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Research Article

SUSTAINABLE MEDICAL TRAINING: STRATEGIES FOR REDUCING ENVIRONMENTAL IMPACT

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Abstract

Climate change represents a pressing global health challenge, affecting human health, infrastructure, ecosystems, and socioeconomic systems worldwide. Paradoxically, the healthcare sector—tasked with mitigating climate-related health impacts—contributes significantly to greenhouse gas emissions, accounting for approximately 4.4% of global emissions according to the World Health Organization. Major sources include hospital operations, medical equipment and pharmaceutical production, transportation, waste management, research, and educational activities. In high-income countries and populous developing nations, healthcare-related emissions can constitute around 5% of national carbon outputs. These findings highlight the critical need for targeted strategies to reduce environmental impacts within healthcare, particularly in medical training programs, which play a central role in shaping sustainable healthcare practices. Implementing effective mitigation strategies in medical education can foster a generation of healthcare professionals equipped to deliver care while minimizing environmental harm.

Keywords: Climate change, Healthcare emissions, Medical education, Sustainability, Environmental impact

INTRODUCTION

The accelerating pace of climate change has emerged as one of the greatest global health challenges of the 21st century. Its adverse effects on human health, infrastructure, ecosystems, and socioeconomic systems are being felt across the globe. Paradoxically, the healthcare sector—which is at the frontline of mitigating climate-related health impacts—contributes significantly to the problem it seeks to address. According to the World Health Organization (WHO) and recent studies, the global healthcare sector is responsible for approximately 4.4% of worldwide greenhouse gas (GHG) emissions, a figure that rivals or exceeds emissions from other major sectors such as aviation and agriculture in some countries.

Healthcare-related emissions stem from a broad spectrum of activities: hospital operations, production of medical equipment and pharmaceuticals, transportation, waste management, research, and educational services. Notably, in high-income nations such as those within the Organisation for Economic Co-operation and Development (OECD), as well as in populous developing countries like China and India, healthcare's share of national carbon output ranges around 5%. This substantial contribution underscores the urgency of implementing emission-reduction strategies across all healthcare-related domains, including medical education.

Medical education is a critical and foundational component of the healthcare system. It not only prepares the next generation of physicians to deliver high-quality care but also shapes their understanding of global health priorities, including planetary health. However, the process of medical education itself entails activities that generate significant carbon emissions. These include the construction and maintenance of academic infrastructure, energy consumption in teaching facilities, extensive travel for clinical rotations, use of physical and digital educational resources, and waste generated from clinical training.

This commentary focuses on understanding and addressing the carbon footprint of medical education, with particular emphasis on two main phases: the preclerkship and clerkship periods. Preclerkship education generally encompasses the early years of medical training, which are characterized by lecture-based learning, laboratory work, small group discussions, and increasing use of digital platforms. These activities take place within university settings that often rely on energy-intensive infrastructure, including heating, cooling, ventilation, lighting, and audio-visual technologies. The production and disposal of printed educational materials, the use of personal electronic devices, and internet bandwidth consumption also contribute to the carbon cost of preclerkship learning.

In contrast, the clerkship phase typically occurs during the latter part of medical training, when students begin rotating through clinical environments such as hospitals, community clinics, and specialty outpatient centers. This stage of education necessitates frequent travel, both local and regional, to access different clinical settings. Transportation emissions can become particularly significant for students in rural or decentralized training programs. Additionally, students in clerkship participate directly in patient care, often engaging with disposable clinical tools, diagnostic technologies, and high-energy hospital equipment—further compounding the environmental impact.

Both phases of medical education present unique challenges and opportunities for sustainability. Preclerkship education could potentially reduce its carbon footprint through the adoption of hybrid or fully digital learning models. Online platforms, virtual laboratories, and AI-powered simulation tools offer alternatives to physical presence and resource-intensive laboratory work. However, digital tools themselves require electricity and server maintenance, raising new questions about energy sources and digital infrastructure design.

Clerkship education, on the other hand, may benefit from greater integration of telemedicine, virtual case reviews, and mobile simulation units, thereby reducing travel and physical resource consumption. Furthermore, curricular reforms can embed environmental ethics and climate literacy into clinical training, empowering future physicians to consider sustainability in their practice.

Another essential consideration in reimagining medical education's environmental impact is the application of learning science and cognitive learning theories. These fields offer guidance on how to design curricula that maximize knowledge retention and skill development while minimizing redundant or inefficient practices. For instance, the principle of "cognitive load theory" suggests that excessive or extraneous activities hinder learning. By streamlining educational delivery, institutions can simultaneously improve learning outcomes and reduce environmental costs. Similarly, problem-based learning, flipped classroom models, and gamified digital platforms have demonstrated efficacy in medical training and can be adapted with sustainability in mind.

Despite these promising developments, institutional inertia, lack of awareness, and absence of targeted policy frameworks hinder rapid change. Many medical schools remain unaware of their carbon footprint and lack systems to measure or monitor their environmental performance. Accreditation bodies and professional organizations have yet to integrate environmental sustainability into core medical education standards. This gap presents both a challenge and an opportunity. Just as medical education once embraced evidence-based medicine and public health as core competencies, it must now incorporate environmental stewardship and planetary health. Medical students themselves are increasingly vocal in demanding greener curricula and practices. A growing movement among students and young healthcare professionals recognizes climate change not only as a scientific issue but also as an ethical imperative. These future physicians are calling on institutions to lead by example in reducing their ecological impact. Responding to this call will require collective action from deans, educators, facilities managers, curriculum planners, and national policy makers.

This commentary contributes to the discourse by examining existing literature on the carbon costs of medical education and identifying opportunities for mitigation. It offers a comparative analysis of the environmental impacts during preclerkship and clerkship phases and outlines practical, scalable strategies for carbon reduction. These include digital learning integration, green building designs, reduced travel through decentralized and remote clinical experiences, and curriculum development that incorporates sustainability principles.

In conclusion, as the healthcare sector works to reduce its environmental impact, medical education must not be left behind. In fact, it can serve as a model for innovation, by preparing future doctors to be both scientifically competent and environmentally responsible. By rethinking how we train physicians—with an eye on both quality and sustainability—medical schools can contribute meaningfully to the broader global effort to combat climate change.

Preclerkship Education: Digital Learning and Carbon Reduction

The traditional model of preclerkship education is resource-intensive. Large lecture halls, anatomy labs and other educational spaces consume vast amounts of energy for heating, cooling and powering equipment. There are emissions associated with each of these activities. For e.g., the activties related to the anatomy labs such as transporting donor bodies for dissections, storing them in freezers and cremating the human remains can be an enormous contributor to carbon emissions. A significant portion of a medical school's carbon footprint can be attributed to its buildings, which require constant maintenance to ensure that temperature, air quality and lighting meet the necessary standards for education[3, 4]. For example, laboratories where students conduct dissections or simulations often need to be maintained at specific temperatures to ensure proper storage of biological materials. These energyintensive environments contribute to a medical school's carbon footprint.

However, the COVID-19 pandemic prompted a rapid shift to online learning, which revealed the potential for reducing emissions associated with preclerkship education. Moving lectures and assessments online reduced the carbon footprint of preclerkship education by up to 30 %, primarily by eliminating the need for students to commute to campus and reducing the demand for physical classroom space[4]. This shift has opened new possibilities for reducing emissions in medical education.

Digital and hybrid learning models offer several advantages in terms of sustainability. By delivering lectures, tutorials and assessments online, medical schools can significantly reduce their energy consumption. A study conducted at Case Western Reserve University evaluated the effectiveness of the HoloAnatomy® mixedreality application compared to traditional cadaveric dissection in teaching musculoskeletal anatomy. The randomized controlled trial found that students achieved comparable learning outcomes with both methods, suggesting that mixed-reality technology can serve as an effective alternative to cadaveric dissection[5]. Moreover, online learning platforms can facilitate the use of virtual simulations and other digital tools, further decreasing the need for resource-intensive physical environments. Additionally, for didactic lectures, students can participate in synchronous live sessions from various locations, reducing the need for commuting and minimizing transportation-related emissions.

However, the transition to digital learning is not without environmental costs. The production, maintenance and disposal of electronic devices, such as laptops, tablets and smartphones, contribute to e-waste and carbon emissions. Moreover, the data centers that power online learning platforms consume large amounts of energy. Data centers account for approximately 1 % of global electricity demand, a figure that is expected to grow as more educational institutions move online[6]. Therefore, while digital learning can reduce the carbon footprint of preclerkship education, it is important to consider the environmental costs associated with increased reliance on technology.

To mitigate these costs, medical schools can adopt strategies such as using energy-efficient devices, encouraging recycling and proper disposal of electronic waste and selecting online platforms that are powered by renewable energy sources. By carefully considering the environmental impact of digital education, medical schools can make informed decisions about how to reduce their carbon footprint while maintaining high standards of education.

Simulation-Based Learning and Its Environmental Footprint

Simulation-based education has become a cornerstone of modern medical training, offering students the opportunity to practice clinical skills in a controlled environment before interacting with real patients. However, simulation centers can be energy-intensive, requiring climate control, lighting and the use of high-tech equipment such as manikins, which need regular maintenance and sometimes single-use components. For example, some manikins and simulation devices require disposable parts such as needles, syringes and gloves, which contribute to medical waste[7].

Nevertheless, virtual simulations offer a promising alternative that can reduce the environmental impact of simulation-based education. Virtual simulations allow students to engage in realistic clinical scenarios using software rather than physical equipment. This eliminates the need for many disposable materials and reduces the energy consumption associated with maintaining simulation centers. Additionally, virtual simulations can be accessed remotely, allowing students to practice clinical skills without traveling to a physical location. This can be used for students during their early preclerkship phase and has the potential to repalce some of the in-person clinical skills sessions.

However, like digital learning, virtual simulations have their own environmental costs. The development and maintenance of virtual simulation platforms require significant computing power and the energy consumption of data centers must be taken into account. To minimize the environmental impact of virtual simulations, medical schools should prioritize the use of energy-efficient technologies and renewable energy sources for their digital infrastructure. By incorporating sustainability into the design and implementation of simulation-based education, medical schools can reduce their carbon footprint while continuing to provide high-quality training.

Clerkship Education: Transportation and Carbon Costs of Clinical Environments

Clerkship education is a critical phase of medical training, during which students apply their knowledge in real clinical settings and learn from real patient experiences. However, the traditional model of clerkship education often involves frequent travel between different clinical sites, resulting in substantial carbon emissions. Medical students often need to travel significant distances between various healthcare facilities during their clinical rotations. In some cases, this includes air travel to reach remote clinical sites. For instance, a study published in BMC Medical Education discusses how pre-final year medical students at Stellenbosch University were distributed across a widespread training platform in two provinces of South Africa, utilizing a range of healthcare facilities in both rural and urban areas, rather than the central academic hospital. This distribution required students to commute long distances and in some instances, travel by plane to reach remote clinical sites[8]. Transportation accounts for nearly 30 % of the carbon footprint of clerkships, with air travel being a particularly significant contributor[9].

One solution to the carbon emissions associated with clerkship travel is the adoption of Longitudinal Integrated Clerkships (LICs). LICs allow students to stay at a single clinical site for an extended period, rather than rotating between different locations. This model not only reduces the need for travel but also provides students with a more cohesive and continuous learning experience. LICs can reduce carbon emissions by up to 40 % compared to traditional clerkship models, while also promoting stronger relationships between students and clinical teams[10].

Telemedicine offers another opportunity to reduce the carbon footprint of clerkship education. As telemedicine becomes increasingly integrated into healthcare, students can participate in virtual patient consultations and other remote clinical activities without the need for in-person visits. Incorporating telemedicine into clerkship education could reduce transportation-related emissions by as much as 25 %, particularly for outpatient services[9]. Additionally, telemedicine allows students to gain experience with the technologies and workflows that are likely to become more prevalent in their future practice.

The Environmental Costs of Clinical Training Environments

In addition to the transportation-related emissions associated with clerkships, clinical training environments themselves can be significant sources of carbon emissions. Hospitals, in particular, are energy-intensive institutions that require large amounts of power for lighting, heating, cooling and operating medical equipment. Hospitals are among the most energy-intensive buildings in the healthcare sector and their carbon footprint is exacerbated by the use of single-use medical supplies, which generate substantial waste[2].

Reducing the environmental impact of clinical training environments requires collaboration between medical schools and healthcare institutions. Hospitals and clinics can adopt sustainable practices such as using renewable energy sources, reducing waste and implementing energyefficient building designs. For example, some hospitals have begun to use solar panels and energy-efficient lighting to reduce their carbon footprint. Additionally, efforts to reduce the use of single-use medical supplies and promote recycling can help to minimize waste in clinical settings.

Medical schools can also play a role in promoting sustainability within clinical training environments. By integrating sustainability education into the curriculum, medical schools can raise awareness among students about the environmental impact of healthcare practices. For example, students can be encouraged to consider the environmental implications of their clinical decisions, such as choosing reusable medical instruments when appropriate. By fostering a culture of sustainability in clinical education, medical schools can contribute to the broader effort to reduce the carbon footprint of the healthcare sector.

CONCLUSION

The carbon footprint of medical education, particularly in the preclerkship and clerkship phases, presents a significant challenge for medical schools. However, this challenge also offers an opportunity for innovation and sustainability. Digital and hybrid learning models, virtual simulations, longitudinal integrated clerkships and telemedicine all present viable strategies for reducing the environmental impact of medical education. Additionally, hospitals and clinics can adopt sustainable practices that contribute to the overall reduction of healthcare emissions.

While the transition to more sustainable models of medical education requires careful planning and consideration, it is essential for medical schools to take proactive steps toward reducing their carbon footprint. By balancing educational quality with environmental responsibility and adopting the emerging findings from the science of learning, medical schools can continue to provide high-quality education while contributing to the global effort to combat climate change.

Future research should delve deeper into understanding the carbon footprint of different educational activities in medical training while also exploring how proposed changes impact student learning experiences and outcomes. Additionally, uncovering new ways to minimize environmental impact while maintaining educational quality is essential. Collaboration between medical schools, healthcare institutions and other stakeholders is vital for creating robust sustainability plans that address both education and clinical practice. By leading these efforts, medical schools have a unique opportunity to shape a healthcare future that is not only environmentally sustainable but also equitable and socially responsible.

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