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The Role of Engineers in Promoting Health Equity

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ABSTRACT

Health equity, the pursuit of fairness and justice in health outcomes, remains a global challenge shaped by social determinants such as race, income, geography, and education. Historically addressed within public health and policy circles, the conversation around health equity is increasingly recognizing the transformative role of engineering. Engineers possess the analytical, technical, and problem-solving skills required to address structural inequities, design equitable systems, and develop inclusive health technologies. This paper examines the multifaceted roles engineers can play in promoting health equity, including data analytics, biomedical innovations, infrastructure design, education reform, policy advocacy, and ethical accountability. Case studies and global initiatives illustrate how engineering interventions have tackled healthcare access, literacy, and environmental health risks in underserved communities. The integration of health equity into engineering curricula and professional societies is proposed as a critical strategy for sustained impact. Ultimately, the convergence of engineering with public health, social sciences, and policymaking holds immense potential to reshape health systems and advance justice-oriented technological solutions worldwide.

Keywords: Health equity, engineering ethics, biomedical innovation, social determinants of health, public health engineering, telemedicine, health disparities, engineering education.

INTRODUCTION

Health Disparities (HD) refer to differences in the incidence, prevalence, mortality, and burden of disease among specific populations affected by social determinants of health. These determinants encompass the circumstances in which individuals are born, grow up, live, work, and age, influenced by the distribution of money, power, and resources at various levels. This definition includes disparities based on gender, residence, ethnicity, and socioeconomic status. A community must exhibit health differences linked to these determinants to qualify as experiencing HD, which are preventable and distinct from inequalities due to biological causes. The importance of addressing HD has intensified due to its scientific implications and broad geographical impact, as new categories continue to emerge. The targeted approach to specific populations amid sustainability challenges has further complicated HD. Additionally, the cost of U.S. healthcare has surged to unprecedented levels, raising concerns about the sustainability of healthcare systems and exacerbating existing health inequities. These issues have significant implications for federal spending forecasts and are increasingly highlighted in a politically charged environment [1, 2].

Understanding the Engineer's Role

One aspect of health disparities that creates a unique opportunity for engineers to contribute is the data-driven nature of much of the work on health disparities at present. Much of the work in this space is dedicated to investigating disparities or addressing health disparities in terms of their statistical detection. The degree to which these issues exist, or disparity, is generally quantified with odds ratios, risk ratios, and other such auditable metrics. These metrics are then considered when investigating pairs of factors that could contribute to this disparity. Different modeling methodologies are utilized to quantify this impact as an odds ratio or risk ratio, which is often a number assessable by a statistician or scientist with little to no biomedical training. These spaces are ideal learning and innovative

environments for engineers. Engineers are directly trained in the application of data analytics for the detection and quantification of issues. With this pre-existing training and exposure to these issues, engineers could easily contribute to current health disparity efforts. With the accessibility, engineers could create directed and interpretable products, resulting in their niche innovation within this space, which has already been successfully implemented. Engineering about health equity does not have to be an exclusive domain of device designers and new modalities. The statistical space of engineer interaction aligns a generalist engineer training well with the current biomedical scientist effort. It provides space for inventive engineers to create and innovate directed products, applicable and interpretable by biomedical scientists, and advance their pursuits within health equity. At the same time, engineers fill a critical need for highly specialized biomedically focused science space communities that require expertise with data in interrogating issues. The convergence and crossover of engineers, scientists, and the public will advance great discoveries and innovative solutions to address the mechanisms behind, and combat these impact-affecting sometimes inequitable issues [3, 4].

Historical Context of Health Equity

Health equity means all citizens should have an equal chance to attain their best health, which is essential for well-being and demanded by all, regardless of race, ethnicity, social status, gender, age, or other traits. Defined as the absence of preventable health disparities among social groups, health equity measures have been proposed globally, leading to significant advancements in many countries. Nonetheless, disparities in health outcomes persist, largely due to varying social, economic, and cultural contexts among ethnic groups. Health equity is closely tied to human rights and social justice, grounded in principles such as the right to the highest standard of health, non-discrimination, and participation in decision-making, accountability, and transparency. These principles are universal and fundamental. The study of health equity, a relatively new branch of public health, originated in the 1800s. Activists from the sanitary movement in France and England highlighted the link between poverty and disease, prompting local authorities to combat unsanitary conditions. Research in the 19th century by reformers in England, France, Germany, and the U.S. focused on the distribution of health issues within populations, employing quantitative analysis to enhance understanding. Significant epidemiological studies conducted in the late 19th to mid-20th century examined health disparities by factors like city, gender, age, and socioeconomic status. However, during this process, biomedical models often overshadow social justice concerns and inequality issues related to disease causation [5, 6].

Engineering Solutions for Health Disparities

Biomedical engineers have significant opportunities to promote health equity amid growing health disparities (HD) in American communities, an area often overlooked by engineering professionals. With increasing awareness of disparities, there is a potential for greater involvement from biomedical engineers, though many remain unfamiliar with the challenges of healthcare access inequities. Establishing partnerships in engineering schools can foster shared models and best practices, laying a foundation for future engagements in health disparity initiatives. Efforts to unify the multidisciplinary nature of biomedical engineering can enhance participation in addressing HD challenges, underscoring the need for professional engagement and dissemination to include these issues within the engineering community. Engineering educators must evolve approaches to foster this engagement through academic and task-focused initiatives, sharing models across disciplines. Professional organizations can drive discussions around design processes and the role of scientific literacy in bridging gaps. Additionally, the engineering curriculum often lacks integration of HD challenges as innovative opportunities. A strategy has been developed to introduce biomedical engineering majors to HD challenges while engaging with biomedical literature. Student feedback indicates varying levels of engagement when comparing those involved in HD activities to those in traditional engineering courses. Data demonstrating the incidence or progression of diseases within communities highlights the intersection of HD with both technical and societal contexts. These initiatives aim to foster transdisciplinary work to address health inequities and broaden participation in this vital area [7, 8].

Case Studies in Health Equity Engineering

Health equity engineering addresses issues to reduce health disparities among various groups facing systemic obstacles in accessing healthcare. Case studies illustrate this subfield, revealing opportunities to engage engineers and scientists in promoting community health equity through well-funded, multi-disciplinary research. The project "Hearts in the Delta" involved engineers creating culturally-acceptable health literacy training for middle school youth in the Mississippi River Delta, focusing on social

influences and utilizing the community's mobile devices. A peer-driven method was effectively employed for training. Meanwhile, the "Heart Health in Marshall Island Children" project assessed cardiovascular health in local children amidst rising adult disease rates, incorporating community-driven training programs to enhance local scientific capacity. Research papers like "The Challenge for Health Disparities" discuss potential health disparities topics, while other efforts across various engineering disciplines aim to promote urban health and reduce toxin exposure effects.

Collaborative Approaches to Health Equity

Health equity is a global imperative yet unrealized, despite efforts to improve population health. A collaborative framework is proposed to unite engineers, scientists, governments, NGOs, industry, and communities in creating beneficial systems that ensure health and well-being. Engineers prioritize safety while designing complex structures, energy, and water systems that interrelate public health and disease risk. However, the understanding of how engineered systems impact health amid climate change is lacking, causing chances for collaborative advancement in health equity with reduced costs and maximized benefits. A paradigm shift towards interdisciplinary collaboration is necessary. Global design and public works focus on addressing complicated challenges with ill-defined solutions through a diverse array of expert insights, thereby fostering innovation from research to application. This 'fuzzy' zone allows for iterative idea development, leading to actionable engagement with decision-makers. Realigning engineers' roles necessitates curriculum changes and professional recognition, facilitating knowledge exchange between resource-rich and less-resourced environments without the dominance of any party. The evolution of roles must align with the 21st-century societal pressures, particularly for traditional professions where educational skills often clash with workforce requirements. Ongoing professional development and communities of practice should support these adjustments. As traditional fields face sustainability threats, questions around identity, training, practice, and the associated opportunities grow increasingly important [9, 10].

Technological Innovations in Health Equity

Technology can enhance health equity by improving access to healthcare. This perspective explores how telemedicine, widely adopted during COVID-19, has affected health equity in the pandemic's response. Technology is influenced by those in power, often reinforcing inequities. Therefore, the socio-political contexts of technology creation are vital to consider for health equity. The design of telehealth technologies needs scrutiny to avoid obscuring or worsening the oppression of marginalized communities. Concerns have been raised that telemedicine could exacerbate health inequities. Yet, during the pandemic, telemedicine was broadly adopted and often equitably, initially improving access and equity across various health conditions. However, the dual nature of telehealth allows for both the perpetuation and alleviation of disparities. Early concerns about telemedicine highlighted existing inequities and raised fears that any improvements might not benefit historically marginalized groups long-term. Access disparities have been a significant factor in health disparities in the USA, further exacerbated by COVID-19, which increased job loss and transportation issues for lower-income and disabled individuals, limiting access to preventive and chronic care. Nonetheless, the pandemic resulted in transformative changes in telemedicine, as health systems rapidly increased their use following regulatory changes in March 2020, recognizing its crucial role in improving access to care during this crisis [11, 12].

Policy Advocacy and Engineers

In the past, engineers greatly influenced public policy, as their foresight shaped proposals impacting the profession. However, their involvement has diminished over time. Today, public policy significantly affects engineers, yet many lack the skills needed to engage in the policy process effectively. Major public policy decisions often occur without adequate technical analysis, and the primary decision-makers frequently exhibit a negative attitude toward engineering. This creates an opportunity for engineers to enhance public policy and public health. The push for corporate accountability highlights the need for engineers to participate in public policy discussions. Growing calls for experts to address technical issues underscore the need for engineers to develop new skills in this area, which has been largely neglected. Engineering education must adapt by revising curricula to emphasize public policy. There's even a proposal for a public policy major, as prior courses addressing the intersection of political science and engineering were removed due to time constraints. With engineers' roles in public policy becoming more critical, reviving this topic is essential. Instead of focusing solely on technical expertise, engineering graduates need training on engaging with policymakers and understanding the legislative process [13, 14].

Ethics in Engineering and Health Equity

Although the challenges of finding health equity solutions are complex, the ethical expectations of engineers are not. Engineers know that they have obligations to do good, to avoid harming, and to be honest. All of those expectations have built-in ethical requirements. As this chapter has shown, engineers can use a very wide range of existing tools from engineering and related fields to pursue health equity. Because of engineering's widespread impact on the world, engineers are ethically responsible to work toward health equity. To prevent the world from being worse than better, engineers need to be aware of their social responsibilities and health equity, and they need to choose activities that promote social justice. An increased awareness of health equity within engineering helps engineers to better find solutions to "wicked" social problems, as engineering education may not recognize these problems and their potential solutions. Many ways for engineers to promote health equity have been pointed out from the ethical expectations of engineering, as well as engineers' expertise, knowledge, their professional societies as organizations, and their ability to communicate. The pursuit of health equity is a process that is likely to change over time, so this chapter encourages engineering societies and engineers to be vigilant in this process and to collectively try many different things. Also, taking into account that health equity is an area that may be relatively new to engineers and their organizations, the exploration of health equity in engineering within this chapter may not be comprehensive. Exploration topics such as the definitions of health equity, the awareness of the engineering community, case studies on health inequities that arise from engineering infrastructures, the current works of engineers in promoting health equity and how engineering organizations promote health equity, and how to better incorporate the topics of health equity within engineering curricula are all worthy of further research [15, 16].

Global Perspectives on Health Equity

Health is unevenly distributed among populations due to social determinants, including historical, economic, and environmental factors, which influence a person's societal status. Those in favorable conditions typically access quality education, decent housing, and natural environments, leading to healthier lifestyles. However, wealthier societies still face health inequities, especially with rapid urbanization worsening these disparities for resource-poor groups. Climate change trends further heighten global vulnerability. Health inequities are prevalent worldwide, often intensified by globalization, leaving marginalized populations behind and enabling the spread of preventable diseases, limiting access to care. Promoting health equity is essential, as existing inequities demand attention and response. A consensus among scholars identifies social determinants as crucial in understanding and addressing health disparities. To advance health equity, it is vital to consider the specific contexts and experiences of those affected. Notably, the focus has been on nations with robust health systems, leading to international comparisons that can further entrench inequities. High-income countries benefit disproportionately from healthcare investments, rendering health disparities in poorer nations seemingly insurmountable. Despite advocating for health equity, discussions often overlook the actual budget distribution, which perpetuates inequitable systems. Therefore, translating high-level conversations on health equity into actionable support within health systems is critical. Theories suggest that global health inequities are partially rooted in unequal access to knowledge [17, 18].

Education and Training for Engineers

The inequities in health service access highlight the need for engineering innovations to alleviate the burden on public health systems in marginalized areas. A shift in public health priorities is needed, emphasizing engineering as a vital partner. Biomedical engineering can significantly contribute to global health initiatives. Engineers should collaborate with public health specialists to introduce disruptive technologies. The increasing demand for health services alongside dwindling resources necessitates new approaches to develop affordable products that enhance service quality and distribution. Low-cost, impactful products are essential for providing accessible healthcare in resource-limited settings. Biomedical and clinical engineers have experience in designing compliant products and can continue to contribute to public health. Ten critical human and technical needs for public health can be directly addressed through engineering innovations. These include measuring productivity, creating staffing models, quantifying existing infrastructure, and developing uncertainty models for historical datasets. Addressing both technical and human capacity needs poses a solvable challenge, with potential for substantial returns on investment in public health productivity. By fostering innovation with engineers in developing countries, there is an opportunity to significantly improve public health solutions. Collaborating with knowledgeable partners is crucial for effectively applying available engineering talent and resources to current global health needs [19, 20].

Challenges Facing Engineers in Health Equity

Engineers, despite their unique role in developing socio-technical contexts essential for health equity initiatives, have been slow to engage in the health equity movement, particularly in biomedical engineering. Many biomedically engineered devices are created for contexts that lack ethical implementation in US healthcare settings, inhibiting a comprehensive understanding of the societal factors during the development phase, leading to ineffective designs. Collaborations with biomedical researchers and community organizations have shed light on systemic inequities affecting low-income communities. Expanding interdisciplinary health-focused scholarship and integrating existing engineering education standards with health equity initiatives could enhance engineers' roles. They have the potential to address systemic inequities affecting health outcomes through straightforward, well-taught design methodologies. Emphasizing low-resourced communities can yield significant benefits alongside broader public health strategies aimed at reducing health disparities. Health disparities represent a major challenge for 21st-century global society, primarily concentrated in low-income communities across various public health metrics. Thus, health equity efforts need to transition from mere awareness-raising to promoting designs focused on prevention, systematic interventions, and policy reforms. While biomedical engineers remain largely absent from these discussions, other engineering disciplines have begun to tackle health disparities with research and community engagement. Institutional acknowledgment of engineering-based health initiatives as valid platforms for scholarship would provide a foundation for their wider implementation and acknowledge health equity as a legitimate career pathway within the engineering field [21, 22].

Future Directions in Health Equity Engineering

A multi-disciplinary effort is proposed to engage K-12 students, undergraduates, and graduates in strategies promoting health equity through engineering. Engineers and the ECE community will assist teams in conducting inquiry-based research to address equity challenges, employing qualitative measures, co-design, and disseminating results. Engineering education must evolve to enhance understanding within the ECE community, transitioning from traditional science and technology to focus on health and community equity. Metrics should evaluate community-to-university impacts, assessing the effectiveness of strategies and the outcomes achieved. This knowledge will raise awareness among engineers about the importance of comprehensive equity approaches and constructivist learning environments, fostering collaboration with non-technical disciplines to enhance health equity and community outcomes. Engineering research must shift from mere application of science and technology to addressing inequities that contribute to disease burden. Emphasizing co-design with affected communities is crucial for promoting social responsibility and equity. The interplay between health and education yields better community outcomes, following the principle of non-maleficence to inform effective inquiry-based education. Engaging biomedical engineering professionals in public health challenges presents an opportunity for engineering curricula to address health disparities as an interdisciplinary focus, essential for innovation. However, current engineering curricula inadequately prepare students to confront health disparities. Resources are provided to help educators integrate this critical subject into engineering education, featuring illustrative class projects and outcomes targeting community populations [23-27].

CONCLUSION

Engineers have a vital and expanding role in the global effort to achieve health equity. From designing culturally competent technologies and inclusive infrastructure to using data analytics for detecting disparities, their contributions can shape more just and accessible healthcare systems. However, this impact hinges on a fundamental reimagining of engineering education, professional development, and ethical responsibility. By embedding health equity into the core of engineering practice and fostering interdisciplinary collaboration, engineers can become essential allies in dismantling systemic barriers to health. This transformation requires not only technical innovation but also deep engagement with affected communities, policymakers, and global partners. As the world faces escalating health crises and persistent disparities, engineers must rise to the challenge not just as builders of systems and devices but as stewards of equity, justice, and societal well-being.

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