive media portrayals and role models, illustrating how external environments indirectly affect perceptions and aspirations in STEM through media and societal influences. The macrosystem level underscores the persistent cultural norms shaping gender roles, reflecting broader societal and cultural values that influence gender diversity in STEM fields, with 63% of respondents in Mozambique, 57% in Nigeria, and 67% in Uganda indicating that societal views on gender roles discouraged participation. Lastly, the chronosystem level captures the temporal changes and progress in gender diversity in STEM, highlighting the need for targeted interventions and policy reforms to address longstanding gender imbalances. Despite progress, significant gender imbalances remain, necessitating targeted interventions and policy reforms. The study proposes a sustainable, collaborative model to foster early interest and sustained participation of females in STEM, emphasizing the importance of seamless cooperation among families, educational institutions, communities, and government bodies. The findings aid in creating supportive environments for sustaining female STEM participation, promoting economic and social development in Sub-Saharan Africa.

Keywords: STEM; ecological systems theory; gender diversity; Sub-Saharan Africa; women

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1. Introduction

STEM (Science, Technology, Engineering, and Mathematics) education has become a cornerstone of global economic and technological advancement, essential for driving innovation, addressing complex global challenges, and sustaining economic growth. A diverse and inclusive STEM workforce is particularly crucial for maximizing the potential of innovation, as diversity brings a variety of perspectives, ideas, and problem-solving

approaches necessary for tackling multifaceted issues and fostering creative solutions [1]. Research indicates that teams with diverse members are more likely to outperform homogeneous groups in terms of innovation and productivity [2]. Therefore, ensuring the participation of underrepresented groups, including women and minorities, in STEM is a strategic imperative for enhancing the overall effectiveness and impact of the STEM workforce [3]. Despite the recognized importance of diversity in STEM, significant disparities persist, with women remaining underrepresented in many STEM fields across the globe. This gender gap represents a substantial loss of potential talent and innovation capacity [4]. Addressing this gap requires concerted efforts to eliminate barriers and create supportive environments that encourage and sustain female participation in STEM. Promoting STEM education and ensuring diverse participation are critical for driving sustainable development and addressing the pressing challenges of our time, such as climate change, healthcare, and sustainable energy [5]. By investing in STEM education and fostering an inclusive environment, societies can harness the full spectrum of talent and ideas necessary to build a resilient and innovative future.

The state of female participation in STEM fields in Sub-Saharan Africa remains a critical area of concern, with significant underrepresentation of women in these disciplines. In Mozambique, women account for less than 10% of STEM graduates, reflecting deep-rooted societal and educational barriers (World Bank 2022, as cited in [6]). Nigeria, the most populous country in Africa, shows similar trends, with women taking less than 25% of STEM jobs and only 14% aspire to become scientists [7]. Uganda also faces significant challenges, where an underrepresentation of female students has been reported in computer science in [8] and other STEM-related subjects such as physics [9]. These disparities are not merely educational shortfalls but are deeply intertwined with cultural and societal norms that often discourage girls from pursuing STEM careers, perpetuating stereotypes that STEM fields are more suited for males [10]. Addressing the gender gap in STEM in Sub-Saharan Africa requires targeted interventions that increase female enrollment and retention in STEM education while creating supportive environments that challenge and change societal norms. By understanding the specific contexts and challenges faced in Mozambique, Nigeria, and Uganda, stakeholders can develop more effective strategies to promote gender equality in STEM and leverage the full potential of the region's human capital for sustainable development [11].

Females in STEM fields face a multitude of challenges that hinder their participation and progression, primarily due to cultural and societal barriers. Traditional gender norms and stereotypes perpetuate the belief that STEM fields are more suitable for males, discouraging girls and women from pursuing these disciplines [12]. These stereotypes often begin in early childhood and are reinforced through family expectations, educational practices, and media representations, creating an environment where females are less likely to envision themselves in STEM careers [13]. Gender stereotypes and traditional gender norms shape attitudes and behaviors that disadvantage females, leading to lower self-confidence and interest in STEM subjects [14]. Another significant challenge is the lack of close female role models, such as a family member, or mentorship opportunities in STEM. The scarcity of women in these fields means that many aspiring female scientists and engineers have few examples to follow and limited access to mentors who can provide career guidance and support [15]. This absence can lead to feelings of isolation and a lack of belonging, making it more difficult for women to overcome the barriers they face in these male-dominated fields [16]. Lastly, poverty significantly impacts female participation in STEM fields by creating economic barriers that limit access to quality education and career opportunities. Financial constraints often prevent girls from enrolling in STEM programs, particularly in low-income families where resources are scarce and education expenses are prioritized for male siblings [17]. Addressing these challenges requires comprehensive strategies that include changing societal attitudes towards gender and STEM, promoting gender-inclusive educational practices, and increasing the visibility and support of female role models and

mentors. By tackling these issues, it is possible to create a more equitable and supportive environment that encourages and sustains female participation in STEM.

Urie Bronfenbrenner's Ecological Systems Theory offers a comprehensive framework for understanding the multifaceted influences on human development and behavior, positing that individuals are shaped by a complex system of interrelated environments: the microsystem, mesosystem, exosystem, macrosystem, and chronosystem [18]. The microsystem encompasses immediate environments where individuals interact directly, such as family, school, and peer groups, including the support and encouragement girls receive from parents and teachers within educational settings. The mesosystem refers to the interconnections between these immediate environments, such as relationships between family and school, which can either support or hinder a girl's interest in STEM [19]. The exosystem consists of broader social systems that indirectly influence individuals, such as parental workplaces and educational policies; for instance, the availability of STEM programs and resources in schools, influenced by governmental and institutional policies, can significantly impact female participation in STEM [20]. The macrosystem encompasses cultural values, norms, and societal structures that shape attitudes and behaviors on a larger scale, such as societal attitudes towards gender roles and the value placed on STEM education for girls [18]. Finally, the chronosystem includes the dimension of time, accounting for changes and transitions over the life course and across historical periods, capturing shifts in societal attitudes towards gender and STEM, as well as individual life events that influence career choices [21]. By applying Bronfenbrenner's Ecological Systems Theory, researchers and policymakers can gain a holistic understanding of the various factors influencing female participation in STEM, facilitating the development of targeted and effective interventions to promote gender equity in STEM fields.

The need for sustainable strategies to foster and maintain female participation in STEM (Science, Technology, Engineering, Mathematics) fields is paramount. These strategies ensure that efforts to increase female engagement in these disciplines are not only implemented but also maintained over the long term, providing enduring support and opportunities for women. Evidence-based policy initiatives have been shown to effectively boost the sustainable representation of women in STEM by addressing the root causes of underrepresentation and fostering an inclusive organizational culture [22]. Projects such as Girls4STEM emphasize breaking stereotypes and encouraging young girls to pursue STEM careers through interactions with female STEM experts, demonstrating success in increasing self-confidence and interest in STEM disciplines among young girls, highlighting the importance of early and sustained intervention [23]. Furthermore, incorporating sustainability education into STEM programs can create advantageous learning environments for underrepresented groups, including women. Community-based learning and interdisciplinary studies have been found to be particularly effective in retaining diverse learners and promoting a positive learning experience [24]. By implementing sustainable strategies, educational institutions can ensure that female participation in STEM is not only increased but also maintained over time. These strategies provide the necessary support systems, mentorship opportunities, and inclusive environments that are crucial for the long-term success of women in STEM fields.

Selecting Mozambique, Nigeria, and Uganda as case studies for analyzing female participation in STEM is justified by the unique socio-cultural, economic, and educational contexts each country presents. Mozambique has demonstrated significant female representation in certain STEM fields, yet faces challenges in providing consistent educational and professional opportunities for women [25]. Nigeria, with its vast population and diverse cultural landscape, shows marked regional disparities in female STEM participation, highlighting the need for tailored interventions across different geopolitical zones [26]. Uganda, despite policy efforts, continues to struggle with gender gaps in STEM fields, necessitating an examination of both policy effectiveness and grassroots initiatives [27]. Comparative analysis is crucial in understanding the different contexts and identifying effective strategies to enhance female participation in STEM. By examining these three countries, we

can uncover specific barriers and successful practices that are context-dependent, thereby offering insights that can be generalized to other regions with similar challenges. This approach enables a holistic understanding of how various socio-economic and cultural factors influence female participation in STEM, and it helps in crafting policies and interventions that are not only effective but also sustainable and culturally sensitive [28].

The overarching objective of this research is to explore and analyze the factors influencing female participation in STEM within the contexts of Mozambique, Nigeria, and Uganda. Guided by Urie Bronfenbrenner's Ecological Systems Theory, this study aims to identify and understand the multiple levels of environmental influences—ranging from immediate personal interactions to broader societal and temporal contexts—that impact girls' and women's engagement in STEM fields [18]. Additionally, the research seeks to propose a sustainable transition and collaborative model to foster female participation in STEM, grounded in the findings and recommendations across all levels of the Ecological Systems Theory.

To achieve these objectives, the study is structured around several specific research objectives, each aligned with a different level of the Ecological Systems Theory:

- Microsystem: To explore the early experiences and influences, such as family, education, and personal interests, that spark interest in STEM among females in Mozambique, Nigeria, and Uganda.
- Mesosystem: To investigate the role of family and community in shaping gender norms related to STEM education and careers, and how these interactions influence female participation in STEM fields.
- Exosystem: To assess the impact of media representations and societal role models on gender stereotypes related to STEM, and to analyze how these stereotypes affect females' perceptions and participation in STEM careers.
- Macrosystem: To examine societal views on gender roles and their effects on decisions to study STEM fields, focusing on cultural norms and their influence on gender diversity in STEM education and careers.
- Chronosystem: To evaluate the changes in gender diversity in STEM fields over time and identify the factors that have contributed to these changes. Additionally, to propose strategies that could make STEM fields more inclusive and attractive to all genders in the future.
- Propose a sustainable transition and collaborative model: Develop a model for fostering female participation in STEM by integrating findings and recommendations from all levels of the Ecological Systems Theory.

By achieving these research objectives, the research aims to provide a comprehensive understanding of the factors that influence female participation in STEM across different ecological levels. The findings will not only highlight the specific challenges and opportunities in Mozambique, Nigeria, and Uganda but also offer insights into effective strategies for promoting gender equity in STEM education and careers. This holistic approach will contribute to developing sustainable interventions that can be adapted to similar contexts globally.

Our research hypothesis is based on the identification of various levels of environmental influence on female participation in STEM (Science, Technology, Engineering, and Mathematics) in Mozambique, Nigeria, and Uganda. Drawing from Urie Bronfenbrenner's Ecological Systems Theory, the hypothesis posits that personal, familial, societal, and temporal factors significantly impact women's engagement in STEM. Each level of the ecological system (microsystem, mesosystem, exosystem, macrosystem, and chronosystem) is hypothesized to have distinct effects on female participation, with personal interests and family encouragement hypothesized as critical at the microsystem level, while cultural norms and media portrayals are hypothesized to play a larger role at the exosystem and macrosystem levels. The hypothesis will be tested using qualitative data gathered through open-ended surveys, with the responses subjected to content analysis to uncover patterns

that either support or refute the predicted relationships between the ecological systems and female participation in STEM fields.

2. Theoretical-Conceptual Framework: Using Ecological Systems Theory

The Ecological Systems Theory, developed by Urie Bronfenbrenner, provides a comprehensive framework for understanding how different layers of environmental influence impact individual development. This theory can be effectively adapted to examine the factors influencing female participation in STEM. Bronfenbrenner's model includes five interconnected systems: the microsystem, mesosystem, exosystem, macrosystem, and chronosystem, each playing a critical role in shaping an individual's experiences and decisions [18].

Microsystem: The microsystem refers to the immediate environments that directly interact with the individual. For female students in STEM, this includes their family, school, and peer interactions. Early educational experiences, support from family, and personal interests play a crucial role in sparking interest in STEM subjects [29]. For example, a young girl encouraged by her parents to explore science kits or participate in math clubs may develop a keen interest in STEM fields.

Mesosystem—Family–School Interaction: The mesosystem encompasses the interrelations between the microsystems, such as the interactions between family and school environments. The role of family and community in shaping gender norms related to STEM education and careers is significant. Families that emphasize the importance of education and provide a supportive environment can positively influence girls' attitudes towards STEM. Additionally, schools that promote gender equality and offer programs to encourage female participation in STEM can reinforce these positive attitudes [30].

Exosystem—Media and Role Models: The exosystem involves external environmental settings that indirectly affect the individual, such as media representation and societal role models. Stereotypes related to gender and STEM are prevalent in media and can significantly impact girls' self-perception and interest in STEM fields. Exposure to female role models in STEM, whether through media, mentorship programs, or community outreach, can counteract negative stereotypes and inspire girls to pursue STEM careers [31].

Macrosystem—Cultural Norms: The macrosystem includes the broader cultural and societal norms that influence an individual's development. Societal views on gender roles can greatly affect decisions to study STEM fields. In societies where traditional gender roles are emphasized, women may be less likely to pursue STEM careers. However, changing cultural norms towards gender equality can lead to increased female participation in STEM [32].

Chronosystem—Changes Over Time: The chronosystem encompasses the dimension of time, reflecting the changes in an individual's environment over their lifespan. Gender diversity in STEM fields has evolved over time, with more initiatives aimed at increasing female participation. Understanding these temporal changes is crucial for identifying effective strategies to make STEM fields more inclusive and attractive to all genders [33].

By analyzing these various systems in Figure 1, we can better understand the complex factors that influence female participation in STEM. This framework not only highlights the importance of early educational experiences and family–school interactions but also underscores the significant impact of media representation, cultural norms, and temporal changes on shaping gender diversity in STEM fields.

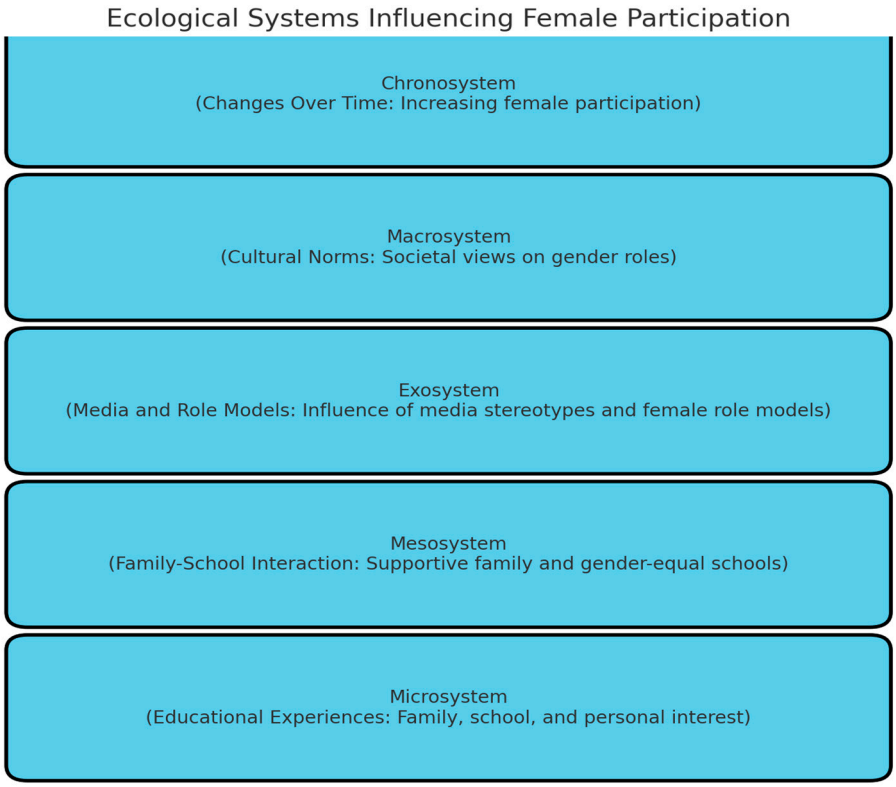


Figure 1. Bronfenbrenner's Ecological Systems Theory with respect to female participation in STEM. Adapted from Bronfenbrenner's Ecological Systems Theory [18].

3. Literature Review

The formation of interest in STEM fields is significantly shaped by early experiences and influences, including family, educational environments, and personal interests. Parental support and encouragement are critical, as parents who engage in their children's education, particularly in STEM subjects, can positively influence their attitudes and aspirations [34]. The educational background and professions of parents also play a significant role, with higher educational attainment and STEM-related careers fostering an environment that values scientific inquiry [35]. Early childhood education and exposure to STEM subjects lay a strong foundation for later learning, with playful learning activities promoting problem-solving skills and curiosity [36]. Teachers who inspire and engage students, combined with a supportive school environment offering STEM resources and activities, can significantly enhance interest in STEM [37]. Hobbies and personal interests, such as technology, science kits, and extracurricular activities, also play a crucial role in fostering a deeper understanding and sustained interest in STEM [38]. Extracurricular activities like science clubs and robotics competitions further increase motivation and competence in these areas [39]. Case studies of successful STEM professionals often highlight early interests and hobbies as pivotal in sparking curiosity and providing a foundation for future careers [40]. Thus, early experiences and influences are vital in shaping a sustained interest and participation in STEM fields.

Gender norms are deeply embedded in societal structures and are significantly influenced by family dynamics and community contexts. Traditional family roles, characterized by distinct gender-specific duties, often reinforce stereotypical career choices for girls, discouraging them from pursuing STEM fields [41]. In contrast, modern family roles, which emphasize gender equality, support more diverse career aspirations, including STEM [42]. Family expectations significantly influence career choices, with supportive family environments fostering greater interest and engagement in STEM among girls [43]. Communities also play a pivotal role in shaping and reinforcing gender norms. Community support programs designed to promote gender equality can significantly alter traditional gender

roles, encouraging more balanced gender representation in STEM [44]. Female leaders and community organizations are influential in promoting gender equality by advocating for policies and initiatives that support girls' education and career development in STEM [45]. The educational environment also shapes gender norms, with single-sex schools sometimes reducing gender stereotyping and coeducational schools fostering mutual respect and breaking down stereotypes [46]. Community perceptions and stereotypes about girls in STEM significantly affect their participation and success, with deeply rooted stereotypes often discouraging girls from pursuing STEM fields [47]. Addressing these stereotypes requires comprehensive community engagement and education to shift perceptions and create a more inclusive view of STEM capabilities for both genders.

Media representations and visible female role models play significant roles in shaping girls' perceptions and aspirations in STEM (Science, Technology, Engineering, Mathematics). Positive media portrayals can inspire and motivate girls to pursue STEM careers, while negative stereotypes can deter them. Media professionals significantly influence these stereotypes, creating a "chilly" climate that discourages girls from pursuing STEM fields [48]. Chesky and Goldstein [49] in 2018 argue that media representations often oversimplify the challenges faced by women in STEM and fail to address structural inequities. Visible female role models are crucial for encouraging girls to pursue STEM, as they can counteract negative stereotypes and provide tangible examples of success. Role model interventions have been shown to improve girls' interest and self-efficacy in STEM subjects [31]. Programs that connect girls with STEM professionals are effective in promoting gender equality, with brief exposures to female role models positively affecting perceptions and increasing enrollment in male-dominated STEM programs [50]. However, the effectiveness of role models depends on their presentation, as feminine STEM role models can sometimes demotivate young girls if their success seems unattainable [51]. Case studies highlight the long-term influence of early exposure to role models, with enhanced visibility through public engagement and mentoring improving the science capital of girls in STEM [52]. In sum, both media representations and role models are essential for breaking down stereotypes and encouraging more girls to pursue and succeed in STEM careers.

Cultural attitudes towards gender roles significantly influence women's participation in STEM. In Mozambique, traditional norms often confine women to domestic roles, limiting their aspirations in STEM fields [53]. Similarly, Nigeria's deeply entrenched gender roles create substantial barriers for women in STEM [54]. Uganda faces cultural challenges where societal expectations limit girls' aspirations in science and technology fields [55]. These societal expectations significantly impact girls' participation in STEM education, with gender biases and stereotypes often discouraging them from pursuing STEM subjects, resulting in lower enrollment and retention rates [56]. Various programs and policies aim to change societal views on gender roles and promote gender equality in STEM. In Mozambique, initiatives to enhance women's education and professional development are gradually changing traditional norms [53]. Nigeria has seen advocacy from women's groups and human rights activists to address discriminatory practices and promote equal access to education and political resources for women [57]. In Uganda, educational programs are helping to shift gender biases and encourage more girls to pursue STEM careers [55]. Success stories from these regions underscore the importance of community involvement and policy support in overcoming cultural barriers and promoting gender equality in STEM.

There are various programs and policies aim to change societal views on gender roles and promote gender equality in STEM. In Mozambique, initiatives to enhance women's education and professional development are gradually changing traditional norms [58]. Nigeria has seen advocacy from women's groups and human rights activists to address discriminatory practices and promote equal access to education and economic resources for women [59]. In Uganda, programs targeting the education sector are helping to shift gender biases and encourage more girls to pursue STEM careers [60]. Historically, women have been underrepresented in STEM fields, with their participation rates gradually increasing over the years. Key milestones, such as policy changes and the implementation of gender

equality programs, have significantly influenced gender diversity in STEM [61]. Recent data indicate a positive trend in gender diversity in STEM fields, although disparities still exist. In Uganda, the number of female students and academic staff in STEM fields has seen a gradual increase, though male dominance remains evident [61]. Similar trends are observed in Mozambique, where educational reforms and policy initiatives have contributed to improved gender diversity in STEM [58]. Several factors contribute to the changes in gender diversity in STEM, including educational reforms, policy changes, and societal shifts. International organizations and global movements advocating for gender equality have played a significant role in promoting these changes [62]. Future trends in gender diversity in STEM are expected to continue improving, with increased efforts to address gender biases and promote equality. However, potential challenges, such as persistent cultural norms and inadequate policy implementation, may hinder progress. Opportunities for further improvement lie in enhancing educational and professional support systems for women in STEM and promoting gender-sensitive policies [61].

Sustainable educational practices in STEM involve creating enduring and effective teaching methodologies, such as integrating professional learning communities and involving external experts to ensure continuous professional development for teachers [63]. Successful initiatives, like the Girls4STEM project, highlight how targeted interventions can break stereotypes and encourage female participation in STEM from a young age [23]. Effective collaborative models involve frameworks that facilitate cooperation among schools, families, communities, and governments, fostering authentic engagement by linking educational institutions with local communities [64]. Integrating the ecological systems model into STEM education can enhance the inclusivity of learning environments by understanding the interactions between various stakeholders [65]. Practical strategies to foster female participation in STEM include designing relational classrooms, teaching the history of gender inequality, and promoting growth mindset strategies [66]. Policy recommendations based on these strategies include increasing teacher autonomy, training, and representation to create a more supportive and inclusive environment. Applying Urie Bronfenbrenner's Ecological Systems Theory can develop a comprehensive model that addresses gender disparities by considering multiple layers of influence, from individual interactions to societal factors [18]. An integrated approach using this theory can help create a more inclusive and supportive STEM environment, benefiting from the synergy of coordinated efforts across different systems.

Against this background, we can conclude that the existing research lacks a comprehensive understanding of the contextual influences on female STEM participation in Sub-Saharan Africa, particularly in Mozambique, Nigeria, and Uganda. Thus, this study aims to address this gap by exploring the following research questions:

I. Microsystem: What are the early experiences and influences, such as family, education, and personal interests, that spark interest in STEM among females in Mozambique, Nigeria, and Uganda?
II. Mesosystem: How do family and community interactions shape gender norms related to STEM education and careers, and how do these interactions influence female participation in STEM fields?
III. Exosystem: What is the impact of media representations and societal role models on gender stereotypes related to STEM, and how do these stereotypes affect females' perceptions and participation in STEM careers?
IV. Macrosystem: How do societal views on gender roles affect decisions to study STEM fields, and what is the influence of cultural norms on gender diversity in STEM education and careers?
V. Chronosystem: What changes have occurred in gender diversity in STEM fields over time, and what factors have contributed to these changes? Additionally, what strategies can be proposed to make STEM fields more inclusive and attractive to all genders in the future?

VI. How can a model be developed to foster female participation in STEM by integrating findings and recommendations from all levels of the Ecological Systems Theory?

4. Method

4.1. The Research Design

This study will employ open-ended survey questions to gather qualitative data from women participating in STEM fields, allowing for rich, detailed responses and flexibility for participants to share their unique experiences. The use of open-ended survey questions in qualitative research is particularly effective in exploring complex phenomena in-depth [67]. Given that experiences of women in STEM can vary widely among individuals, this method enables participants to express their thoughts and feelings in an unrestricted manner, capturing the full range of their experiences. By grounding this approach within the context of fostering sustainable female participation in STEM through Ecological Systems Theory, the study aims to uncover nuanced insights into the factors influencing women's involvement in STEM across three African countries. This depth of understanding is crucial for identifying effective strategies and interventions to support and enhance female participation in STEM fields.

4.2. Participants

The study involved a total of 81 women currently participating in STEM fields across three African countries: Mozambique, Nigeria, and Uganda. The Nigerian sample consisted of 34 women, predominantly at the undergraduate level (32). The age distribution for the Nigerian participants included various age groups: 18–20 years, 21–22 years, 23–25 years, and 26 years and above. Their courses of study were diverse, including Pure and Applied Chemistry, Pharmacy, Physiotherapy, Environmental Management and Toxicology, Biology, Computer Science, Psychology, and a predominant number in Biochemistry. In Uganda, 29 women participated, with educational levels ranging from undergraduate to masters. The age distribution for Ugandan participants included 18–20 years, 21–22 years, 23–25 years, and 26 years and above. Their courses of study included Environment and Disaster Management, Medicine and Surgery, Finance, Computer Science, Geomatics, Nursing, Clinical Medicine, Applied Biochemistry, Applied Design and Fine Art, Electrical Engineering, MSc Pharmacology, Environmental Science, MSc Forestry, and Bachelor of Civil Engineering. The Mozambican sample included 18 women, all aged between 18 and 20. Seventeen participants were studying Chemistry Education, and one was studying Physics Education, all at the undergraduate level.

4.3. Instrument

Before initiating the design, an exhaustive review of the pertinent literature was conducted to ensure the relevance and comprehensiveness of the questionnaire. This review identified established frameworks and models, with a particular focus on Bronfenbrenner's Ecological Systems Theory, to guide the development of the questionnaire. The microsystem level addressed early educational experiences and influences with items such as "What early experiences or influences made you interested in STEM (like family, education, or personal interests)?" [68]. The mesosystem level examined family–school interactions through questions like "What role do you think family and community play in shaping gender norms related to STEM education and careers?" [69]. The exosystem level included items on media and role models, such as "Have you encountered any stereotypes related to gender and STEM?" and "How have these stereotypes affected you or others?" [70]. The macrosystem level explored cultural norms with questions like "In your opinion, how does society's view of gender roles affect people's decisions to study STEM fields?" [42]. Finally, the chronosystem level addressed changes over time with items such as "How do you see gender diversity in STEM fields?" and "What changes do you think could make STEM fields more inclusive and attractive to all genders?" [71]. Specific items were crafted based on insights from the literature to capture the multidimensional influences on

gender diversity in STEM. To reduce response bias, the questionnaire included neutral and non-leading questions, and employing open-ended questions, refined through pilot testing for clarity and effectiveness.

4.4. Data Collection

This study utilized convenience sampling due to its cost-effective nature and ease of accessing subjects for the researcher. This method involves selecting female participants who are readily available, without considering their distribution across the population [72]. Email invitations containing a direct survey link were sent to potential participants, ensuring they could access the survey at their convenience. A follow-up reminder email was sent one week later to encourage those who had not yet responded, aiming to enhance the overall response rate [73]. Participants were given a two-week period to complete the survey, offering them ample flexibility [67]. Regular reminders were sent out to ensure a higher response rate, gently nudging participants to complete the survey if they had not already done so. This not only highlighted the importance of their input but also catered to those who might have forgotten or overlooked the initial invitation [74]. The digital approach facilitated easy distribution and quick response times, while the platform allowed for real-time tracking of responses and streamlined data collection [75].

4.5. Ethical Considerations

An informed consent form was presented to each participant from the outset. Each participant read the form that details the study's objectives, their role in the research, and assurances of confidentiality and anonymity. Additionally, participants were informed of their right to withdraw from the study voluntarily at any point without any repercussions. Data protection measures were stringently applied; the survey platform used complied with relevant data protection regulations, incorporating encryption and secure data storage. To further ensure anonymity, participants' responses were coded, with any potentially identifiable information being removed or altered.

4.6. Data Analysis

Content analysis, a systematic, quantitative, and objective technique used to analyze the content of communication, aimed to identify and quantify the presence, meanings, and relationships of certain words, themes, or concepts [76]. The objective was to transform qualitative data into quantitative data by coding the text into manageable categories, either predefined or emerging during analysis. The data analysis for this study was conducted using Atlas.ti 22, a powerful qualitative data analysis software. The textual data collected from the open-ended survey responses were imported into Atlas.ti 22, and predefined categories based on the research objectives were created, such as "family influence", "educational experiences", "personal interests", "community support", "media stereotypes", and "cultural norms" [76]. An initial open coding process was conducted where segments of text were assigned to these categories, with new categories emerging during this process [77]. Following open coding, axial coding linked categories and subcategories, identifying relationships and patterns within the data [78]. The frequency of each code was calculated to quantify the occurrence of different themes, and patterns of co-occurrence were examined to identify how different themes were related [79]. For instance, the relationship between "educational experiences" and "STEM career interest" was analyzed. The results of the coding process were compiled into statistical summaries that provided a detailed quantitative description of the content [80]. This structured approach emphasized the frequency and patterns of words or concepts, providing a comprehensive understanding of the data that could be used to develop targeted interventions for promoting gender equity in STEM fields.

5. Results

The bar chart (Figure 2) illustrates the distribution of early influences such as Family, Education, and Personal Interests on female participation in STEM across Mozambique,

Nigeria, and Uganda, based on survey responses. The data shows that personal interests significantly influenced female participation in Uganda, with 16 responses, and Nigeria, with 15 responses. Mozambique recorded fewer responses, with only 6. This suggests that personal interest is a key factor in Uganda and Nigeria, while other influences might play a larger role in Mozambique.

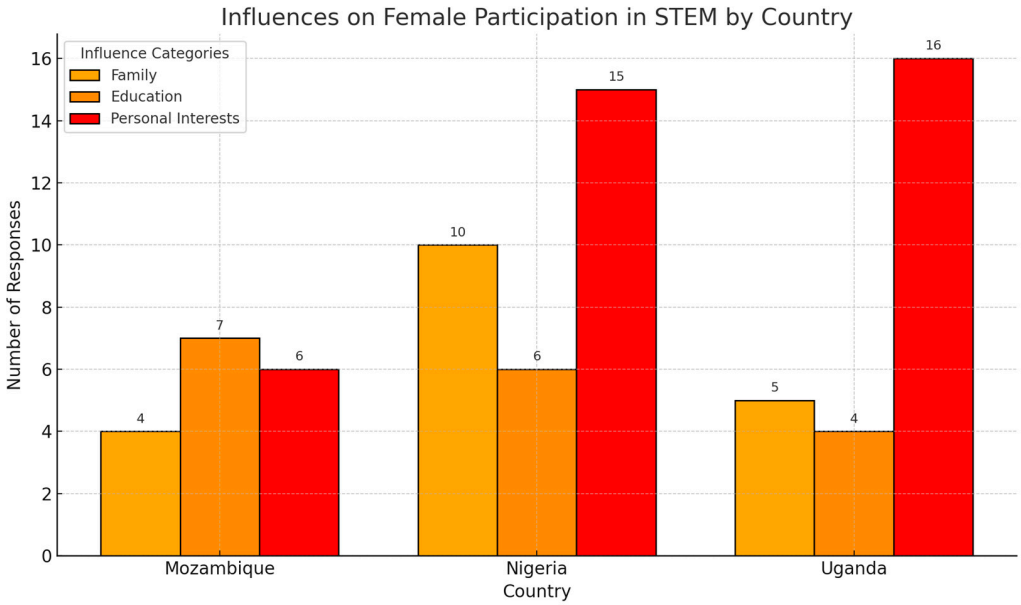


Figure 2. Early influences of female participation in STEM in Mozambique, Nigeria, and Uganda.

The analysis of responses to research objective 2 in Figure 3 reveals the impact of encouragement and support from family and community on shaping gender norms related to STEM education and careers. It is evident that these factors are predominant across all three countries: Mozambique, Nigeria, and Uganda. The responses suggest that most respondents view family and community support as essential in fostering positive attitudes towards female participation in STEM, thus highlighting the role of social structures in shaping gender norms.

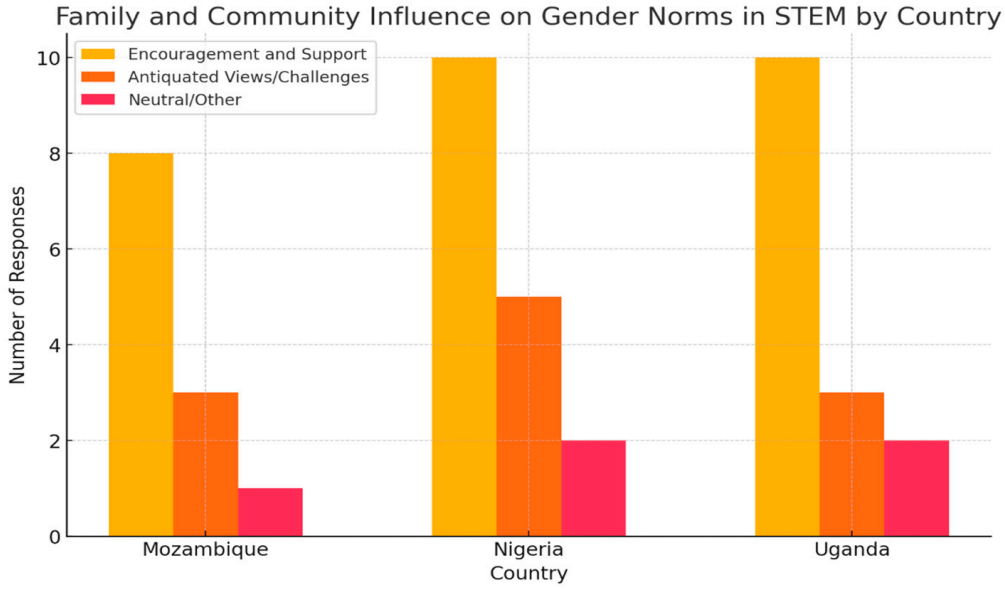


Figure 3. Influence of family and community on gender norms in Mozambique, Nigeria, and Uganda.

The analysis of responses to research question 3 in Figure 4 reveals the prevalence of gender stereotypes encountered in STEM fields across the three countries. Uganda reported the highest occurrence with 18 responses, followed by Nigeria with 15 responses, and Mozambique with the lowest at 7. The chart also details the effects of these stereotypes: they are most discouraging in Nigeria (10 responses) and Uganda (12 responses). Mozambique presents a more balanced distribution, with 3 responses indicating discouragement, 4 showing motivation, and 3 indicating no effect. This highlights that while gender stereotypes are a significant barrier in all three countries, their impact varies, with Uganda and Nigeria facing greater discouragement.

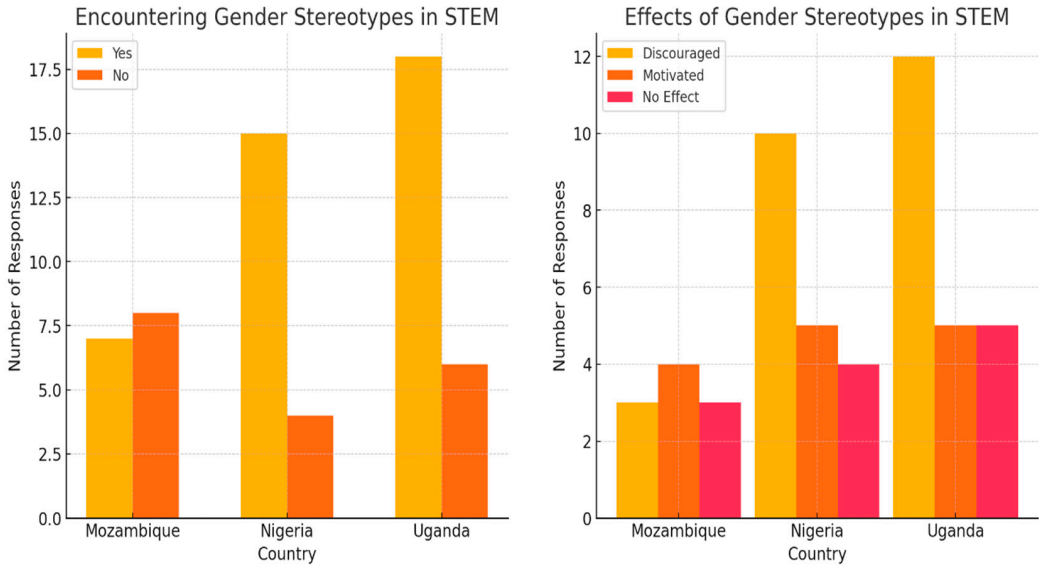


Figure 4. Level of gender stereotypes and its effect on STEM in Mozambique, Nigeria, and Uganda.

The bar charts in Figure 5 show the positive influence of media representation on STEM participation in Nigeria and Uganda (7 responses each) and Mozambique (6 responses). Similarly, the impact of role models is acknowledged across all three countries. These findings underscore the importance of positive media portrayal and role models in encouraging female participation in STEM fields, suggesting that increased visibility and representation in media can have a substantial motivational impact.

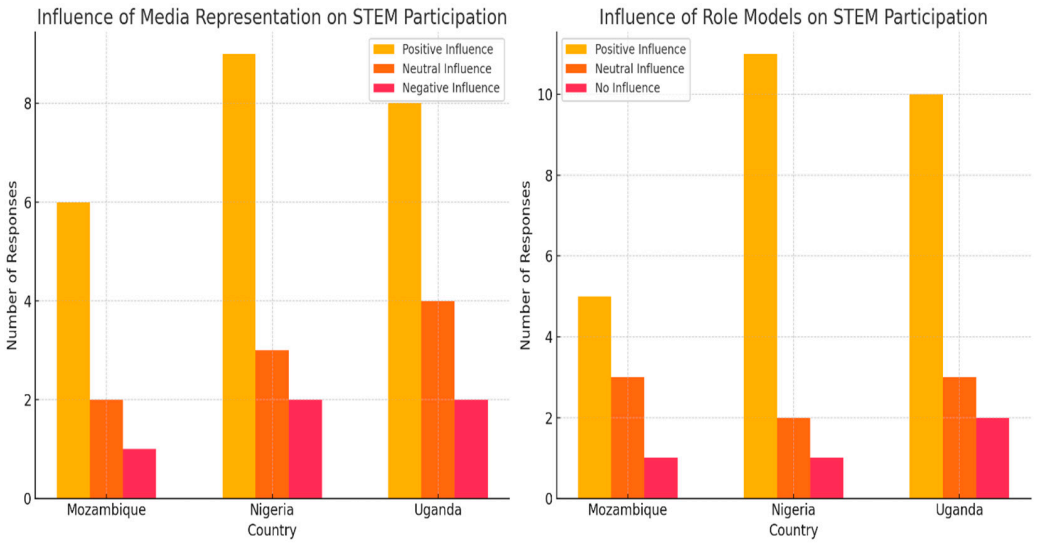


Figure 5. Role of media and role models on STEM participation in Mozambique, Nigeria, and Uganda.

The analysis of responses to research question 5 in Figure 6 indicates that societal views on gender roles predominantly exert a negative influence on decisions to study STEM fields across Mozambique, Nigeria, and Uganda. However, a smaller but notable number of responses from Nigeria (5), Mozambique (3), and Uganda (3) suggested that cultural norms can also positively influence these decisions. Mixed or neutral influences were reported by 5 respondents in Mozambique, 4 in Nigeria, and 4 in Uganda, indicating a more nuanced or balanced perspective among some individuals.

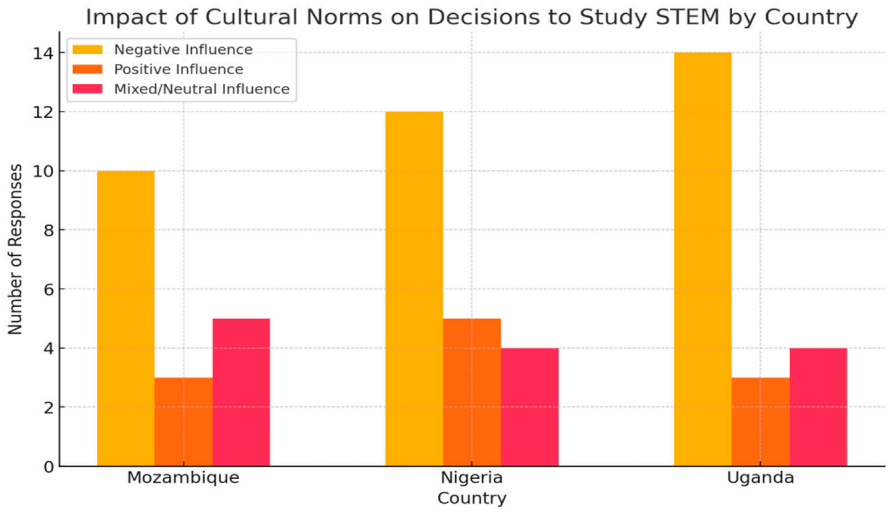


Figure 6. Impact of cultural norms on decision to study STEM in Mozambique, Nigeria, and Uganda.

The analysis of responses to research question 6 (Figure 7) shows that respondents in the three countries perceive that the participation of females in STEM has been on the increase over time, particularly in Uganda (14 responses), followed by Nigeria (12) and Mozambique (10). Despite this progress, gender imbalance remains a critical issue, with Mozambique reporting the fewest mentions of improvement (4). Additionally, Mozambique had the highest number of responses indicating no change in female participation (4). To promote inclusivity, gender equality initiatives were the most frequently mentioned solution across all three countries, along with educational support and scholarship opportunities, particularly emphasized in Mozambique (6 responses).

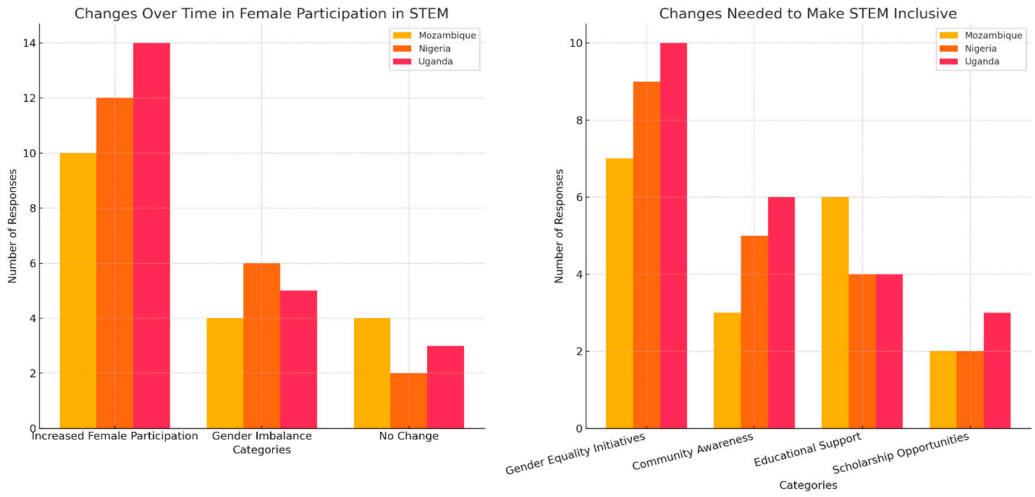


Figure 7. Changes over time in female participation and critical changes needed to make STEM inclusive in Mozambique, Nigeria, and Uganda.

The Proposed Sustainable Model to Foster Early Interest in STEM Among Females

The proposed sustainable transition and collaborative model for fostering early interest in STEM among females emphasizes seamless collaboration between key stakeholders, ensuring a supportive and inclusive environment from home to school and community. Moreover, based on Urie Bronfenbrenner's Ecological Systems Theory, each step of the model reflects the progression from the most immediate and direct influences on the individual (microsystem level) to the broader, more distal influences (macrosystem and chronosystem levels). As shown in Figure 8, the model incorporates key recommendations to justify its development.

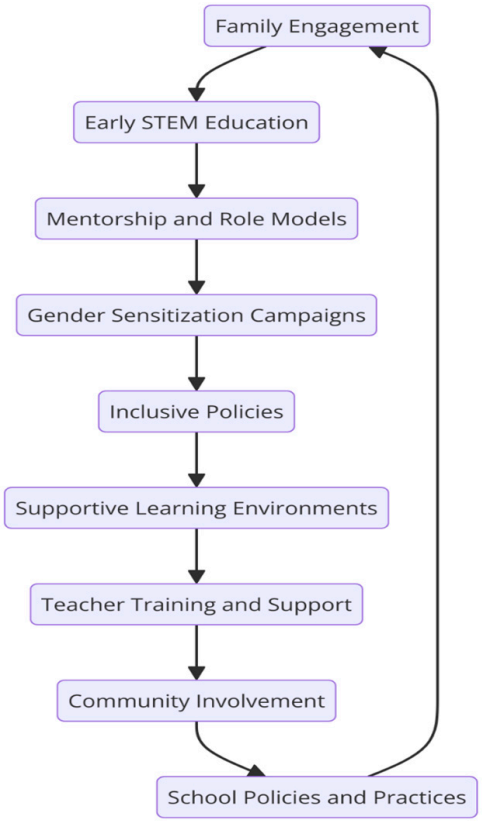


Figure 8. A proposed sustainable model to foster early interest in STEM among females.

Step 1: Personal Interest Supported by Family
Personal Interest: Highest in Nigeria, followed by Uganda and Mozambique.

- Parents attend workshops and seminars conducted by teachers and community leaders.
- This step lays the foundation by providing resources and opportunities for girls to explore STEM at home.

Step 2: Early STEM Education
Educational Influence: Consistent across the three countries, with Mozambique having a slight edge.

- Integrate STEM subjects into school curricula, managed by teachers and supported by school administrators and government policies.
- This phase encourages active student participation through clubs and competitions.

Step 3: Mentorship and Role Models
Personal Interests: Most significant in Uganda and Nigeria, with Mozambique showing relatively fewer responses in this category.
Positive Influence of Role Models: Highest in Nigeria, followed by Uganda and Mozambique.

- Female STEM professionals mentor students, facilitated by teachers and supported by local and international organizations, providing real-world connections and guidance.

Step 4: Gender Sensitization Campaigns
Antiquated Views/Challenges: More prevalent in Nigeria compared to Mozambique and Uganda.

- Challenge societal stereotypes with community leaders and organizations launching awareness campaigns and events.
- Female STEM professionals share their success stories, supported by government bodies and funded by organizations, promoting gender diversity.

Step 5: Inclusive Policies
Negative Influence: Predominant theme across all three countries.

- Government bodies implement policies for equal opportunities, with school administrators monitoring compliance and organizations providing scholarships and advocacy.

Step 6: Supportive Learning Environments
Support and Encouragement: Predominant theme across all three countries.

- Ensure policies are effectively implemented by creating safe, inclusive environments, addressing discrimination, and fostering positive experiences.

Step 7: Teacher Training and Support

- Prepare educators with gender-sensitive methods, supported by school administrators, government-funded programs, and resources from organizations, ensuring educators can effectively support female students.

Step 8: Community Involvement
Community Awareness: Highest in Uganda, followed by Nigeria and Mozambique.

- Extend support beyond schools with community leaders, parents, and government bodies promoting STEM education, organizing events, and initiatives that reinforce school efforts.

Step 9: School Policies and Practices
Gender Equality Initiatives: Most frequently mentioned change needed to make STEM inclusive across all three countries.

- Formalize collaborative efforts with policies for equal support in STEM, implemented, monitored, and continuously improved based on feedback from families and community involvement, creating a sustainable cycle that fosters female participation in STEM.

By following this model, key stakeholders can collaboratively create a supportive and inclusive environment that encourages and sustains female participation in STEM fields, addressing and leveraging the specific influences and challenges identified in Mozambique, Nigeria, and Uganda.

6. Discussion

The first research objective was to delve into early experiences and influences within the microsystem level, such as family, education, and personal interests, that inspire interest in STEM among females in Mozambique, Nigeria, and Uganda. Personal interests emerged as the most significant factor in Uganda (64%) and Nigeria (48% responses), whereas Mozambique had relatively fewer responses (35%). These results underscores the importance of extracurricular activities and hobbies in sustaining STEM interest, as noted by [38]. One participant from Uganda stated, "*As a person who likes discovering and exploring, I have all experiences in all aspects of STEM. Looking at nature and the science that is within, I am always so much interested in the formation of some things and all the chemistry and physics that is within. The love for discovery and science within the world therefore made*

me do a course that would somehow dig deeper into what I am always interested in knowing concerning environmental science". Thus, understanding these early influences provides valuable insights for developing targeted interventions to promote and sustain female participation in STEM, highlighting the need for supportive family environments, engaging educational practices, and opportunities to cultivate personal interests.

The second research objective aimed to explore the mesosystem level, focusing on how family and community interactions shape gender norms related to STEM education and careers, and influence female participation in STEM fields in Mozambique, Nigeria, and Uganda. The findings indicated that encouragement and support from family and community are predominant themes across all three countries (Mozambique 67%, Nigeria 59%, and Uganda 67%), suggesting a positive influence on shaping gender norms. For instance, one participant from Mozambique noted, "*My family always influenced me to like sciences because they believed that the more interest I developed in these subjects the better my academic performance would be*". These results are consistent with previous studies that emphasized the significant role of family and community support in fostering positive attitudes towards STEM among girls [41]. For instance, Ref. [44] highlighted the impact of community support programs in promoting gender equality and encouraging more balanced gender representation in STEM. Additionally, the findings align with [81] who noted the influence of local leaders and community organizations in advocating for girls' education and career development in STEM. In conclusion, addressing traditional gender norms and enhancing family and community support systems are crucial for increasing female participation in STEM fields.

The third research objective explored the exosystem level, focusing on the impact of media representations and societal role models on gender stereotypes in STEM, and how these stereotypes influence females' perceptions and participation in STEM careers in Mozambique, Nigeria, and Uganda. The findings revealed that encountering gender stereotypes in STEM is most prevalent in the three countries. Also, these stereotypes have predominantly discouraged effects in all the three countries. One participant from Nigeria expressed, "*Sometimes as a girl, people think that I don't have the capacity to excel in some fields like science courses*". However, this prevalence of gender stereotypes cannot be linked to the influence of media. This is contrary to prior research indicating that media often perpetuates gender stereotypes [48,49]. Our studies show a high level of positive influence of media representation in the three countries (Nigeria 69%, Uganda 57%, and Mozambique 67%). Moreover, the presence of female role models in Mozambique (56%), Nigeria (79%), and Uganda (67%) plays a critical role in counteracting negative stereotypes and inspiring girls to pursue STEM careers, as supported by [31]. Programs that connect girls with female STEM professionals have shown to positively impact perceptions and increase enrollment in male-dominated STEM programs [50]. In conclusion, promoting positive media representations and increasing the visibility of successful female role models are crucial strategies for reshaping perceptions and creating an inclusive environment that encourages and sustains female participation in STEM careers.

The fourth research objective examined the macrosystem level, focusing on how societal views on gender roles affect decisions to study STEM fields and the influence of cultural norms on gender diversity in STEM education and careers. The findings reveal that negative societal views on gender roles predominantly discourage female participation in STEM fields across all three countries (Mozambique 63%, Nigeria 57%, and Uganda 67%). Positive influences were significantly fewer, suggesting that while some cultural shifts towards gender equality exist, they are not yet widespread. One participant from Mozambique noted, "*Society's view of gender roles negatively affects individuals' decisions to enroll in STEM fields. For men, they say you must be very intelligent and gifted to be part of STEM. For women, they make it seem impossible, which is not true. We are all capable*". These results align with previous studies which highlighted the substantial impact of entrenched cultural norms on limiting female aspirations and participation in STEM [53]. For instance, the author found that traditional norms in Mozambique often confine women to domestic roles,

similarly observed in Nigeria and Uganda. Additionally, societal expectations significantly affect girls' participation in STEM education, perpetuating gender biases and stereotypes that discourage them from pursuing STEM subjects [56]. The role of educational programs and advocacy by women's groups, as noted in previous studies, is crucial in shifting these societal views and promoting gender equality in STEM [81]. In conclusion, addressing negative cultural norms and promoting positive societal views on gender roles are essential for improving gender diversity in STEM fields. This requires sustained efforts through educational reforms, community engagement, and policy interventions to create a more inclusive environment that encourages female participation in STEM careers.

The fifth research objective addressed the chronosystem level, evaluating the changes in gender diversity in STEM fields over time and identifying contributing factors, while proposing strategies for future inclusivity. The findings indicate an increase in female participation in STEM fields over time across the three countries (Mozambique 56%, Nigeria 60%, and Uganda 64%). Despite these gains, gender imbalances persist (Mozambique 29%, Nigeria 30%, and Uganda 24%). One participant from Nigeria noted, "*Currently, many females have come up to study science courses than before*". These findings align with previous studies that document gradual improvements in gender diversity in STEM due to educational reforms and policy initiatives [58]. Historical trends highlight significant milestones such as the implementation of gender equality programs, which have positively impacted female participation in STEM [61]. However, persistent cultural norms and inadequate policy implementation continue to challenge progress [53]. To address these issues, respondents emphasized the need for gender equality initiatives (Nigeria 45%, Uganda 43%, and Mozambique 39%). Community awareness campaigns and educational support were also highlighted as essential strategies. These strategies are supported by previous research that underscored the importance of creating supportive and inclusive environments through community engagement and policy interventions [44]. In conclusion, while there have been positive changes in gender diversity in STEM fields, sustained efforts through comprehensive gender equality initiatives, community awareness, and enhanced educational support are crucial for creating a more inclusive and attractive STEM environment for all genders in the future.

The final research objective focused on proposing a sustainable transition and collaborative model by synthesizing insights from the microsystem, mesosystem, exosystem, macrosystem, and chronosystem levels. The findings highlight the critical role of personal interest supported by family in fostering interest in STEM, particularly in Nigeria and Uganda, as emphasized in the study [34]. Community involvement and supportive educational environments also play significant roles across all three countries, reinforcing previous research on the importance of comprehensive strategies that include family and community engagement [43]. Successful initiatives like the Girls4STEM project illustrate the effectiveness of targeted interventions in breaking stereotypes and encouraging female participation in STEM [23]. Effective collaborative models involve cooperation among schools, families, communities, and governments, fostering authentic engagement by linking educational institutions with local communities [64]. The proposed model emphasizes seamless collaboration among key stakeholders to create a supportive and inclusive environment that nurtures and sustains female participation in STEM fields. This integrated approach, grounded in the Ecological Systems Theory, addresses the root causes of underrepresentation and fosters long-term success in STEM education and careers [18]. In conclusion, the proposed sustainable transition and collaborative model leverages insights from all ecological levels to promote and maintain female participation in STEM, ensuring a more inclusive and diverse STEM workforce.

The relevance of Urie Bronfenbrenner's Ecological Systems Theory in this research is paramount, as it provides a comprehensive framework for understanding the multiple levels of environmental influences that affect female participation in STEM (Science, Technology, Engineering, and Mathematics). By examining the microsystem, mesosystem, exosystem, macrosystem, and chronosystem, this study captures the intricate interplay

between personal, familial, societal, and temporal factors. The findings underscore the critical role of family support and early educational experiences at the microsystem level, which aligns with previous studies highlighting the importance of parental engagement in fostering STEM interest [34]. At the mesosystem level, the positive influence of community and school interactions is evident, supporting the notion that a supportive environment can enhance female participation in STEM [43]. The exosystem analysis reveals the impact of media and role models, emphasizing the need for positive representations to counteract gender stereotypes [48]. The macrosystem highlights the pervasive influence of cultural norms on gender roles, consistent with previous findings on societal barriers to female STEM participation [53]. Finally, the chronosystem perspective shows changes over time, reflecting gradual improvements due to policy initiatives and educational reforms [61]. By integrating these levels, this research provides a holistic understanding of the factors influencing female STEM participation and offers a robust foundation for developing targeted interventions to promote gender equity in STEM fields.

The practical implications and significance of this study are multifaceted, offering critical insights for policymakers, educators, and community leaders aiming to enhance female participation in STEM fields in Sub-Saharan Africa. Grounded in Urie Bronfenbrenner's Ecological Systems Theory, which examines the influence of various environmental factors on female engagement in STEM, the study emphasizes the importance of adopting a holistic approach that integrates efforts across multiple levels, including family, school, community, and government. The pivotal roles of family support, early educational experiences, and community involvement underscore the need for comprehensive strategies to foster female participation in STEM. For instance, initiatives like the Technovation Challenge have proven effective in breaking stereotypes and fostering interest among young girls by providing role models and mentorship [82]. Furthermore, collaborative models that link schools, families, communities, and governments are essential for creating supportive environments conducive to sustaining female participation in STEM [83]. This study suggests that targeted interventions and policy reforms are crucial for addressing deep-seated cultural norms and stereotypes that hinder women's advancement in STEM. To this end, educational programs must address stereotypes and biases within classrooms and society by incorporating gender-sensitive training for educators, promoting inclusive curricula that highlight female role models in STEM, and conducting workshops that challenge existing gender norms [84]. Additionally, offering scholarships and grants specifically for women pursuing STEM education can reduce financial barriers, especially for women from underrepresented or economically disadvantaged backgrounds [85]. These financial incentives should be complemented by mentorship programs pairing beneficiaries with successful female STEM professionals, providing guidance throughout their academic and early career journeys. Finally, creating networking opportunities through mentorship relationships, internships, and professional networking events is vital for bridging the gap between academic training and career placement, reinforcing commitment to STEM fields [86]. These practical recommendations are supported by the existing literature which highlights the effectiveness of sustained, multi-faceted interventions in fostering inclusive and diverse STEM environments [87].

7. Limitations of the Study

The study has several limitations that should be acknowledged. First, the use of convenience sampling may introduce bias, as the selected participants may not fully represent the diverse experiences and perspectives of all women in STEM fields across Mozambique, Nigeria, and Uganda, which limits the generalizability of the findings [88]. Moreover, the small sample size of only 81 female university students from these three countries further restricts the applicability of the results to other regions with different socio-cultural, economic, and educational contexts. The reliance on open-ended survey responses as the sole method of data collection limits the study's depth, as it does not benefit from methodological triangulation, such as incorporating interviews or focus groups

to enhance the robustness of the conclusions [72]. Additionally, the research captures a snapshot in time without accounting for temporal changes or the evolving nature of female participation in STEM, which could be influenced by ongoing social, cultural, and policy developments. Another limitation is the lack of consideration for intersectional factors such as ethnicity, socioeconomic status, or disability, which could provide a more nuanced understanding of the barriers and facilitators affecting women's participation in STEM. The potential for response bias, where participants may overstate or understate their experiences due to social desirability or recall, could also affect the accuracy of the data collected [89]. Moreover, the absence of longitudinal data limits affect the study's ability to observe changes over time, preventing insights into the long-term effects of various interventions and shifts in societal attitudes [90]. Finally, while the study recognizes the impact of cultural norms, it may lack a deeper exploration of the cultural nuances specific to each region, suggesting a need for a more culturally sensitive approach to understand how local traditions and beliefs influence female participation in STEM. Given these limitations, the conclusions drawn from this study should be interpreted with caution.

8. Conclusions

This study analyzes factors influencing female participation in STEM fields in Mozambique, Nigeria, and Uganda through Urie Bronfenbrenner's Ecological Systems Theory. It examines the interplay of personal, familial, societal, and temporal influences on women's STEM engagement across five environmental levels. At the microsystem level, personal interest is crucial. The mesosystem highlights community and family interactions in shaping gender norms. The exosystem shows the positive impact of media portrayals and role models, while the macrosystem addresses cultural norms affecting gender roles. The chronosystem level reveals that gender diversity in STEM fields has gradually improved over time due to educational reforms and policy initiatives.

Despite these gains, persistent cultural norms and inadequate policy implementation continue to challenge progress in gender diversity. The study underscores the importance of comprehensive strategies that integrate efforts across multiple levels of influence by proposing a sustainable, collaborative model that involves seamless cooperation among families, educational institutions, communities, and government bodies. This model aims to create supportive environments that encourage and sustain female participation in STEM fields, ultimately contributing to broader economic and social development goals in Sub-Saharan Africa.

All the hypotheses formulated were supported by the findings. The research successfully demonstrated that each level of Bronfenbrenner's ecological system plays a pivotal role in influencing female participation in STEM. Personal interest, often nurtured by family support, was confirmed as a key driver at the microsystem level, while community engagement and school interactions (mesosystem) were shown to positively shape gender norms. The exosystem and macrosystem hypotheses, which suggested the importance of media representations and societal role models, were validated through participants' responses that highlighted both the discouraging effects of stereotypes and the motivational power of positive role models. Finally, the chronosystem hypothesis, which addressed changes in gender diversity over time, was confirmed as participants indicated a gradual but significant increase in female representation in STEM fields, bolstered by policy initiatives and cultural shifts. The study's findings align closely with the hypotheses, underscoring the complex and multi-layered influences on female STEM participation.

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Informed Consent Statement: Informed consent was obtained from all participants prior to their involvement in the study. Participants was fully informed about the nature, purpose, and potential risks and benefits of the research. They were assured that their participation was voluntary, and they could withdraw from the study at any time without any consequences.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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