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Exploring sex/gender perspectives in nanotechnology and nanomaterials research

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Abstract— **This article aims to draw attention to the integration of sex/gender dimensions within the scientific community investigating nanomaterials and nanotechnology. Despite the significant impact of these fields on society, there remains a gap in understanding how the gender dimension can intersect with research practices and outcomes. The presence of gender-specific terminology, involving references to gender, sex, masculinity, femininity, and other related concepts can allow us to shed light on the current state of a sex/gender dimension integration in nanotechnology research. By analyzing the presence of gender-related terms in the proceedings of the IEEE Nano-Community, this paper contributes to the ongoing discussions on the importance of integrating a sex/ gender dimension in research and education in the field and highlights the need to make the nanotechnology and nanomaterials research landscape more inclusive and insightful in the future.**

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I. Introduction

In this paper, we propose a possible approach to emphasize the importance of including the sex/gender dimension in research on nanotechnology and nanomaterials. This approach is specifically tailored to the community participating in the current conference as it includes a focused investigation within selected IEEE Nano Conference Proceedings.

Since the 5th Framework Programme for Research and Development (1999-2002), the EU has placed great emphasis on integrating a sex/gender perspective into research activities.

Sex encompasses a range of biological characteristics found in humans and animals. These include physical and physiological characteristics such as chromosomes, gene expression, hormone functionality and reproductive/sexual anatomy. Gender refers to the socially constructed roles, behaviors and identities associated with female, male or genderqueer individuals [1]. It plays a central role in shaping self-perception, interpersonal interactions, behavioral patterns and the distribution of social power and resources.

Sex is usually classified as female or male, but the biological characteristics that constitute sex and their expression can vary; gender is often mistakenly perceived as a binary entity (female/male), there is a spectrum of gender identities and expressions that illustrate how individuals define themselves and display their gender [2].

Horizon Europe (2021-2027), the current EU Framework Programme for Research and Innovation, has also introduced the appropriate consideration of the gender dimension in research and innovation content among the award criteria of the excellence in Research and Innovation Actions and Innovation Actions proposals. The requirement to consider sex and gender in the entire research and innovation process is now mandatory, unless explicitly stated otherwise in the topic description [3].

Following the EU stimulus to promote gender equality and progressive inclusion as a pervasive dimension in research, research organizations have adopted three strategic approaches to issues in science and technology, focusing on the following points: (i) “"Fix the Numbers" focuses on increasing the participation of women and underrepresented groups to promote balanced representation, (ii) "Fix the Institutions" promotes career equality through structural institutional changes in research organizations, and (iii) "Fix the Knowledge" by adopting new perspectives in the research process that promote excellence in science and technology through the integration of gender, sex, and intersectional analyses in research and teaching [4,5]. These approaches have been applied sequentially over the past decades, but all three remain significant as none of them provide definitive results.

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The multidisciplinary aspects of materials research and innovation and the strong interest in bio-related applications have been analyzed by Pollitzer [6] in terms of the benefits of equal participation in this research area (the "Fix the numbers" strategy). However, beyond this focus on gender balance, it is important to promote better awareness of gender equality issues in materials research and engineering (the "Fix the knowledge" strategy), especially when research involves biomedical applications of nanomaterials.

Although the Horizon Europe Programme clearly states that the integration of the gender dimension in R&I content is mandatory unless it is explicitly mentioned in the topic description [3], it is still unclear at what extent consortia applying for funding have a clear understanding of how to take into account these requirements in research on nanomaterials and nanotechnology.

A first step to understand the level of awareness, not having the possibility to access the research proposals, is to analyze the literature in the field, to identify studies addressing the intersections of gender dynamics with nanotechnology research and applications. By analyzing, for example, the presence of gender-related terms (such as "gender", "sex", "female", "male" ....) in the titles, abstracts and full texts of scientific articles, it is possible to gain initial insights into the prevalence and recognition of the gender dimension in the current literature.

The aim of this work is to introduce a framework that can be applied and expanded upon in future research. To achieve this, we present the analysis of gender-related terms in selected proceedings of the IEEE Nano-Community with the aim of demonstrating the feasibility and potential of the proposed methodology. By doing so, we focus on illustrating how this approach can be effectively used, rather than delving into an exhaustive analysis which is beyond the scope of this preliminary study. We believe that this methodological contribution is valuable as it extends the approach previously suggested in Pollitzer's work [6], making it accessible and applicable to the community addressed by the IEEE Nano conference. We hope that this will encourage further investigation and refinement of the method in more detailed and expansive studies.

II. METHODS AND RESULTS

A. Identification of relevant topics

Despite the efforts made by the European Union to mandate the adoption of gender perspectives in research and teaching, and the work carried out by universities and research centers to meet the EU's demands, there are still inequalities in the representation and engagement of women and men in research and innovation, as shown in the ERA Progress [7] and in the She Figures 2021 [8] reports. Including a gender perspective in research and innovation content is expected to be beneficial for improving research quality in terms of excellence, precision, reproducibility, creativity and commercial opportunities. It also promotes a deep understanding of the different needs, behaviors and attitudes of individuals, facilitating the development of products and services that meet the diverse needs of all members of society [9,10].

In the field of biomedicine, for instance, it is essential to consider sex and gender differences across various applications to achieve comprehensive and effective outcomes.

The scientific community of IEEE NANO has long been sensitive to the applications of nanomaterials for biomedical applications dedicating specific topics to this area. In light of this, for a proper assessment of gender inclusion, it is important to identify sub-topics—those areas where evaluations of sex and/or gender are relevant. Response to drug treatments [11], for example, can vary between sexes due to differences in metabolism, hormonal fluctuations, and organ function. A clear sex-gap exists in pharmaceutical research spanning from preclinical studies, clinical trials to post-marketing surveillance with a bias towards males [12].

Tailoring nanomaterial-based drug delivery systems to account for sex-specific physiological differences can thus enhance therapeutic efficacy and minimize adverse effects. This is even more relevant in cancer treatments: Conforti and co-authors [13] found that immune checkpoint inhibitors, a type of cancer treatment, have varying efficacy in men and women. This suggests the need for sex-specific approaches in cancer therapy. Kim *et al.* [14] and Dorak *et al.* [15] both underscored the significance of sex differences in cancer epidemiology, genetics, and susceptibility, with implications for the development of personalized therapeutic strategies. These studies collectively highlight the importance of considering sex in cancer treatment and the potential for tailored therapies to improve outcomes.

Sex and gender play a crucial role in diagnostic imaging, influencing disease presentation and treatment outcomes [16]. However, there is a lack of understanding of how these factors should influence imaging choices and this is further complicated by the underrepresentation of women in clinical studies, leading to a lack of sex-specific data in the development of diagnostic and therapeutic strategies. Developing nanomaterial-enhanced imaging agents [17], that account for sex-specific variations in tissue composition, blood flow, and other factors, will ensure accurate diagnostics.

Another emerging area of application is the development of wearable devices which has traditionally focused on functionality, electronics, mechanics, usability, and product design [18]. However, a crucial aspect often overlooked is the gender perspective. In [19] authors demonstrated that integrating gender considerations into wearable device design can enhance adherence, expand the user base, and reshape the design paradigm. The proposed approach involves addressing electronic design by considering morphological, anatomical, and socialization impacts. The paper advocates for a user-centered methodology that incorporates a gender perspective at every stage, analyzing factors such as functionality, sensors,

communications, and location, along with their interdependencies.

By addressing sex and gender differences in these applications, the development and application of nanomaterials in biomedicine can become more personalized and effective, ultimately improving patient outcomes. It also aligns with the broader goal of achieving precision medicine by considering individual variations in treatment responses.

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B. Searching for gender related terms

A preliminary screening was conducted across five conference editions of IEEE NANO (2008, 2012, 2015, 2018, 2023), encompassing about 1400 papers. The objective was to evaluate the prevalence of health-related topics, specifically the application of nanostructured materials in health and medicine. A systematic "search term" approach was employed to identify relevant papers. Initially, a subset of papers was identified from each conference proceeding volume by searching for specific terms, including Biomedical Optical Imaging, NanoBioscience, Biological Systems, Biomembranes, Biosensors, Biochemistry, Biological System Modeling, Molecular Biophysics, Tumor, Cancer, Drug, Medicine, and Health, within the Author Keywords/IEEE Terms /table 1).

Subsequently, the number of papers was refined by excluding those not directly related to human health, such as bio-inspired materials/mechanisms, bacteria, and botanical studies, for example. The next step involved a detailed analysis of subtopics, with a specific focus on categories where the sex/gender issue is particularly relevant. This was achieved by searching, within the abstracts, for terms related to: 1) Wearable, Skin, Sensors, 2) Tumor, Cancer, Drug, Therapy, 3) Scaffold, Tissue, 4) Imaging, Diagnostic, and 5) Others (table 1). The careful examination of these subtopics aimed to identify and highlight areas within health-related nanostructured materials research where considerations of sex and gender are more pertinent.

Number of items	**Search terms in the Proceedings volumes**	**Over 1400 Proceedings papers analyzed from 5 IEEE Nano editions**
130	Biomedical optical imaging; NanoBioscience; Biological systems; Biomembranes; Biosensors; Biochemistry; Biological system modeling; Molecular Biophysics; Tumor; Cancer; Drug; Medicine; Health	Objective: selection of the abstracts/studies strictly correlated to human health
Number of items	**Search terms in the selected abstracts**	
18	Wearable; Skin, Sensor	
39	Drug; Cancer; Tumor; Therapy	Objective: identification of the number of abstract for each sub-topic
5	Scaffold; Tissue Engeneering	
21	Diagnostic; Imaging; Optical	
44	Others	

Table 1. Preliminary screening of sex/gender related terms in 5 IEEE Nano Conference Proceedings volumes (Source: https://ieeexplore.ieee.org/xpl/conhome/1000487/all-proceedings)

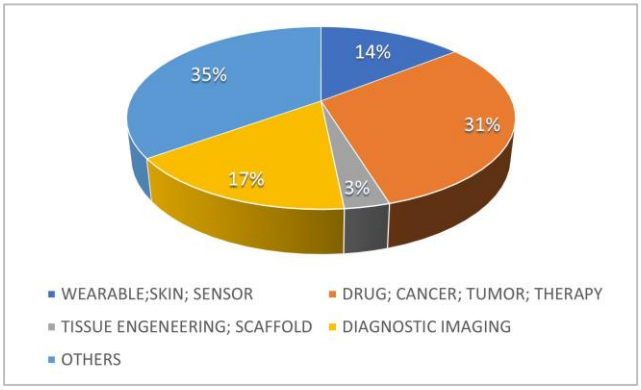

Figure 1. % distribution of health-related topics in 5 editions of IEEE Nano Conference Proceedings

None of the analyzed abstracts makes a clear reference to sex/gender differentiation. The terms "female," "woman," and "women" are only found in cases where the application is specifically directed towards a treatment related to the specific category. For instance, this occurs in applications of nanomaterials in the diagnosis or treatment of endometrial cancer, for example [20]. A careful monitoring activity, here exemplified by the analysis on a limited reference community, can still be extended to diverse research communities; this can be pursued by analyzing, for example, articles produced within a research institute/organization or in the framework of scientific conferences that gather large communities of materials scientists focusing on applications where issues of sex/gender inclusions are relevant (the International Conference on Magnetism, for example).

III. Conclusion

This study is aimed at highlighting the importance of incorporating a gender perspective in research, which can be extended to various research communities. By analyzing, for example, articles within institutes and/or scientific conferences, it is possible to better understand the extent of the sex/gender inclusions. The preliminary results presented in this paper, albeit carreid on a restricted sample, demonstrate a limited attention to the sex and gender dimension in biomedical application of nanomaterials; this highlights the need for further awareness and educational initiatives to equip researchers in nanotechnology and nanomaterials with the necessary skills. Addressing these gaps will be crucial for fostering more inclusive and socially relevant research and innovation. Future efforts should focus on addressing training programs and policies

that encourage the consideration of gender perspectives across all stages of research and development. By doing so, scientific advancements will be more inclusive and lead to more equitable and effective solutions.

REFERENCES

[1] S. Coen and E. Banister, "What a difference sex and gender make: a gender, sex and health research casebook," 2012. [Online]. Available: https://open.library.ubc.ca/collections/ubccommunityandpartnerspublicati/52387/items/1.0132684. [Accessed: 25-Feb-2024].

[2] S. Heidari, T. F. Babor, P. De Castro, S. Tort, and M. Curno, "Sex and Gender Equity in Research: rationale for the SAGER guidelines and recommended use," *Research Integrity and Peer Review*, vol. 1, no. 1, May 2016, doi: https://doi.org/10.1186/s41073-016-0007-6.

[3] European Commission, "Guide to Horizon Europe Programme, 17 December 2021," 2021. [Online]. Available: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/programme-guide_horizon_v1.4_en.pdf.

[4] L. L. Schiebinger, *Gendered Innovations in Science and Engineering.* 2008.

[5] L. L. Schiebinger, Ineke Klinge, and European Commission. Directorate General For Research, *Gendered innovations: how gender analysis contributes to research: report of the expert group "Innovation through Gender."* Luxembourg: Publications Office Of The European Union, Directorate General For Research & Innovation, 2013.

[6] E. Pollitzer, "Why gender is relevant to materials science and engineering," *MRS Communications*, Sep. 2021, doi: https://doi.org/10.1557/s43579-021-00093-1.

[7] European Commission, ERA Progress Report 2018, 2019. Available at: https://ec.europa.eu/info/publications/era-progress-report-2018_en

[8] *She figures 2021: gender in research and innovation : statistics and indicators*. European Commission, Directorate-General for Research and Innovation, Publications Office; 2021. Available from: doi/10.2777/06090

[9] L. Schiebinger, 2. Expert Paper: Gender-responsible research and innovation for small and medium-sized enterprises: Nanotechnology, ICT and healthcare. Vienna: COMPASS/European Union, 2017. https://innovation-compass.eu/wp-content/uploads/2017/09/Londa-Schiebinger_Gender-Responsible-Research-and-Innovation.pdf

[10] S. Garcia-Campa and R. Sanahuja, "Gender Mainstreaming and RRI: The Double Challenge," *Lecture Notes in Computer Science*, pp. 188–202, Jan. 2023, doi: https://doi.org/10.1007/978-3-031-33177-0_12.

[11] X. Mou, Z. Ali, S. Li, and N. He, "Applications of Magnetic Nanoparticles in Targeted Drug Delivery System," *Journal of Nanoscience and Nanotechnology*, vol. 15, no. 1, pp. 54–62, Jan. 2015, doi: https://doi.org/10.1166/jnn.2015.9585.

[12] O. P. Soldin, S. H. Chung, and D. R. Mattison, "Sex Differences in Drug Disposition," *Journal of Biomedicine and Biotechnology*, vol. 2011, pp. 1–14, 2011, doi: https://doi.org/10.1155/2011/187103.

[13] F. Conforti *et al.*, "Cancer immunotherapy efficacy and patients' sex: a systematic review and meta-analysis," *The Lancet Oncology*, vol. 19, no. 6, pp. 737–746, Jun. 2018, doi: https://doi.org/10.1016/S1470-2045(18)30261-4.

[14] H.-I. Kim, H. Lim, and A. Moon, "Sex Differences in Cancer: Epidemiology, Genetics and Therapy," *Biomolecules & Therapeutics*, vol. 26, no. 4, pp. 335–342, Jul. 2018, doi: https://doi.org/10.4062/biomolther.2018.103.

[15] M. T. Dorak and E. Karpuzoglu, "Gender Differences in Cancer Susceptibility: An Inadequately Addressed Issue," *Frontiers in Genetics*, vol. 3, 2012, doi: https://doi.org/10.3389/fgene.2012.00268.

[16] V. M. Miller, "Why are sex and gender important to basic physiology and translational and individualized medicine?," *American Journal of Physiology-Heart and Circulatory Physiology*, vol. 306, no. 6, pp. H781–H788, Mar. 2014, doi: https://doi.org/10.1152/ajpheart.00994.2013.

[17] G. Singh *et al.*, "Synthesis of gadolinium oxide nanodisks and gadolinium doped iron oxide nanoparticles for MR contrast agents," *Journal of Materials Chemistry B*, vol. 5, no. 3, pp. 418–422, 2017, doi: https://doi.org/10.1039/c6tb02854c.

[18] Pavlo Makushko *et al.*, "Flexible Magnetoreceptor with Tunable Intrinsic Logic for On-Skin Touchless Human-Machine Interfaces," *Advanced Functional Materials*, vol. 31, no. 25, Mar. 2021, doi: https://doi.org/10.1002/adfm.202101089.

[19] E. Romero, C. Sáinz, and C. López-Ongil, "Electronic Design for Wearables Devices Addressed from a Gender Perspective: Cross-Influences and a Methodological Proposal," *Sensors*, vol. 23, no. 12, pp. 5483–5483, Jun. 2023, doi: https://doi.org/10.3390/s23125483.

[20] E. Xu, A. McClelland, and Tingying Helen Zeng, "A Potential Nanosensing Method for Early Diagnosis of Endometrial Cancer with Sialic Acid Biomarker," Jul. 2023, doi: https://doi.org/10.1109/nano58406.2023.10231272