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Basic Sciences: Opportunities and Challenges in the 21st Century

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Abstract

Basic sciences - including physics, chemistry, biology, and mathematics - underpin scientific and technological advancement. In the 21st century, their utility is further reinforced by global challenges like climate change, pandemics, digitalisation, and chasing the Sustainable Development Goals (SDGs). Whereas fundamental sciences create expansive horizons for interdisciplinary work and innovation with the help of digital tools such as AI and international collaboration, they are also subject to systemic hurdles. These are disproportionate funding allocation, excessive dependency upon bibliometry, inadequate support for early-career scientists in low- and middle-income countries (LMICs), and increasing issues related to research ethics, mental well-being, and employment insecurity within academia. This article investigates the twin landscape of opportunity and challenge in modern basic sciences. It emphasizes the imperative to rethink funding mechanisms, facilitate open science, foster inclusive public engagement, and reform research evaluation frameworks to reward long-term value and global justice. The author makes the case for a fresh, inclusive, and curiosity-fostered commitment to basic science to ensure that it remains a foundation of sustainable human development and innovation.

Keywords: Science Policy, Public Engagement, Research Funding, Interdisciplinary Collaboration, Sustainable Development Goals (SDGs)

Introduction

Basic sciences, including physics, chemistry, biology, and mathematics, form the foundation of all scientific progress (Schauz, 2014). Basic science is the basis of scientific development. Basic sciences have an even more central role in a world characterized by rapid technological advances, global connectedness, and pressing social and environmental issues. Characterized by its pursuit of understanding basic principles without direct application, basic science fosters intellectual curiosity and is the foundation upon which applied research and innovation thrive. They support medical discoveries, guide policy on climate change, facilitate digital transformation, and drive energy, agriculture, and infrastructure advancements. Contrary to the view of basic sciences as abstract or detached from practical applications, they are still central to contemporary life. Breakthroughs in particle physics resulted in medical imaging technology; abstract mathematics powers

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encryption algorithms that encrypt digital communication; and achievements in molecular biology form the basis of biotechnology and vaccine research. Max Planck's pronouncement that "knowledge must precede application" remains true. Fundamental science sustains inquisitive exploration, resulting in information that, even if not instantaneously applied, provides the basis for utilised developments that solve global issues such as antimicrobial resistance, food safety, and clean energy (Scientific Advisory Board, 2015).

However, basic sciences are confronted by a paradox: as their relevance expands, they are also confronted by unprecedented challenges. The editorial "Where is science heading? " by Ramakrishna et al. (2023) presents a nuanced overview of the changing face of science that gives us insights into the driving forces behind scientific investigation today. Basic sciences in the 21st century have been confronted with numerous opportunities and challenges sculpted by globalisation, technological advances, sustainable development imperatives, and socio-political considerations. This article delves into these aspects, taking cues from international science policy reports (Schneegans, 2015) and recent debates on the direction of science (Ramakrishna et al., 2023). This article also takes forward that debate, with a special emphasis on basic sciences and their dual realities: the immense opportunities and systemic issues that continue to exist.

The Value of Basic Science

Basic science, usually misrepresented as abstract and not practical, has an essential function in technological advances and social progress. According to the UNESCO Science Report, basic science and applied science are two sides of the same coin. Basic science triggers the long-term innovations developed through applied research (Soete et al., 2015). There are many examples. The finding of the double-helix nature of DNA and the ensuing Human Genome Project resulted from basic research into genetic architecture. These advancements led to revolutions in personalized medicine and biotechnology (Neupane, 2015).

The Expanding Landscape of Basic Sciences

Traditionally, scientific research in the foundation sciences was spurred by curiosity and philosophical interest. Investigators worked in solitary or tiny clusters, sometimes with little in terms of funded arrangements, infrastructure, or institutionalized training. Science is an international undertaking, and millions of investigators are undertaking specialized, cross-disciplinary, and commercially sponsored research endeavours (Wood, 2024). Ramakrishna et al. (2023) define this shift as a movement towards "career and outcome-driven" from "inquisitive and interest-led," with a tremendous increase in professional administration, governmental spending, and a focus on responsibility.

Opportunities in Basic Sciences

1. Multidisciplinary Collaboration: Scientific problems of today are intricate and multi-faceted. Solving climate change, pandemics, or sending humans to space demands poly-disciplinary insight from physics, biology, and engineering. Basic scientists already started to cooperate across disciplines more often, resulting in the innovation that came about with quantum computing, CRISPR, and novel materials (Betz et al., 2023). Contemporary science increasingly demands approaches that cut across the traditional silos. Science today is shifting towards transdisciplinary approaches in which scientists collaborate with policymakers, private sector actors, and civil society to co-produce knowledge (Lemarchand, 2015).

2. Digital Tools and Generative AI: Generative AI and large-scale data redefine scientific

investigation. Software such as ChatGPT and AlphaFold enable scientists to develop hypotheses, inspect data at scale, and view intricate molecular arrangements (Wood, 2024). Ramakrishna et al. (2023) point out that embracing these technologies opens up new paradigms in science communication and discovery.

3. Global Investment and Emphasis on SDGs: Governments and international organizations regarded science as necessary to meet the SDGs, such as clean water, energy, and health. More funding, international collaboration, and policy coordination emphasize the resolution of humanity's greatest challenges through fundamental scientific research (Confraria et al., 2024). The 2030 Agenda for Sustainable Development sets out 17 goals addressing the world's challenges, from poverty and health to climate action and innovation. Underpinning the scientific breakthroughs that will enable the goals to be reached is basic science. For instance, it contributes to SDG 3 (Good Health and Well-being) through the knowledge of antimicrobial resistance and vaccine development and to SDG 13 (Climate Action) through the development of knowledge of the climate systems (Scientific Advisory Board, 2015).

4. Open Science and Knowledge Sharing: The open-access publishing movement and shared databases provide new avenues for basic scientists to share their work worldwide, collaborate with others, and interact with citizen scientists (Maedche et al., 2024). Open science movements are making research more democratically accessible, improving transparency, and driving innovation faster. National and international open data initiatives facilitate researchers' easier contribution to scientific advancement worldwide - particularly in developing nations (Hertig, 2015). Initiatives expanding literacy and education in science provide greater equal opportunity to knowledge. Young scientist development programs and investments in educational infrastructure enhance global research ecosystems, particularly in low- and middle-income nations (Scientific Advisory Board, 2015).

Challenges in Basic Sciences

1. Unequal Global Distribution of Resources: Developed countries enjoy superior infrastructure and reliable financing, while low- and middle-income nations deal with sub-standard facilities, bureaucratic hurdles, and inadequate professionals (Dabla-Norris et al., 2015). Nations have a clear cleavage as far as research capacity, infrastructure, and possibilities are concerned. Scientists from low-income nations may not have proper resources, institutional assistance, or means to collaborate, preventing them from engaging in global scientific conversations (Ramakrishna et al., 2023). With respect to collaborations, there are sufficient opportunities suggested by different governments, yet it is still difficult for most who begin with basic science as carriers. While competition can drive excellence, it also introduces pressures that can lead to unethical behaviour or reduced collaboration. Conversely, though beneficial, international collaboration is not without challenges - such as conflicting interests, differing goals, and unequal power dynamics (Ramakrishna et al., 2023).

2. The Financing Crisis: Scientific research, particularly in basic sciences, demands high investment and may encounter competition for financing. Financing is increasingly linked to short-term outcomes, bibliometrics, and industry applicability. Basic sciences, frequently long-term and foundational, have difficulty competing on this results-based model (Aziz et al., 2023; Ding & Moreira, 2025). Though it brings long-term advantages, basic science tends to fight for financing over more commercial applied research. Middle-income country governments spend less than the

average on basic research, and even in China, basic research accounts for only 4-6% of the research expenditures (Soete et al., 2015).

3. Excess dependence on Bibliometrics: Quantifiable metrics like h-index, impact factors, and citations predominate performance evaluation. The trend has been criticized for causing stress to researchers and discouraging high-risk or long-term research (Hansen, 2010; Wouters et al., 2015). As Bornmann and Leydesdorff (2014) point out, researchers may shy away from areas less likely to generate quick citations (fundamental scientific research), particularly when the pressure to publish and be cited rapidly is high. Longitudinal studies, exploratory studies, and projects with indeterminate outcomes are less likely to satisfy the expectations of these performance indicators. The "publish or perish" ethos might reward behaviours undermining the integrity of science, such as citation falsification or focusing on fashionable but superficial research that stands a higher chance of getting cited. As Ioannidis (2005) pointed out, the rivalry underlying citation-counting metrics could pervert the priority of research to favour gaining individual academic merit over the expansion of knowledge. Indicators like the h-index and impact factor disproportionately favour researchers affiliated with prominent institutions, most often in North America and Europe, and against those affiliated with smaller or underrepresented institutions and nations. A study by Thelwall (2023) reveals that citation practice tends to reflect structural biases, where publications of particular groups are cited more, creating a self-perpetuating recognition loop for such groups and marginalizing others further. Science policy systems tend to prefer short-term, outcome-based measures. Conventional evaluation systems based on bibliometrics deter exploratory or high-risk research. This may inhibit innovation and restrict progress in basic sciences (Ramkissoon & Kahwa, 2015).

4. Ethical and Regulatory Pressures: Fundamental research frequently overlaps with ethically sensitive areas such as genetics and neuroscience (Amadio et al., 2018; de Kanter et al., 2023). Religious and political interference in certain areas creates further obstacles (Tham et al., 2022).

5. Uncertainty in Career and Mental Health: Researchers document rising burnout and mental distress due to overwork, pressure to publish, and uncertain career trajectories. With an increasing oversupply of highly trained scientists and a relatively stable number of permanent academic positions, many young researchers are stuck in extended temporary appointments with minimal job security or long-term futures (Powell, 2016). A survey conducted by Nature across more than 6,000 graduate students established that 36% had tried to access aid for depression and anxiety connected to their careers in academia (Woolston, 2019). Scholarships, particularly within the initial career phases, often fail to meet industry compensation offers, driving researchers toward devaluation (Alberts et al., 2014). It can be frustratingly incongruent despite the prolonged and specialized preparation period for a research career. To respond to these challenges, institutions and funding agencies must prioritize mental health resources, encourage open career development pathways, and rethink the incentive structures for academic achievement.

The Future Trajectory: A Balanced and Inclusive Approach

1. Reimagining Research Evaluation: Institutions must implement comprehensive assessments based on metrics, practical impact, collaboration, and novelty. Several researchers have suggested new evaluation approaches to address the drawbacks of bibliometrics. Wilsdon et al. (2015) address the possibility of employing qualitative reviews, peer evaluations,

and narrative assessments to evaluate research impact. These approaches may diminish the excessive use of quantitative measures and provide opportunities for more integrated evaluations of research excellence, such as its social value and long-term knowledge contribution. Emerging initiatives like the San Francisco Declaration on Research Assessment (DORA) also promote improved practices that emphasize the context in which research products are produced instead of using defective measures like journal impact factors (DORA, 2013).

It is also essential to integrate openness and innovation into the criteria for assessment. Open-access publications, sharing data, community-engaged research, and knowledge translation activities are increasingly recognised as important scholarly outputs. The European Commission's Open Science Policy supports the recognition of different contributions of research, such as software development, policy briefs, and public engagement, as valid research outputs in the evaluation process (European Commission, 2017).

2. Promoting Early-Career Researchers: Funding programs must be re-organized to promote young researchers, especially in low- and middle-income countries (LMICs). The biggest challenge is in distributing research funding to HICs and LMICs. Most current funding programs are biased in favour of veteran researchers from high-income countries (HICs), leaving young researchers in LMICs with very little opportunity to perform independent research (Gaillard, 2010). The absence of financial support undermines local scientific advancement and deters high achievers from sticking with research, leading to a consistent brain drain from these areas (Lancho-Barrantes et al., 2013). To counteract this, the funding systems must be redesigned to incentivize early-career researchers, with focused grants that fund research proposals and infrastructure for building research environments, such as laboratories and training courses. Global funding institutions, charity foundations, and governments must cooperate and design inclusive initiatives like the TWAS Research Grants, which have empowered scientists in the Global South (TWAS, 2025).

In addition, programs like the Global Young Academy (GYA) emphasize the significance of leadership training, mentorship, and networking in retaining and empowering early-career researchers. GYA calls for policies that include early-career representatives in national and global science policy debates, striving to create a more inclusive scientific ecosystem (GYA, 2024).

3. Developing Infrastructure in LMICs: Building labs, de-barring equipment exports, and establishing technical capacity in low-income countries is essential to bridge the world science gap. National agendas must be synchronized with international objectives as science gets further embedded in global problem-solving. Nations must invest in fundamental and applied research to create durable, future-oriented knowledge systems (Avenyo et al., 2015).

4. Encouraging Interdisciplinary Research: For interdisciplinary collaborations to be facilitated, academic and funding frameworks must be realigned. Institutional systems for promoting transdisciplinary research need to be developed. These comprise adaptable funding mechanisms, interdisciplinary education, and interfaces that connect academia, industry, and society (Soete et al., 2015; IJIRD, 2023).

Bridging Academia, Industry, and Society: Transdisciplinary research also demands knowledge exchange platforms beyond the conventional university environment. Some examples are living labs, public innovation forums, and joint university-industry research centers (Scholz & Steiner, 2015). Such platforms facilitate co-creation processes where diverse knowledge systems can feed into scientific research and policy innovation, including Indigenous, local, and experiential knowledge.

6. Encouraging Public Engagement: Scientists must involve the public in comprehending their work. Enhancing public trust in science is crucial to sustain support and validity. In the age of disinformation and institutional distrust, particularly in times of crisis like the COVID-19 pandemic, restoring public trust in science has become imperative (Scheufele & Krause, 2019). Trust is developed when the public views scientists as credible, open, and responsive to public concerns (Funk et al., 2019). Science needs to be more inclusive and participatory. Citizen science, science diplomacy, and open-access platforms can empower the communities and make science inclusive of various societal needs (Neupane, 2015). "Science Café" initiatives, citizen science initiatives, and open lab days are ideal models to fill the gap between the public and scientists (Irwin, 2006). This communication has to be inclusive as well, with marginalized groups having access to science education and engagement.

Conclusion

Basic sciences stand at the crossroads. Because basic sciences are not indulgences of yesterday but imperatives of tomorrow. Their value to humanity has never increased, from cracking the human genome to simulating climate systems. However, the way ahead is beset by systemic, cultural, and economic obstacles. As Ramakrishna et al. (2023) stress, "Research talent is everywhere, but opportunities are not." Closing this gap is critical to making the scientific enterprise equitable and effective. By coordinating policies, funding, infrastructure, and cultural values, stakeholders can empower basic sciences to flourish and continue to advance knowledge for all humankind. The 21st century offers tremendous promise and great challenges for basic sciences. Basic science can address humanity's most challenging problems through strategic policy changes, global collaboration, and increased public involvement. Rededication to fundamental research - driven by curiosity, equity, and thinking ahead - will be instrumental in forging a sustainable and equitable future. As the world grapples with interconnected challenges - from pandemics and climate change to digitalization and resource shortages - only a solid foundation in science will deliver sustainable solutions. The way forward is to adopt open, inclusive, and integrated strategies for scientific research, policymaking, and partnership. The 21st century is a defining moment for basic sciences. With sound policies, investment, and international cooperation, they can prosper once more, enabling societies to ride complexity, promote innovation, and realize their aspirations.

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