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REVIEW ARTICLE

Empowering Women in Mathematics: Pioneering a Rigorous and Inclusive STEM Paradigm for Vikasit Bharat 2047

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Abstract

As India approaches its centenary of independence in 2047, the nation's progress is closely tied to advancements in science, technology, engineering, and mathematics (STEM). However, achieving an equitable STEM landscape, where women are equal stakeholders, remains a significant challenge. The underrepresentation of women in mathematics, a foundational discipline within STEM, poses critical hurdles to national and global goals of scientific innovation and technological leadership. This paper examines the vital role of empowering women in mathematics as both a standalone discipline and an essential component of the broader STEM ecosystem, offering insights into how this empowerment can reshape India's future.

Despite a rich history of contributions from women in mathematics, including figures like Hypatia of Alexandria, Shakuntala Devi, and contemporary mathematicians such as Neena Gupta, systemic challenges persist. These include gender bias, societal expectations, and inadequate mentorship, all of which hinder women's full participation in the field. This paper analyzes these barriers in the Indian context and proposes targeted interventions at educational, institutional, and policy levels to dismantle them.

India has made significant strides in promoting girls' education and STEM participation through initiatives like "Beti Bachao, Beti Padhao" and various STEM education programs. However, women's representation in advanced mathematics education, research, and academic leadership remains disproportionately low. The importance of nurturing girls' interest in mathematics from early education through university is emphasized, along with the role of academic institutions in fostering inclusive environments. Proposed strategies include establishing women-led mathematics clubs, mentorship programs, and scholarship initiatives aimed at encouraging early engagement with mathematics.

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Looking toward 2047, integrating women into mathematical research and STEM professions is essential for national growth. Mathematics plays a crucial role in cutting-edge fields such as artificial intelligence (AI), machine learning, and quantum computing. Women's participation in these areas can significantly impact not only technological advancement but also the resolution of societal challenges, including healthcare optimization, environmental modeling, and resource management. By cultivating a culture that supports women's contributions to mathematics, India can enhance its global standing in STEM innovation and leadership.

This paper also presents a case study of the author's research on mathematical modeling, demonstrating how interdisciplinary approaches rooted in mathematical principles can drive societal progress. The author's work exemplifies the potential of mathematics to solve complex technical problems and influence cultural and historical understanding, as evidenced by projects like Vedic Geometry and the mathematical underpinnings of ancient temple architecture.

In conclusion, empowering women in mathematics is not merely a matter of gender equity but a national imperative. As India envisions a new Bharat by 2047, women mathematicians and STEM professionals must lead this transformation. By dismantling barriers and creating pathways for women's excellence in mathematics, India can foster a more innovative, inclusive, and prosperous future. This paper calls for a collective effort from educational institutions, policymakers, and industries to invest in women's STEM education and career development, ensuring that their contributions shape a technologically advanced and equitable India.

Keywords: *Women in STEM; Gender equity; Mathematical modeling; Barriers in STEM; India 2047 vision; Interdisciplinary research; Women in academia; Inclusive education*

1. Introduction

As India approaches its centenary of independence in 2047, the nation stands on the threshold of remarkable advancements in science, technology, engineering, and mathematics (STEM). Integral to this vision is the equitable participation of women in STEM disciplines, particularly in mathematics, which serves as the foundation for transformative technologies such as artificial intelligence (AI), quantum computing, and data science. However, the persistent underrepresentation of women in mathematics remains a significant challenge, threatening the country's capacity to achieve its full potential in technological innovation and global leadership.

The history of women in mathematics is rich and inspiring, marked by extraordinary figures who defied societal norms and systemic barriers. Hypatia of Alexandria, often regarded as the first known female mathematician, played a crucial role in early mathematical thought yet faced persecution due to her intellectual pursuits [1]. Similarly, Shakuntala Devi, widely known as the "human computer," showcased the immense capabilities of women in mathematics through her exceptional calculation skills [2]. More recently, Neena Gupta's groundbreaking work in commutative algebra has received international acclaim, highlighting the potential of Indian women to excel on the global stage [3].

Despite these remarkable achievements, women in STEM continue to encounter significant challenges. Implicit and explicit gender biases shape the experiences of women in mathematics from early education through professional careers [4]. Societal expectations, cultural norms, and inadequate mentorship further exacerbate these challenges, discouraging young girls from pursuing mathematics beyond secondary education [5]. In India, initiatives such as "Beti Bachao, Beti Padhao" have made commendable strides in promoting girls' education, yet the proportion of women pursuing advanced degrees in mathematics remains disproportionately low [6].

This paper aims to explore the intersections of gender, mathematics, and STEM education within the Indian context. By examining the contributions of women mathematicians and identifying the systemic barriers they face, the paper seeks to propose actionable strategies for women's empowerment in mathematics as part of India's broader STEM landscape. Special attention will be given to fostering early engagement in mathematics through targeted interventions, such as mentorship programs, scholarship initiatives, and the establishment of women-led mathematics clubs in schools and universities [7]. The critical role of academic institutions, policymakers, and industries in creating inclusive environments will also be explored, as these stakeholders are vital to ensuring women's equal participation in shaping India's scientific future [8].

As we strive to build a robust and inclusive STEM paradigm, it is imperative to address the systemic barriers that hinder women's participation in these fields. The role of mathematics in addressing pressing societal challenges, such as healthcare optimization and environmental sustainability, underscores the importance of fostering a culture that encourages and supports women in their mathematical pursuits [9]. Research has highlighted the critical role of role models in inspiring young women to pursue careers in science, technology, engineering, and mathematics [10]. By showcasing successful female figures in STEM, educational institutions can cultivate an environment where girls feel empowered to engage with these subjects. Additionally, gender-sensitive pedagogy has emerged as a vital strategy for addressing disparities in STEM education, emphasizing the need for teaching practices that consider the unique challenges faced by female students [11]. Furthermore, the COVID-19 pandemic has exacerbated existing inequalities in education, making it essential to harness the potential of online learning to support STEM engagement among women [7]. By implementing evidence-based practices and fostering a culture of inclusivity, we can work towards achieving the ambitious goal of increasing the representation of women in STEM, ultimately contributing to a more innovative and equitable society [12,13]. This paper seeks to explore practical strategies for this endeavor, aiming to create a rigorous and inclusive STEM paradigm for Vikasit Bharat 2047.

1.1. Objectives of Study

Identify and analyze systemic barriers: To identify and analyze the systemic barriers that hinder women's participation in mathematics and STEM education in India.

Highlight contributions of women mathematicians: To highlight the contributions of prominent women mathematicians, both historical and contemporary, as a means of inspiring future generations.

Explore and propose practical strategies: To explore and propose practical strategies, including mentorship programs and institutional reforms, aimed at increasing the representation of women in mathematics at all educational levels.

Examine impact on technological innovation: To examine the potential impact of empowering women in mathematics on India's technological innovation, economic growth, and global STEM leadership by 2047.

2. Hypothesis

Empowering women in mathematics through targeted interventions such as mentorship, institutional support, and policy reforms will significantly increase their participation in STEM fields. This increased participation will not only bridge the gender gap but also enhance India's technological innovation, economic development, and global leadership in STEM by 2047.

3. Methodology

This study employs a qualitative, literature-based methodology to explore the empowerment of women in mathematics within the STEM framework, with a focus on mathematical modeling as a case study.

3.1. Literature review

The research draws upon a comprehensive review of existing academic literature, policy reports, and case studies related to women's contributions to mathematics and the systemic barriers they face. This review will encompass key themes such as gender bias, the impact of mentorship, and successful initiatives aimed at promoting women's participation in mathematics.

3.2. Case study analysis

A specific case study of mathematical modeling will be analyzed to illustrate how women mathematicians contribute to addressing real-world problems. This analysis will highlight the significance of their work and its implications for fostering gender equity in the field.

4. Case Study Problem: The Lady Beetle Population Dynamics

4.1. Problem statement

The lady beetle (or ladybug) population can serve as an excellent model for studying dynamics in ecology. In this case study, we'll explore how the population of lady beetles changes over time due to factors such as birth rates, death rates, and predation.

4.2. Mathematical model

We can use a simple population growth model based on the logistic growth equation, which incorporates carrying capacity to represent the maximum population that the environment can sustain.

4.3. Logistic growth equation

$$\frac{dP}{dt} = \boldsymbol{rP1} - \frac{\boldsymbol{P}}{\boldsymbol{K}} \quad (1)$$

where:

- P = population of lady beetles
- r = intrinsic growth rate
- K = carrying capacity of the environment
- t = time

4.3.1. Parameters

Intrinsic growth rate (r): This represents how quickly the population would grow under ideal conditions.

Carrying capacity (K): This represents the maximum population that the environment can sustain.

Example Values

r=0.1 (10% growth rate per time unit)
K=1000 (maximum sustainable population)

4.4. Explanation

This case study illustrates how mathematical modeling can be applied to understand the dynamics of lady beetle populations in an ecological context. The logistic growth model allows researchers to predict how populations grow over time, accounting for limitations imposed by resources in the environment.

By studying such models, women mathematicians can contribute significantly to ecology, conservation, and environmental management. This highlights the importance of interdisciplinary approaches, where mathematics plays a crucial role in solving real-world problems.

Table 1: *Summarizing statistical data about women achievers in mathematics and STEM fields.*

Category	Data	Source
Percentage of Women in STEM	28% of STEM workforce worldwide	[14] UNESCO (2020)
Women in Mathematics	30% of undergraduate mathematics students	National Science Foundation (NSF)
Women in PhD Programs	43% of mathematics PhD candidates	American Mathematical Society (AMS)
Women Faculty in Mathematics	27% of full-time mathematics faculty	[15] NSF (2019)
Women in Technology	26% of computing jobs	National Center for Women & Information Technology (NCWIT)
Women in Engineering	21% of engineering degrees awarded	American Society for Engineering Education (ASEE)

Female Mathematicians in Academia	14% of tenure-track positions	[16] AMS (2018)
Notable Women Mathematicians	- Hypatia of Alexandria	Historical Reference
	- Ada Lovelace	Historical Reference
	- Mary Cartwright	Historical Reference
	- Shakuntala Devi	Contemporary Reference
	- Neena Gupta	Contemporary Reference
Women in Leadership Roles in STEM	25% of senior leadership roles in STEM organizations	[17] Catalyst (2020)

5. Indian Women Mathematicians: History to Contemporary Times

5.1. Ancient and medieval contributions

Women's contributions to mathematics in India can be traced back to ancient texts, though they often remain under-documented. However, the cultural importance of education in mathematical sciences allowed women to engage with intellectual pursuits, albeit in more limited ways compared to men.

Lilavati (12th century): A prominent name associated with Indian mathematics is Lilavati, the daughter of the mathematician Bhaskara II. While she is mentioned primarily in the context of her father's work, Lilavati is a mathematical treatise named after her. Bhaskara's *Lilavati* is an important text in arithmetic, dealing with various practical mathematical problems. The connection of her name to this work symbolizes the engagement of women with mathematics during that time. Lilavati is often regarded as a symbol of potential for female mathematicians in India.

Women scholars in ancient India: Beyond specific names, it is essential to recognize that ancient India had a rich tradition of learning where, in certain cultural contexts, women participated in intellectual and mathematical discussions, though much of their work remains undocumented or lost over time.

5.2. Modern pioneers (19th to early 20th century)

The British colonial period marked a significant shift in education systems in India, with formalized academic structures being introduced. This period saw the emergence of women pioneers in various fields, including mathematics, as the early steps toward gender equality in education began.

Rukhmabai (19th century): Though primarily known for her activism and pioneering work in medicine, Rukhmabai's education included an introduction to mathematics. She symbolizes the importance of mathematics in general education for women during this era.

Anandi Gopal Joshi: Although known as India's first female doctor, her education, which included an understanding of scientific principles and basic mathematical concepts, reflects the growing intersection of women's education with the sciences in the late 19th century.

5.3. Mid-20th century: establishing a scientific presence

As India approached and attained independence, education systems became more inclusive, and more women pursued higher education, including in mathematics and science.

Sakuntala Devi (1929–2013): Known as the "Human Computer," Shakuntala Devi is one of the most celebrated figures in Indian mathematics. Her incredible mental calculation skills showcased the potential of human cognition in performing complex mathematical operations without the aid of technology. Devi's contribution was not just in performing these calculations, but also in inspiring future generations to engage with mathematics as a discipline of creativity and mental rigor. While her work was not in formal academia, she brought mathematics into the public consciousness.

E. K. Janaki Ammal (1897–1984): Though primarily known for her contributions to botany, Ammal's work involved quantitative research that required deep mathematical analysis, showcasing how women in India began engaging with mathematics in interdisciplinary contexts during the mid-20th century.

5.4. Contemporary achievements (late 20th century to present)

The last few decades have seen a surge in the recognition of women mathematicians in India, particularly in research, education, and applications of mathematics to real-world problems.

Neena Gupta: An internationally recognized mathematician, Neena Gupta has made significant contributions to algebraic geometry, a field considered highly abstract and technically challenging. Her solution to the Zariski Cancellation Problem in commutative algebra earned her the prestigious Ramanujan Prize for Young Mathematicians in 2021. Gupta's work stands as a testimony to the growing prominence of Indian women mathematicians in the global arena.

R. Vasuki: A leading expert in Magnetohydrodynamics (MHD), Vasuki's research integrates theoretical mathematics with practical applications, particularly in studying the behavior of fluids under magnetic fields. Her work has significant implications for space weather and fusion energy research, illustrating the deep involvement of Indian women in applied mathematics.

Padmavati Ghosh: Working in the field of number theory and cryptography, Ghosh's research involves prime numbers, elliptic curves, and the mathematical algorithms used in modern cryptographic systems. Her work is an example of how Indian women mathematicians are contributing to advancements in technology and cybersecurity.

5.5. Women in academia and research institutes

A growing number of women are now holding prestigious positions in academia and research institutions across India. According to data from the Indian Institute of Science (IISc) **and** Tata Institute of Fundamental Research (TIFR), the representation of women in mathematical sciences, while still not on par with men, has been steadily improving. Women are playing vital roles not just in research but also in curriculum development, mentoring, and advancing pedagogical methods for teaching mathematics.

6. Strengthening the Scientific and Mathematical Approach

The history of mathematics is marked by significant contributions from women, many of whom have made profound impacts in fields ranging from number theory to applied mathematics. While these achievements are often underrepresented in mainstream narratives, the role of women mathematicians, especially in India, has been instrumental in shaping the scientific landscape. This section highlights key mathematical contributions from women in India, addressing both historical influences and contemporary breakthroughs, while providing a rigorous and data-driven approach to understanding their impact.

6.1. Historical contributions of women in Indian mathematics

One of the earliest known influences of women in Indian mathematics is Lilavati, the daughter of the famed mathematician Bhaskara II. Bhaskara's work, Lilavati, named after his daughter, is a seminal treatise in arithmetic. It features mathematical problems presented in poetic form, providing solutions to basic arithmetic, algebra, and geometry. Lilavati's engagement with these ideas showcases the early role of women in the intellectual and mathematical traditions of ancient India. While the influence of women in mathematics during ancient times may not have been extensively documented, Lilavati serves as a symbol of the potential that was nurtured even in those early days.

6.2. Contemporary contributions: bridging theory and application

Moving forward into contemporary times, Indian women mathematicians have contributed immensely to both theoretical and applied mathematics. Shakuntala Devi, widely known as the "human computer," astonished the world with her ability to perform incredibly complex mental calculations. Devi's ability to calculate large numbers, such as the 23^{rd} root of a 201-digit number in record time, demonstrated not only an extraordinary mathematical mind but also the powerful interplay between human cognition and mathematical algorithms. Devi's work serves as an inspiration, especially in the realm of educational mathematics, where the development of mental calculation techniques has sparked interest in computational mathematics and artificial intelligence.

Another significant figure is Dr. R. Vasuki, whose work in fluid dynamics has placed her among the leading women mathematicians in applied mathematics. Her contributions to Magnetohydrodynamics (MHD), which involves the study of the dynamics of electrically conducting fluids in magnetic fields, have advanced our understanding of complex physical phenomena such as space weather, fusion energy, and plasma physics. Vasuki's research, grounded in the Navier-Stokes equations, demonstrates the deep connection between theoretical mathematics and practical applications in physics and engineering. Her work exemplifies the high level of mathematical sophistication required to tackle real-world challenges.

In the realm of abstract mathematics, Dr. Neena Gupta stands as a beacon of excellence. Her groundbreaking research in algebraic geometry, specifically her solution to the Zariski Cancellation Problem, has earned her recognition on the global stage, including the prestigious Ramanujan Prize. Algebraic geometry, which studies solutions to polynomial equations, is a foundational area in both pure mathematics and its applications in fields such as cryptography and robotics. Gupta's work delves into the heart of commutative algebra and contributes to our understanding of complex mathematical structures, advancing both theoretical knowledge and technological innovation.

6.3. Mathematical modelling of real-world problems

Beyond individual contributions, the application of mathematical models to solve pressing real-world problems has also been a significant area where women mathematicians in India have made notable strides. During the COVID-19 pandemic, mathematical modelling became a critical tool for understanding and predicting the spread of the virus. Women mathematicians were involved in the development of epidemiological models that used differential equations to forecast infection rates, hospital capacities, and vaccination strategies. These models have had a profound impact on public health policy and decision-making during global crises.

Another example is the use of partial differential equations (PDEs) in environmental science, particularly in climate modeling. Indian women mathematicians have contributed to the mathematical frameworks used to simulate atmospheric and oceanic systems, providing critical insights into the dynamics of climate change [18]. By solving complex PDEs that describe fluid flows in the atmosphere, these mathematicians have helped predict patterns in weather systems, rainfall, and temperature changes, offering solutions to the pressing environmental challenges facing the world today.

6.4. Data and trends in women's participation in mathematics

While the contributions of individual mathematicians are commendable, the broader participation of women in mathematics also needs to be addressed. Recent data from the All-India Survey on Higher Education (AISHE) indicates a growing trend of women enrolling in mathematics at the undergraduate and postgraduate levels. However, the representation of women in academic and research positions remains disproportionately low. According to reports, only 15%-20% of faculty positions in mathematics departments across major universities are held by women. Furthermore, the number of women receiving prestigious awards like the Shanti Swarup Bhatnagar Prize remains limited, highlighting the continued gender disparity in mathematics research and academia.

Efforts to bridge this gap have been undertaken through initiatives such as the Women in Science and Engineering (WISE) program, which offers scholarships and mentoring to young women pursuing careers in STEM. Additionally, the Tata Institute of Fundamental Research (TIFR) and the Indian Statistical Institute (ISI) have established programs aimed at encouraging more women to enter mathematical research.

6.5. Technological innovation and future prospects

In the context of technological innovation, women mathematicians are increasingly making their mark in artificial intelligence (AI) and machine learning (ML). Prerna Goyal, an Indian mathematician working in quantum cryptography, is at the forefront of applying mathematical algorithms to secure communication systems. The development of quantum-resistant encryption methods requires deep mathematical expertise, particularly in areas such as number theory and complexity theory. These contributions not only enhance the security of digital communication but also place women mathematicians at the cutting edge of technology and innovation.

Looking toward the future, the contributions of women in mathematics will be crucial in shaping the next generation of technological advances. As AI, data science, and cryptography

continue to evolve, the role of mathematicians in developing algorithms and models will remain indispensable, providing women mathematicians with even greater opportunities to contribute to both theory and practice [19]. By weaving together historical perspectives, contemporary breakthroughs, and data-driven insights, this section underscores the pivotal role of women mathematicians in shaping both the scientific community and society at large. Their contributions, spanning a wide range of mathematical disciplines, offer a vision of a more inclusive and innovative future where women lead in the development of new scientific paradigms.

7. Challenges Faced by Women Mathematicians in STEM

7.1. Gender bias and stereotypes

Persistent stereotypes that portray mathematics as a male-dominated field can discourage women from pursuing mathematics and STEM careers.

7.2. Lack of representation

Underrepresentation in higher education, academic positions, and leadership roles can create an unwelcoming environment for women.

7.3. Work-life balance

Balancing professional responsibilities with family obligations can be more challenging for women, particularly in demanding fields like mathematics.

7.4. Limited mentorship and networking opportunities

A lack of female role models and mentors in mathematics can hinder women's career advancement and professional development.

7.5. Access to resources and funding

Women may have less access to research funding, grants, and academic resources, impacting their ability to conduct research and publish.

7.6. Cultural and societal pressures

Cultural norms in some societies may prioritize traditional gender roles, limiting women's participation in STEM.

8. Opportunities for Women Mathematicians in Contemporary Times

8.1. Increased awareness and advocacy

Growing awareness of gender equity in STEM has led to more initiatives aimed at promoting women's participation and addressing biases.

8.2. Supportive networks and organizations

Organizations like the Association for Women in Mathematics (AWM) provide networking, mentorship, and professional development opportunities.

8.3. STEM education initiatives

Government and private sector initiatives (e.g., "BetiBachao, BetiPadhao" in India) are focused on promoting girls' education in STEM fields [20].

8.4. Flexible work arrangements

Increasing acceptance of remote work and flexible schedules in academia and industry can help women balance professional and personal responsibilities.

8.5. Interdisciplinary research opportunities

The rise of interdisciplinary research in areas like data science, artificial intelligence, and environmental modeling provides avenues for women to apply mathematical skills in impactful ways.

8.6. Funding and grants for women

Some organizations offer specific grants and funding opportunities aimed at supporting women researchers in mathematics and STEM.

8.7. Growing community and representation

The visibility of successful women mathematicians in media and academia is increasing, inspiring new generations and fostering a more inclusive environment.

9. Conclusion

Empowering women in mathematics is essential not only for achieving gender equity but also for fostering innovation and growth within the broader STEM landscape. This paper highlights the historical contributions of women mathematicians and identifies systemic barriers that continue to hinder their participation in the field. By examining contemporary initiatives and challenges, it becomes clear that while progress has been made, significant gaps remain.

9.1. Key conclusions include

- The underrepresentation of women in mathematics and STEM is a multifaceted issue influenced by cultural, institutional, and societal factors.
- Targeted interventions, such as mentorship programs, scholarships, and inclusive educational practices, can help break down barriers and encourage women's engagement in mathematics.
- Integrating women into the fabric of mathematical research and STEM professions is vital for national development and addressing societal challenges.

9.2. Future scope

As India approaches its centenary of independence in 2047, it is crucial to continue advocating for women in mathematics and STEM. Future research and initiatives can focus on:

Longitudinal studies: Conducting studies that track the career trajectories of women mathematicians over time to better understand the impact of interventions and identify ongoing challenges.

Policy development: Collaborating with policymakers to create and implement policies that promote gender equity in education and professional settings.

Innovative educational practices: Exploring and implementing pedagogical approaches that encourage young girls to engage with mathematics from an early age, fostering a positive attitude towards the subject.

Cross-disciplinary collaborations: Encouraging collaborations between mathematics and other STEM fields to showcase the relevance of mathematics in addressing real-world problems, thereby attracting more women to the discipline.

Global perspectives: Investigating international best practices for promoting women's participation in mathematics and STEM, adapting successful models to the Indian context.

Increased funding and resources: Advocating for more funding opportunities specifically aimed at supporting women in mathematics and related fields, facilitating research and professional development.

By addressing these areas, India can shape a more inclusive and innovative STEM landscape by 2047, ensuring that women mathematicians play a pivotal role in the nation's scientific and technological advancement.

10. Declarations

Conflict of Interest

We have no conflict of interest

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As I work in a private organization, I do not receive any funds for my research work. But my passion has never stopped me from my research

Contributions

Majority of the part was contributed by the corresponding author and the conclusions and future scope by the second author

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