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Article

Medical student attitudes toward healthcare sustainability education at a multi-site private United States medical school

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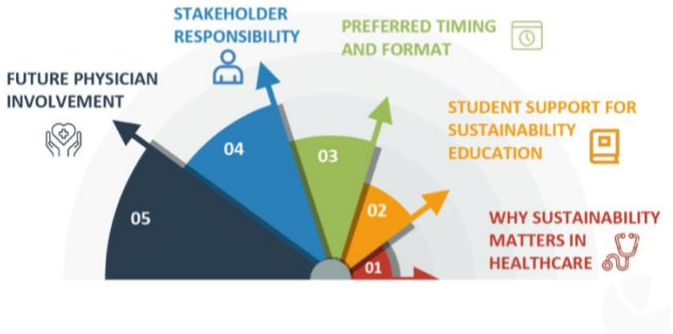

Highlights

- *Climate change demands physicians engage in healthcare sustainability efforts.*
- *Medical students favor sustainability as a theme across training.*
- *Students want to apply sustainability in their future clinical practice.*
- *Sustainability teaching varies in medical school and is rare in residency and post-training.*
- *National requirements are key to standardizing and legitimizing sustainability training.*

Abstract

Climate change and healthcare's environmental impact pose urgent global health challenges, yet little is known about how United States (U.S.) medical students view their role in advancing sustainable healthcare. This study surveyed students at a private, tri-site U.S. medical school to assess their perspectives on sustainability in medicine, its place in medical education, and its relevance to future careers. Two anonymous online surveys were distributed in January and July 2024 to all enrolled students at Mayo Clinic Alix School of Medicine, USA. Descriptive statistics and chi-square analyses assessed attitudes toward curricular needs, stakeholder responsibility, and future involvement in sustainability efforts. Students identified government regulators and healthcare administrators as holding the greatest responsibility for improving healthcare sustainability, while still attributing meaningful responsibility to physicians. Across both surveys, 88% of respondents agreed that healthcare sustainability should be taught in medical training ($p < 0.001$), and 62% reported insufficient education in their current curriculum ($p < 0.001$). Students preferred sustainability content integrated throughout the curriculum rather than delivered as isolated sessions and identified the preclinical years and residency as the most appropriate stages for this instruction. Interest in future sustainability involvement was high at 65% ($p < 0.001$), with students expressing interest in clinical practice,

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policy, advocacy, and medical education. These findings highlight strong student motivation to participate in sustainability initiatives and underscore the need for standardized, longitudinal sustainability education across medical training.

1 Introduction

Climate change and human environmental impact profoundly affect global health through factors such as extreme heat, infection, flooding, and poor air quality, with air pollution alone resulting in an estimated 6.7 million premature deaths in 2019 (Fuller et al., 2022). The global healthcare sector itself has a significant environmental impact, contributing an estimated 4.4% of global greenhouse gas emissions, a figure that rises to 9% to 10% in the United States (Eckelman and Sherman, 2016; Health care climate footprint report, 2019; Lenzen et al., 2020). Traditionally, hospitals have been the most resource-intensive component of the healthcare system, significantly contributing to a negative environmental impact through energy consumption, waste generation, and greenhouse gas emissions (Magasich-Airola et al., 2024; Dolcini et al., 2025; Flynn et al., 2025). The pharmaceutical industry also contributes through the mass production and transportation of medical supplies and pharmaceuticals globally (Selvakumar et al., 2025). Water and electricity consumption across these healthcare stakeholders is substantial, requiring large volumes of water and electricity to power medical equipment, lighting, and hospital heating, ventilation, and air conditioning (HVAC) systems (Brown et al., 2012; Sepetis et al., 2025). While less well-documented, private practices and other healthcare sectors may have lower impact due to greater emphasis on personalized, preventive care, reducing unnecessary tests and procedures (King-Mullins, 2024).

The environmental impact of artificial intelligence (AI) is accelerating as its use in healthcare grows, already contributing to a 29–48% rise in greenhouse gas emissions reported by major technology companies such as Google and Microsoft (Osmanlliu et al., 2025). Although AI's increasing efficiency and near human-level performance have been praised for easing clinician workload and improving patient outcomes (Bekbolatova et al., 2024), its rapid expansion carries broader implications. In healthcare, AI is primarily used to enhance diagnostic reasoning, support virtual care and remote monitoring, advance research and drug discovery, and streamline administrative workflows, ultimately enabling more personalized and efficient care (Al Kuwaiti et al., 2023; Alowais et al., 2023; Faiyazuddin et al., 2025). However, growing attention is being drawn to the ethical and environmental costs of these technologies (Bekbolatova et al., 2024). AI's environmental footprint is substantial, driven by the high electricity demands of model training and inference and the intensive, water-dependent cooling systems required to operate data centers (Karakaş and Özdemir, 2025).

As these concerns grow, they intersect directly with a larger conversation already taking place in healthcare: the push towards sustainability. Sustainable healthcare was defined by the International Association for Medical Education as improving healthcare delivery such that we "*provide high-quality healthcare now without compromising the ability to meet the health needs of the future*" (Shaw et al., 2021), a process which involves balancing environmental, economic, and social resource limitations. As key players in the healthcare system, physicians are increasingly called upon to advocate for and implement sustainable practices as part of their duty to protect health (Mortimer, 2010; Macpherson and Hill, 2017). This obligation necessarily requires education in these concepts (Wellbery et al., 2018; Otto et al., 2020).

Since 2018, the General Medical Council in the United Kingdom (UK) has mandated that medical school graduates be able to incorporate sustainable healthcare principles into clinical practice (Outcomes for graduates – GMC, 2018). Though the U.S. medical education system does not have these requirements, recent years have seen substantial efforts from both medical students and faculty to improve healthcare sustainability education (Marill, 2020; Sullivan et al., 2021; Navarrete-Welton et al., 2022). The improvement in sustainable healthcare education has been reflected in a steady increase in medical schools with climate change and environmental health as required curricular topics (Curriculum Topics in Required and Elective Courses at Medical School Programs, 2023; Curriculum Topics in Required and Elective Courses at Medical School Programs, 2024). In spite of these gains, there is a disconnect between the sustainability education being provided and the students' self-reported confidence in these topics (Hampshire et al., 2021), with ratings of the education across the U.S. varying significantly (Roden et al., 2025). The goal of healthcare sustainability education is to provide the foundation for future physicians to feel confident in both addressing sustainability challenges in medicine and being proactive change agents in their respective fields of influence. Therefore, improvement must stem from a greater understanding of how students want to be educated and what role they view that education playing in their future careers.

Although prior papers have investigated perceived responsibility for sustainability in other fields (Andic and Vorkapic, 2017; Eco-Anxiety Negatively Impacts Daily Lives of One in Two U.S. Youth According to SHU Poll, 2024; Roewe, 2024), no research has yet studied the medical student perspective on the degree of responsibility physicians hold for healthcare sustainability. Internationally, several surveys have explored medical students' interest in expanded education on healthcare sustainability, their preferred timing for integrating this content, and their desire to participate in resource-conservation efforts. For example, a survey of medical students and residents in Italy found that 84% supported incorporating resource-conservation training into both pre-clinical and clinical curricula (Sarcone et al., 2025). However, comparable data for medical students

within the U.S. largely does not exist. Prior U.S. studies have primarily examined student perspectives on climate-related health education rather than on healthcare resource utilization and sustainability (Hampshire et al., 2021). We aim to address this gap in the literature through a survey of Mayo Clinic (private tri-site medical school with locations in Rochester, MN; Scottsdale, AZ; and Jacksonville, FL, USA) medical students' opinions on healthcare sustainability, its place in medical training, and its role in their future careers.

2 Methods

2.1 Study design

The study was approved by the institution's Education Research Committee and was deemed exempt by the Mayo Clinic Institutional Review Board. Participants consented to the use of the collected information for research purposes after the removal of all identifiers. A convenience sample was obtained through an anonymous online Qualtrics survey distributed to all students in all four class years at the Mayo Clinic Alix School of Medicine via a schoolwide student email list twice at two time points. The population was resampled at the second time point in order to capture the new cohort of first year students who were enrolled in the school after the administration of the first survey. The survey was distributed via templated email including informed consent with a single-use link and advertised as a survey on medical student perspectives on sustainability.

The first survey was distributed in January 2024, and the second survey was distributed in July 2024. For both surveys, participants created a unique identifier consisting of the first letter of their first name and the last three digits of their phone number, which was used to identify repeat respondents while ensuring anonymity. Only the respondents' first response to the surveys was included to better control for the influence of the survey on the respondents' opinions.

2.2 Surveys

The survey consisted of multiple choice, multi-select, Likert scale, and optional free response questions pertaining to year in school, perspectives on healthcare sustainability in medical education, and interest in future involvement in healthcare sustainability (Supplementary data, **Figure S1**). Questions 9, 10, and 11 were displayed using OR-logic, such that each question was administered if and only if any of the specified prior conditions were met. The survey underwent two-step validation, first with independent review by two Mayo Clinic faculty with involvement in education, followed by a pilot survey of medical students and undergraduate students who were not part of the Mayo Clinic student body.

2.3 Statistics

Descriptive statistics were employed to analyze survey responses. Response rate was calculated using the class sizes. Number of responses are reported both for the two survey time points separately and as a total. Statistical significance was defined as $p < 0.05$. For Likert scale questions, *p*-values between the responses to the two surveys were first calculated using chi-squared analysis to determine if there was a difference in response frequency across time. *P*-values were calculated with responses grouped as either *agree* or *disagree* for comparison of frequencies. For questions with response rates that did not vary significantly over time, *p*-values were calculated for the survey population as a whole using chi-square analysis, with the null hypothesis that there was no difference between frequencies of *agree* versus *disagree*. Neither *disagree* nor *agree* responses were excluded from chi-square analysis. *P*-values were not calculated for multi-select answers. To analyze the question relating to responsibility for healthcare sustainability, data were pooled and visualized using a bubble diagram. Data analysis and visualization were conducted using Microsoft Excel for Windows and Matplotlib in Python (Version 3.9.13) (Hunter, 2007).

3 Results

The response rates for the January and July surveys were 7.7% (n = 34, out of 439 surveyed students) and 9.0% (n = 40, out of 443 surveyed students), respectively. Both surveys contained respondents from all years in medical school and included MD-PhD students, whose year in medical school was included under the category "Other". Respondent characteristics are presented in **Table 1**.

A bubble diagram representing medical student ranking of the responsibility of various stakeholders within healthcare for healthcare sustainability is presented in **Figure 1**, in which a larger bubble represents more responses for that category. Overall, government regulators were thought to hold the most responsibility, followed in order by healthcare administrators, corporate partners,

Table 1. *Descriptive statistics of respondent characteristics.*

Individual-level characteristics	January (n = 34)	July (n = 40)
Year in medical school	*Total and percentage of respondent*	
First year	9 (26%)	21 (53%)
Second year	11 (32%)	4 (10%)
Third year	4 (12%)	11 (28%)
Fourth year	8 (24%)	1 (3%)
Other	2 (6%)	3 (8%)
Current or past involvement with healthcare sustainability	6 (18%)	8 (20%)

Table 2. *Medical student attitudes towards healthcare sustainability curriculum in medical training.*

Questions and responses	January (*n* & %)	July (*n* & %)	Total (*n* & %)	P-value (agree vs. disagree)
Question: My medical school curriculum provides sufficient education on healthcare sustainability.	*n* = 34	*n* = 40	*n* = 74	< 0.001
Strongly agree	1 (2.9%)	0 (0%)	1 (1.4%)	
Somewhat agree	0 (0%)	3 (7.5%)	3 (4.1%)	
Neither agree nor disagree	8 (23.5%)	16 (40%)	24 (32.4%)	
Somewhat disagree	14 (41.2%)	13 (32.5%)	27 (36.5%)	
Strongly disagree	11 (32.4%)	8 (20%)	19 (25.7%)	
Question: Healthcare sustainability should be taught in medical training.	*n* = 34	*n* = 40	*n* = 74	< 0.001
Strongly agree	12 (35.3%)	24 (60%)	36 (48.6%)	
Somewhat agree	16 (47.1%)	13 (32.5%)	29 (39.2%)	
Neither agree nor disagree	6 (17.6%)	2 (5%)	8 (10.8%)	
Somewhat disagree	0 (0%)	1 (2.5%)	1 (1.4%)	
Strongly disagree	0 (0%)	0 (0%)	0 (0%)	
Question: In your opinion, what stage of education should healthcare sustainability be taught in? (check all that apply)	*n* = 34	*n* = 39	*n* = 73	Not applicable
Preclinical medical school	24 (70.6%)	31 (79.5%)	55 (75.3%)	
Clinical medical school	22 (64.7%)	28 (71.8%)	50 (68.5%)	
Residency	29 (85.3%)	30 (76.9%)	59 (80.8%)	
Post-residency	19 (55.9%)	29 (74.4%)	48 (65.8%)	
Question: In your opinion, what format should healthcare sustainability be taught in? (check all that apply)	*n* = 30	*n* = 37	*n* = 67	Not applicable
Longitudinal coursework	11 (36.7%)	22 (59.5%)	33 (49.3%)	
Integration as a theme	25 (83.3%)	34 (91.9%)	59 (88.1%)	
Separate required course	3 (10%)	3 (8.1%)	6 (9%)	
Separate selective/elective	14 (46.7%)	9 (24.3%)	23 (34.3%)	
Student organization	13 (43.3%)	14 (37.8%)	27 (40.3%)	
Other:	0 (0%)	0 (0%)	0 (0%)	

physicians, and finally insurance companies with the least responsibility.

A summary of medical students' attitudes towards healthcare sustainability curriculum in medical curriculum is given in **Table 2**. There were no statistically significant changes in responses between the first and second surveys, for which the *p*-values have not been reported. Total across both surveys, 88% of students agreed that healthcare sustainability should be taught in medical training ($p < 0.001$), and 62% of students felt that their medical school was providing insufficient education on health care sustainability ($p < 0.001$). On the July survey, the increase in respondents who neither agreed nor disagreed that the medical school provided adequate education on healthcare sustainability was attributable to first-year students in their first month of medical school. Total across both surveys, 88% of respondents preferred healthcare sustainability education to

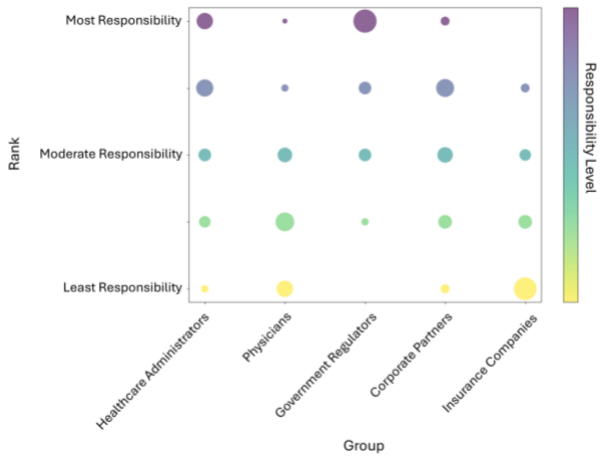

Figure 1. *Responsibility for healthcare sustainability.*

be integrated as a theme throughout their medical school education, which was preferred to any of the other options. Preclinical medical school and residency were the most highly favored periods of time for teaching healthcare sustainability, though each phase of education was selected by at least 65% of respondents, indicating significant interest in sustainability education in all phases of medical training (**Figure 2**).

Medical student interest in future involvement in healthcare sustainability is summarized in **Table 3**. 76% of students disagreed that there is currently enough work addressing sustainability in medicine ($p < 0.001$). 65% of respondents also want to be involved in healthcare sustainability in their careers. Cumulatively, the respondents were most interested in healthcare sustainability involvement in clinical practice at 83%, followed by healthcare policy and advocacy at 60% and medical education at 56%.

4 Discussion

The most effective efforts toward improving healthcare sustainability will involve multiple stakeholders with unique roles, as demonstrated in a discussion emphasizing the shared responsibility of manufacturers, healthcare professionals, and the government in sustainable medication disposal (Shared Responsibility and Proper Medication Disposal, 2022). Medical students demonstrate an informed understanding of the most influential stakeholders in improving healthcare sustainability, with particular attention paid to government regulators and healthcare administrators. Government regulators are in the position to both require minimum sustainability standards and to offer advantages such as tax incentives and sustainability certifications to hospitals and healthcare organizations in order to encourage the development of sustainable healthcare at a system level (Sustainable Healthcare Certification, 2025). In turn, healthcare administrators play a crucial role in shaping and implementing sustainability policies, balancing regulatory compliance with strategic decision-making that impacts institutional sustainability initiatives. However, medical students, as future practitioners and policy makers, are in a unique position to become involved in healthcare sustainability early on.

Previous surveys of medical students have shown that although they believe physicians should not hold the most responsibility for healthcare sustainability, they still believe physicians have some responsibility as a moral duty of the profession (Macpherson and Hill, 2017; Ryan et al., 2020). However, this study is the first to identify which stakeholders medical students believe hold the greatest responsibility for healthcare sustainability. The physician's responsibility for healthcare sustainability is further supported by students demonstrated interest in both sustainability education and sustainability-related work as part of their future careers, even among those who have not yet engaged in formal sustainability efforts.

Medical students continue to express the desire to learn about healthcare sustainability in their medical training. In this study, 88% of respondents agreed that healthcare sustainability should be taught in medical training, mirroring findings from U.S. and international cohorts (Marill, 2020; Hampshire et al., 2021; Gupta et al., 2022). Students also indicated interest in sustainability education during residency and beyond, reflecting career-long engagement even among those without prior involvement. In line with educator recommendations (Tun, 2019; Blanchard et al., 2023), respondents favored integrating sustainability content into the standard curriculum. Integration may address common concerns about limited curricular time (Tun, 2019; Shea et al., 2020) and aligns with existing models that have successfully embedded sustainability into medical education (Sullivan et al., 2021; Liu et al., 2022; Navarrete-Welton et al., 2022). Efforts to map sustainability learning objectives to ACGME (Accreditation Council for Graduate Medical Education) competencies further support incorporation across preclinical coursework, clinical rotations, residency, and continuing medical education (Philipsborn et al., 2021). This integration could be further strengthened through the implementation of U.S. national guidelines from the AAMC

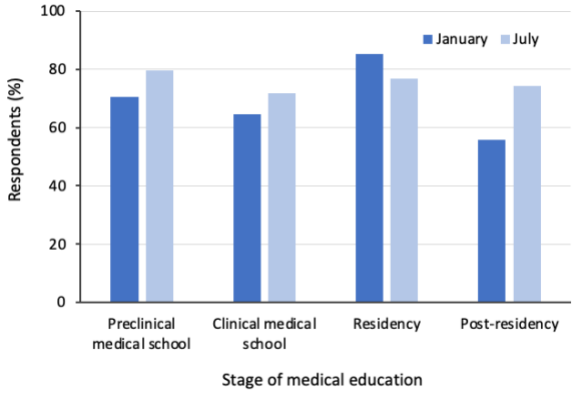

Figure 2. *Stage of education for healthcare sustainability curriculum.*

Table 3. *Medical student interest in healthcare sustainability involvement.*

Questions and responses	January (*n* & %)	July (*n* & %)	Total (*n* & %)	P-value (agree versus disagree)
Question: There is currently enough work addressing sustainability in medicine.	*n* = 34	n = 40	*n* = 74	< 0.001
Strongly agree	0 (0%)	0 (0%)	0 (0%)	
Somewhat agree	0 (0%)	2 (5%)	2 (2.7%)	
Neither agree nor disagree	8 (23.5%)	8 (20%)	16 (21.6%)	
Somewhat disagree	14 (41.2%)	15 (37.5%)	29 (39.2%)	
Strongly disagree	12 (35.3%)	15 (37.5%)	27 (36.5%)	
Question: I want to be involved in healthcare sustainability work in my career.	*n* = 34	*n* = 40	*n* = 74	< 0.001
Strongly agree	3 (8.8%)	10 (25%)	13 (17.6%)	
Somewhat agree	15 (44.1%)	20 (50%)	35 (47.3%)	
Neither agree nor disagree	11 (32.4%)	5 (12.5%)	16 (21.6%)	
Somewhat disagree	4 (11.8%)	5 (12.5%)	9 (12.2%)	
Strongly disagree	1 (2.9%)	0 (0%)	1 (1.4%)	
Question: In my career, I would like to be involved in healthcare sustainability in (check all that apply):	*n* = 18	*n* = 30	*n* = 48	Not applicable
Healthcare policy/advocacy	10 (55.6%)	19 (63.3%)	29 (60.4%)	
Clinical practice	15 (83.3%)	25 (83.3%)	40 (83.3%)	
Medical education	7 (38.9%)	20 (66.7%)	27 (56.3%)	
As a volunteer	4 (22.2%)	19 (63.3%)	23 (47.9%)	
Other: Sustainability research	0 (0%)	1 (3.3%)	1 (2.1%)	

(American Association of Medical Colleges), LCME (Liaison Committee on Medical Education), and ACGME. Given that students most often express interest in sustainability within clinical practice, both broad foundational education and specialty-specific training are warranted. Incorporating healthcare sustainability into multiple levels of education will bring necessary awareness to the issue and reinforce important skills as the learner progresses throughout training and into practice.

While education provides the foundation for sustainability awareness, translating this knowledge into meaningful change requires engagement strategies that extend beyond the classroom and involve diverse stakeholders in collaborative action (Pereno and Eriksson, 2020). By participating in such curricular initiatives, students may experience progressive shifts in their attitudes as repeated engagement with practical sustainability efforts refines their perspectives over time. Medical students increasingly view corporate partners as responsible for sustainability, a perspective shaped by evolving norms around corporate accountability (What Is Corporate Social Responsibility?, 2021), which can be leveraged by highlighting the alignment between sustainability and cost savings. Multistakeholder sustainability committees represent one mechanism through which hospitals and health systems can mobilize physicians, nurses, administrators, supply chain managers, and facilities staff toward shared environmental goals. These committees' function at the institutional level to identify high-impact sustainability interventions, coordinate implementation across departments, and track progress over time. The collaborative structure addresses the reality that no single group holds complete authority over healthcare's environmental footprint; sustainable outcomes

rely on coordinated contributions from all stakeholders, ensuring that environmental responsibility is integrated at each level of healthcare delivery (Aboueid et al., 2023).

There is growing interest among medical students in advocacy and policy work, reflecting their belief that sustainability requires systemic action and involvement from those with the greatest capacity to shape healthcare systems: government regulators and healthcare administrators. Students' interest in policy and advocacy also demonstrates a view of physician engagement as part of the profession's responsibility. Early opportunities to develop this interest exist through learner-focused organizations such as Medical Students for a Sustainable Future, the Medical Society Consortium on Climate and Health, and similar advocacy networks (Rha et al., 2024; Medical Students for a Sustainable Future, 2025; The Medical Society Consortium on Climate and Health (MSCCH), 2025). Platforms such as Climate Resources for Health Education provide centralized, expert-reviewed curricular materials and pathways for students to participate in the broader climate–health education movement (Our Program – CRHE, 2023). Organized advocacy campaigns led by physician groups and medical societies can amplify individual efforts, pushing for climate-friendly policies at institutional, regional, and national levels. Perhaps most powerful would be the integration of sustainability metrics into quality measurement frameworks and reimbursement structures (Podein and Hernke, 2024). Linking sustainability performance to hospital accreditation standards, value-based care models, or Center for Medicare and Medicaid Services quality programs, healthcare organizations would create direct financial and regulatory incentives for organizations to reduce their environmental impact. This approach would shift sustainability from a voluntary initiative championed by motivated individuals to a fundamental component of healthcare delivery that affects organizational revenue and regulatory standing.

To our knowledge, this is the first survey of medical students within the U.S. to examine healthcare sustainability specifically through the lens of environmentally responsible resource use. Prior U.S. studies have focused primarily on the health impacts of climate change rather than sustainability within healthcare operations, similarly through survey approaches (Ryan et al., 2020). Furthermore, no previous US-based research has assessed which stakeholders students believe hold the greatest responsibility for advancing healthcare sustainability, the degree to which students want to engage in sustainability efforts in their future careers, or the modalities through which they envision this involvement.

5 Limitations

The study is constrained by low response rates, which introduces the possibility of participation bias, as students with greater interest in sustainability or strong opinions on the topic may have been more likely to take part. This reliance on survey data also limits the generalizability of our findings to the broader population of medical students. The composition of the student body shifted slightly between the two surveys in January and July, reflecting a cohort bias, with the fourth-year medical students graduating and a new cohort of first-year medical students starting school in July. As a result, observed differences in student opinion could indicate changes in cohort composition rather than true longitudinal changes in attitudes which could not be controlled for in the analysis. Students earlier in their medical training may have inadequate information to comment on the quality of healthcare sustainability education in the medical school curriculum. This is a single-institution study, and the results might not be generalizable to the entire population of medical students in the United States. These limitations should be considered when interpreting the results, as they can influence the reported levels of awareness and attitudes toward healthcare sustainability.

6 Conclusion

In a survey at one medical school, we uncovered a unique understanding of how future physicians view their responsibility for healthcare sustainability relative to that of other stakeholders and demonstrated medical student interest in sustainability in multiple stages of education and in their careers. Education is required to equip current and future physicians with the knowledge and tools necessary to actively contribute to sustainability efforts. While we have made admirable strides in healthcare sustainability education at the medical school level, the quality and effectiveness of such education vary widely between schools, and less attention is paid to this education beyond medical school. The next step is standardizing national requirements at all levels of medical training in healthcare sustainability education. Further research can support this goal by gathering insight into resident and physician interest in the topic and understanding how these groups see themselves integrating healthcare sustainability into their careers. By fostering sustainability education, we can empower the next generation of physicians to play an active role in creating a sustainable healthcare system.

7 Data availability statement

The participants of this study did not give written consent for their data to be shared publicly, so supporting data is not available due to the participants' vulnerable status as learners. The blank survey questionnaire is provided in the Supporting Information.

8 Ethical statements

Ethical approval was not required for this research. All data used were obtained through proper channels, with consent where applicable.

9 Conflict of interest

The authors have no conflicts of interest to disclose.

10 Acknowledgement

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11 Author contributions

Elisa Bass, BA: study conception and design, data analysis, drafting the article, and critical review. Rachel Fisher, MS: study conception and design, drafting the article, and critical review. Suraj Puvvadi, BS: study conception and design, data analysis, drafting the article, and critical review. Nisha Reddy, BS: study conception and design, drafting the article, and critical review. Ewoma Ogbaudu, MBA: study conception and design, and critical review. Chikodi Ohaya, MA: study conception and design, and critical review. Neera Agrwal, MD PhD: study conception and design, and critical review. All authors approved the final version of the manuscript.

12 Copyright statement

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