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Climate and health education: Defining the needs of society in a changing climate

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Climate and health education: Defining the needs of society in a changing climate

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Editorial: Climate and health education: defining the needs of society in a changing climate

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Editorial on the Research Topic
Climate and health education: defining the needs of society in a changing climate

The effects of climate change due to the burning of fossil fuels are apparent and present increasingly complex challenges to human health (1). Climate change poses direct health risks, including extreme weather events, and indirect risks, such as long-term ecological changes leading to changes in air quality or vector habitats that alter patterns of infectious disease (2–9). The changing climate also poses diffuse and deferred risks because of long-term societal changes, civil conflict, and disrupted livelihoods leading to mental or physical health effects and refugee displacement (10, 11). Healthcare delivery is jeopardized either through barriers to community access or hospital operations via supply chain issues and extreme weather events (12–14). These impacts intertwine structural racism and environmental injustice that result in poor communities, communities of color, and communities in the global south being impacted disproportionately. With many complex, intersectional, and transdisciplinary challenges, there is an urgent need to train health professionals across disciplines, yet most health professionals have not been trained and climate and health curricula are nascent in programs around the world (15).

We need to build health professional workforce capacity to understand the risks of climate change, what they as providers can do to help patients mitigate and adapt, and how to be changemakers in health systems. Climate-smart health professionals need a nuanced understanding of the intersectionality of inequity, structural racism, and other social determinants of health. Further, these needs do not exist in a vacuum; building capacity to train climate-smart professionals is also an opportunity to provide clinical, policy, education, and advocacy career paths to help address the innumerable intersectional challenges adversely affecting patients around the globe.

The recent series from *Frontiers in Public Health*, "*Climate and health education: defining the needs of society in a changing climate*" provided an opportunity for many

educators around the world to showcase their critical work addressing these challenges. The work described in this series sets the context for the current direction of climate change and health education and begins to point the path forward on areas for future work. Some manuscripts described the rapidly evolving state of climate and health education. Houghton reviewed 99 courses at 3 different United States universities covering issues related to climate change, health, and equity in the built environment. Though they found more courses covering these topics than prior analyses, too often the content was isolated. There is a need to explicitly connect population health, the built environment, and climate change with transdisciplinary content as the built environment plays a leading role in creating the context that drives disparities in population health and is a substrate for exacerbating inequity in the climate crisis. Arora et al. found that half of public health schools in the United States offered at least one climate change related course and half of climate change courses specifically covered health impacts. Simon et al. performed a qualitative analysis of medical school stakeholders in Germany, highlighting a high prevalence of positively reviewed climate curricula, but unmet needs in transdisciplinary education, incorporation of ethics, and practical skill training, such as patient communication and physical diagnosis.

Other manuscripts detailed initiatives that centered on student-faculty co-creation of content related to climate and health. Navarrete-Welton et al. demonstrated the power of a student driven, bottom-up approach to build an integrated, broad-reaching curriculum at a United States medical school that not only covers health effects related to climate, but also built capacity to train students to be changemakers with a dedicated course on waste management in healthcare. Liu et al. performed a qualitative analysis of medical students completing climate and health curricula, uncovering a desire for more small group learning, clinical skills integration, and community-based opportunities. Along with the student perspectives described by Simon et al., it is clear that while students positively perceive climate and planetary health initiatives, there is a need to connect these topics to additional societal issues taught in schools.

Lastly, several works described projects at the intersection of leadership, accountability, and communication that point to how healthcare and public health professionals might help mitigate, adapt, and respond to the climate crisis. Dambre et al. performed a qualitative analysis of focus groups of undergraduates in a Global Responsibility and Leadership program at a Netherlands University that participated in a planetary health course. Their course received high marks for transdisciplinary integration of climate, health, and communication, but the major unmet need was transcultural content. Schmeltz and Ganesh highlighted student-led collaborations with local organizations, demonstrating how undergraduate students can be part of capacity building initiatives. Lastly, Campbell et al. reviewed current research on climate and health communication strategies and highlighted evidence for health-based messaging to increase engagement and political will for climate solutions, in addition to evidence for naming the role of fossil fuels when discussing climate change.

This series from *Frontiers in Public Health* highlights the efforts of educators and students around the globe to rapidly innovate and train the next generation of health professionals to be equipped to treat patients, build capacity, and advocate for essential societal change to confront the climate crisis. This field is expanding rapidly. For example, after a recent burst of new curricular development, over 50% of US medical schools now include climate-related topics (16), though integrated curricula are more limited (17). Longitudinal integration of climate and health touchpoints in multiple existing curricular activities is necessary for students to develop a climate and health lens to incorporate climate into their future health practice (Liu et al.) (17–20). Further, existing climate curricula could benefit from more transdisciplinary and community-oriented approaches. Partnerships with environmental justice organizations, pairing students with community organizations to learn directly from stakeholders, and involving collaborators from disciplines beyond healthcare are just a few possible solutions to help break down the silos and paradigms of existing educational approaches that can inadequately prepare students to partner with communities. We need more institutions and individuals to innovate, evaluate, and disseminate longitudinal, integrated training programs that enable the next generation to fill these roles.

Author contributions

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Broad spectrum integration of climate change in health sciences curricula

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In response to a University of California systemwide initiative to expand the knowledge base of climate change, two half-day workshops were held for faculty in the College of Health Sciences at the UC Irvine. In the first workshop, 20 participants who teach in the Schools of Nursing, Medicine, Pharmacy, and Pharmaceutical Science, or the Program in Public Health convened to explore concepts of sustainability, theoretical models of curriculum integration, challenges to adding new competencies into professional training, and strategies for integrating climate change modules and case studies into the curricula. The second half-day workshop was held a year after the first workshop to review how faculty members have modified their syllabus to integrate climate change information with varying degrees of success. A case study is presented regarding an asynchronous fully online course Introduction to Global Health, which is open to enrollment by students from all campuses of the University of California. The outcomes revealed preferential adoption of models of curriculum integration which minimized disruption of the sequence of topics in pre-existing courses. These include, for example, the use of longitudinal climate datasets for quantitative analysis of disease outcomes, and description of episodic events involving extreme weather conditions to explore differences in social determinants of vulnerability to climate change impacts in different populations. Integration of climate change as a distinct topic seems easier in elective courses in comparison with required courses designed to cover pre-established professional knowledge, competencies, and skills. The emergent requirement for interprofessional training in the health sciences provides an opportunity for the development of a cross-cutting competency domain including climate change as a unifying theme in a stand-alone course or set of courses in a sequenced model of curriculum integration.

KEYWORDS

climate change, education, health sciences, curriculum integration, medicine, public health, nursing science, pharmacy and pharmaceutical sciences

Introduction

The early framing of international response to climate change, for example through the reports of the Intergovernmental Panel on Climate Change, emphasized assessments to confirm the scientific basis of human contributions. In comparison to approaches to mitigation, issues related to impacts, adaptation, and vulnerability were even less

understood in part due to highly variable characteristics of populations distributed globally and confounding with preexisting conditions (1). Specifically, the framing of the health impacts of climate change focused on the range of vector-borne diseases such as malaria, and on the exacerbation of pre-existing burden of such diseases in under-resourced regions (2–4). Consequently, the integration of climate change as a risk factor in educating health scientists was narrow and tentative. Increasing knowledge about the ways in which climate change impacts population health is now considered one of the major strategies for expanding public understanding of the challenges, and for encouraging political action beyond the rhetoric (5).

In response to the increasing understanding of the widespread adverse impacts projected to occur if the trend of greenhouse gas emissions leading to abrupt climate change is not reversed, the University of California established the Global Climate Leadership Council in 2014 with the goal of providing advice on strategies for achieving carbon neutrality by 2025. The UC GCLC was also charged with providing guidance on integrating carbon neutrality and sustainability goals into teaching, research and public service mission of the university. Specifically, the health sciences and services, faculty and student engagement were three of nine key areas of contribution for the council's organizational structure and function.

In this context, our initiatives focus on strategies to formally integrate the understanding of climate change impacts and sustainability broadly into the educational curricula across the health sciences and into healthcare practices. The first workshop was convened in Winter Quarter of 2020 with 20 faculty members in the Susan and Henry Samueli College of Health Sciences to integrate health impacts of climate change, including solutions, sustainability, adaptation, and resilience of the health sector into their existing courses. The College offers undergraduate (Bachelor of Science) degrees in Nursing Science, Pharmaceutical Sciences, Public Health Policy, and Public Health Science; graduate (Master of Science and Doctor of Philosophy) degrees in Nursing Science, Public Health (Global Health and Disease Prevention), Pharmaceutical Sciences, Epidemiology, Environmental Health, and in the Biomedical Sciences in collaboration with the School of Biological Sciences. The College also offers professional degrees in Medicine (Doctor of Medicine), Public Health (Master of Public Health), Nursing Science, and Pharmacy. Each participating faculty member receive $1,100 for transforming their course over the period of 1 year. The second workshop convened a year after the first one with presentations from each faculty member on how the transformed their courses, to discuss specific difficulties and to share best practices. A pre-workshop survey of participants was conducted with a 10-item questionnaire before the first workshop, including questions on their current teaching activities and their expectations for curriculum integrations regarding climate change. For example, to make recommendations about appropriate strategy for engaging students on the topic climate change in each course (Table 1), we asked participants to respond to the following question:

"In what format do you expect to integrate climate change information in your course(s)? Select all that apply:"

a. *The entire course is about climate and health*
b. *A lecture on climate and health*
c. *Introduction or discussion of a case study or example of the impacts of climate on health*
d. *Assignment of articles for the students to read or videos to watch on climate and health*
e. *Guest lecture on climate and health*
f. *Other:*_____

Models of curriculum integration

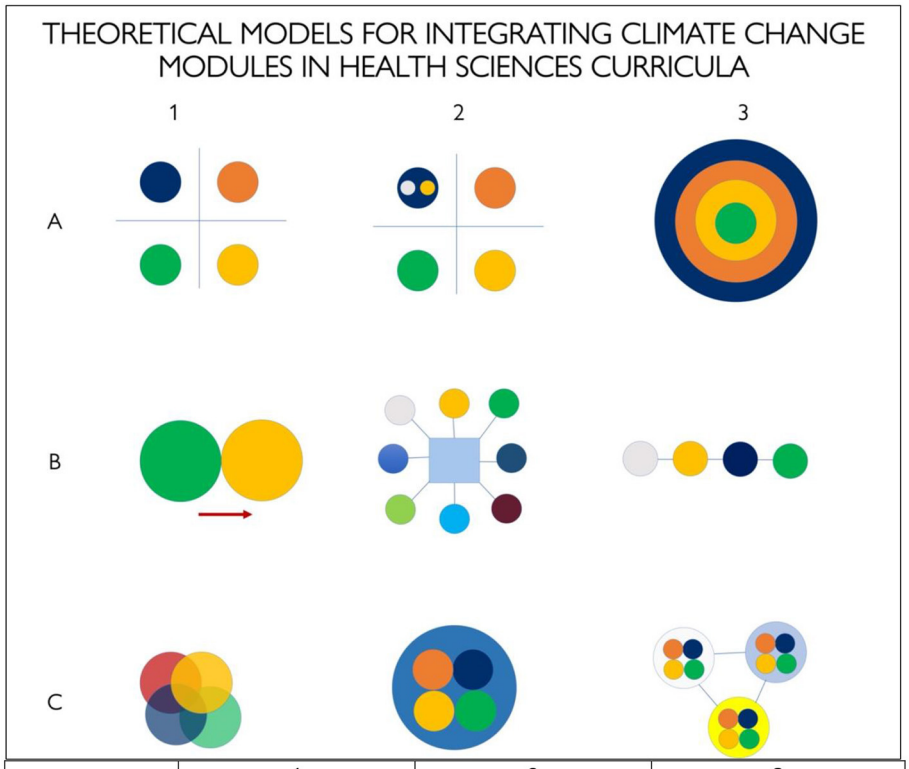
The development of theoretical frameworks about "Curriculum Integration" (CI) is a very well-established subject of research in the academic and professional discipline of education. An integrated curriculum is typically designed to implement learning that is synthesized across two or more traditional disciplines and across a variety of experiences which reinforce the learning objectives (6). The theoretical models of CI include nine strategies which may serve different purposes for developing interdisciplinary curricula (Figure 1). For example, the traditional fragmented curricula that align with different professional training in health sciences have the advantage of presenting clear and distinct perspectives of the respective disciplines but is unsuitable for presenting climate change information because connections, for example, between the physical scientific basis of climate change are not well-connected to aspects of vulnerability, adaptation, and mitigation with respect to the health impacts. Therefore, the transfer of learning may be ineffective. Alternately, the connected and nested curriculum models may offer the opportunity to connect key concepts thereby generating assimilation of ideas within a discipline. Climate change-related modules and topics such as natural disasters, emergency preparedness, infectious disease outbreaks, air quality, heat stress, and water resources into existing courses can enhance the learning experience. A sequenced curriculum allows the introduction of a broad topic such as climate change followed by a more advanced presentation of specific topics related health outcomes and the role of healthcare providers and the healthcare system in responding to emerging threats. Climate change is also a suitable topic for interprofessional education where specific courses are designed for enrollment of students from various disciplines as exemplified by the webbed, immersed, integrated, and networked models (8). Problem-solving case studies and role plays are particularly suited for such interprofessional courses whereby trainees from different disciplines can debate and

TABLE 1 Courses taught by workshop participants.

Full course title	Undergraduate (UG) or graduate (G)	Enrollment size	Frequency quarters/year
Public health statistics	G	23	1
Foundations of community health	UG	123	1
Research design	G	11	1
Public health practicum and upper division writing	UG	202	3
Cities: focal point for sustainability problems and solutions	UG	23	1
Natural disasters	UG	152	1
Environmental geology	UG	70	1
Compassionate care for underserved populations	G	20	1
Health communication R	UG	80	1
Health communication	G	17	1
Risk communication	G	10	0.5
Communities justice and health	G	36	1
Obesity epidemic	G	4	1
Health behavior change theory	UG	30	1
Introduction to community health sciences	G	30	1
Introduction to global health	UG	150	2
Global health ethics	UG	150	2
Cancer epidemiology	UG/G hybrid	50	1
Epidemiology in global health	G	15	1
Introduction to epidemiology	UG	163	1
Climate change and global health	UG	New	1
Theory of data analysis	G	11	1
Community-based healthcare	U	56	1
Speaking about science	UG	30	3
Research methods and applications in health care	UG	50	1
Advanced GIS and spatial epidemiology	G	20	1
Infectious disease dynamics	UG	New	1
Population dynamics in ecology, epidemiology, and medicine	UG	25	1
Computational modeling of diseases	G	New	1
Introduction to environmental health science	UG	70	1
Environmental health sciences	G	29	1

share various perspectives and methods to enrich the collective learning experience.

Thirty-one courses were presented for transformation with climate change information, among which there were 12 graduate-level courses, 19 graduate-level courses, including a course which simultaneously enrolls undergraduate and graduate students. Together, these courses enroll about 2,400 students annually. Among the courses considered for integrating climate change into the health sciences curricula, three were being developed including one specifically about climate change and global health. Enrollment data were not available for these three. The inclusion of datasets related to climate change was one of the most cited strategies for introducing the topic into quantitative courses such as public health statistics, theory of data analysis, and epidemiology courses. In this regard, the U.S. Environmental Protection Agency maintains a data-rich resource on climate change for educators and students (9). Modular case studies for reviewing, problem solving, and role play were typically considered for general health science courses such as risk communication, introduction to global health, and natural disasters. In this regard, the National Oceanic and Atmospheric Administration (NOAA) maintains an archive of teaching resources entitled "Teaching Climate" (10). The National Aeronautics and Space Administration (NASA) also maintains a resource website for educators (11). For physical science-oriented courses such as environmental geology, and natural disasters, the U.S. Geological Survey maintains a web archive for educational resources (12).



	1	2	3
A	Fragmented	Connected	Nested
B	Sequenced	Webbed	Threaded
C	Integrated	Immersed	Networked

FIGURE 1
Diagrams of curriculum integration models suitable for including climate change in curricula health sciences curricula (7). A1, A2, and A3 models are strategies for courses within a single discipline or professional training; B1, B2, B3, and C1 are ideal for interdisciplinary courses that bring students from various schools together for interprofessional education; C2 and C3 are ideal for continuing professional development training.

Transforming "introduction to global health"

In 2015, the systemwide University of California Global Health Institute (UCGHI) began investing in the development of fully online asynchronous courses available for enrollment by students on all campuses (13). Funds for developing the courses were provided through a competitive request for proposals issued by the Innovative Learning Technology Initiative (ILTI; now known as UC-Online) (14). To promote interdisciplinary collaboration, curriculum integration, and cross-campus engagement, each proposal from UCGHI was expected to be developed and, if funded, implemented by faculty members from two or more UC campuses. "Introduction to Global Health" is among the earliest courses to be implemented. The course was co-developed by the author representing the biomedical perspective and Dr. Tom Csordas, the Founding Director of the Global Health program and Director of the Global Health Institute at UC San Diego, representing anthropological perspective. In addition, Dr. Laura Rosenzweig, staff at UCOP assisted as a professional course designer in production and implementation of the course. The adoption of a "Learning Quadrangle" framework facilitated course design in a modular format that aligned specific topics with weekly assignments in five sections *Inspiration* including readings and video recorded introduction of students to each topic (Figure 2). The inspiration section is followed by *Research* (guided and independent) whereby students are expected to read assigned documents and independently to find information including research and news articles, videos, and images relevant to the topic. This section reinforced the objective to have each student explore the topic on their own. The next section, *Reveal*, requires each student to post their findings in a community Asset Library and to construct concept maps using provided prompts. The next section, *Reflect*, invites students to review the concept maps of other students and to identify gaps

FIGURE 2
The *Learning Quadrangle* adopted in *Introduction to Global Health* uses a modular assignment structure to integrate special topics into the curriculum. Diagram of Earth with population density spikes by Anders Sandberg - https://www.flickr.com/photos/arenamontanus/375127836.

in their own understanding or to specific their own unique perspective and conceptual understanding. The final section of the Learning Quadrangle, *Reform*, poses a challenging problem to be solved based on the student's understanding of the fundamental knowledge of the causative agents, current policies, and limitations in the realm of funding, political, or other socioeconomic difficulties. This sequential modular structure facilitated the review of an existing topic on *Global Health Impacts of Natural and Anthropogenic Disasters*. In this context, climate change is framed as an anthropogenic disaster because of the strong evidence linking human activities to greenhouse gas emissions, and consequently the increase in average global temperatures which forces changes in climactic conditions worldwide with projections of damage to quality of life and healthful conditions (15, 16). The case study of a climate-sensitive disease, Valley Fever (coccidioidomycosis) is used here as an example of curriculum integration because it covers climate science, epidemiological data, health impacts, vulnerable populations, health communication and adaptation strategies, and an argument for investing in mitigation strategies.

Case study on valley fever

For more than a decade the incidence of coccidioidomycosis has increased steadily in the southwest United States where it is considered endemic. The disease develops in some individuals who are exposed through breathing the spores of the causative pathogen *Coccidioides imitis* present in soils. Dust from soils harboring *C. imitis* may be distributed widely under certain wind conditions, thereby creating vulnerability for populations over a wide geographic range. The ecological niche for *C. imitis* is defined by arid, desert zones where spores are found in lower elevations, $\geq$4 inches under sandy soil. Droughts, earthquakes, and building construction are all regarded as factors that increase vulnerability. The availability of epidemiologic data, climatic data, and social determinants of population vulnerability to coccidioidomycosis in response to climate change in California renders this case study suitable for the integration in to *Learning Quadrangle* teaching platform (17, 18). The *Inspiration* section of the module highlights the plight of patients who suffer from coccidioidomycosis, including a presentation on vulnerable domestic and agricultural animals. In the *Research* section students are guided to read peer-reviewed articles on the link between climate change and the expanding geographic range of *C. imitis*. Students may also bring articles that they discover about coccidioidomycosis outside California, including other states in the southwest region of the U.S., Central America and South America. In the *Reveal* section, students are expected to contribute concept maps to the Asset Library using the *Padlet* software linked to the *Canvas* learning platform. In the *Reflect* section, students compare and contrast their concept map on coccidioidomycosis, specific populations, climate data, occupational hazards, socioeconomic data, soil pH, soil composition, and weather patterns. In the final *Reform* section, students are given a prompt for which they respond by writing an essay, for example, on how to create a public information campaign for disease awareness and prevention; or a proposal to conduct research to fill gaps in knowledge. Students may also write about the inherent trade-offs in climate mitigation efforts and the potential impacts of statewide policies on climate mitigation on population health (19, 20).

Conclusion

The application of theoretical models of curriculum integration can facilitate broad-spectrum integration of climate change education in health sciences curricular. The opportunity to adopt various models of curriculum integration including modification of existing course syllabi with new sub-topics, adding datasets for analysis, or presentation of case studies for guided research appeals to situations where addition of entirely new courses on climate change into a packed curriculum proves to be too difficult. Deep integration of climate change topics in courses which already address transboundary movement of people and environmental risk factors, for example in global health is facilitated by a learning quadrangle platform which supports independent and guided student engagement such that a wider range of topics are included in the climate change module beyond potential impacts on

infectious disease epidemiology. Sub-topics within the climate change module include mental health impacts, damage to physical infrastructures which support water quality, waste management, energy supply, air conditioning, sea-level rise, food supplies, and inequity issues in access to health care. The models of curriculum integration presented in these workshops are applicable to in-person, hybrid, and online modes of course delivery, although the impacts of these modes on long-term impacts on the retention of climate change knowledge among students will require longer-term monitoring than review after a year of implementation. Institutionalization of workshops to integrate urgent topics into the curricula of health sciences professions can also serve topics beyond climate change, for example, the integration of diversity, equity, and inclusion into educational activities in the health sciences is becoming common. Incentives for faculty engagement and training-of-trainers workshops may be necessary to sustain wholescale transformation of saturated curricula in interprofessional education.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

OO conceived and executed the project and wrote the manuscript.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A grassroots approach for greener education: An example of a medical student-driven planetary health curriculum

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Given the widespread impacts of climate change and environmental degradation on human health, medical schools have been under increasing pressure to provide comprehensive planetary health education to their students. However, the logistics of integrating such a wide-ranging and multi-faceted topic into existing medical curricula can be daunting. In this article, we present the Warren Alpert Medical School of Brown University as an example of a student-driven, bottom-up approach to the development of a planetary health education program. In 2020, student advocacy led to the creation of a Planetary Health Task Force composed of medical students, faculty, and administrators as well as Brown Environmental Sciences faculty. Since that time, the task force has orchestrated a wide range of planetary health initiatives, including interventions targeted to the entire student body as well as opportunities catering to a subset of highly interested students who wish to engage more deeply with planetary health. The success of the task force stems from several factors, including the framing of planetary health learning objectives as concordant with the established educational priorities of the Medical School's competency-based curriculum known as the Nine Abilities, respecting limitations on curricular space, and making planetary health education relevant to local environmental and hospital issues.

KEYWORDS

planetary health, medical education, climate change, medical waste, curriculum development, environment, public health

Introduction

With the rising urgency of climate change, medical schools cannot ignore the impact of environmental problems on students and patients. In recent years, increased attention has been focused on how to prepare future doctors to address the health impacts of climate change, biodiversity loss, and environmental degradation. However, the medical education community has not settled on a unified approach to planetary health (PH) education. Implementing a PH curriculum is a

particularly daunting challenge given the novelty of the field for many doctors and the overwhelming number of topics encompassed within (1). The magnitude of this challenge is significant, as revealed by surveys completed by the International Federation of Medical Student Associations in 2019–20 that found that only 14.7% of medical schools globally included climate change and health within the curriculum and only 11% incorporated education about the health impacts of air pollution (2).

Multiple groups have proposed overarching principles to guide the creation of PH curricula from a top-down perspective. For instance, in 2019 the Planetary Health Alliance convened a task force to develop a framework for PH education intended "to move beyond a prescriptive list of competencies". The task force proposed five foundational domains for PH education (equity and social justice, interconnection within nature, movement building and systems change, systems thinking and complexity, and the Anthropocene and health) that they conceptualized as being embedded within learning priorities guided by local and global conditions (3). Alternatively, Maxwell and Blashki proposed using a triad of outcomes to guide curriculum development: climate change preparedness (involving clinical management of climate-related illness and knowledge of how to provide healthcare sustainably), depth of education (using climate change as an illustrative example to deepen the existing knowledge and skills of medical graduates), and breadth of education (public and eco-health literacy) (4). Separately, an international workshop used a collaborative approach to identify five domains meant to provide an overarching framework for the development of specific learning objectives. The domains included eco-medical literacy and clinical preparedness, proficiency in promoting eco-health literacy both among patients and at the community level, education in the delivery of sustainable systems, and incorporating sustainability as an element of medical professionalism (5).

In other cases, PH education has evolved spontaneously in response to student advocacy and concerns. Students at the Florida International University Herbert Wertheim College of Medicine built on the impacts of environmental degradation that they observed during community service to develop a series of slides about planetary health topics that were inserted into existing lectures (6). At Emory University, two students began by organizing a lunch panel discussion on climate and health and, after the lunch panel garnered a surprising amount of interest, then harnessed the enthusiasm of the student body to develop a proposal for incorporating planetary health topics into the medical school curriculum. Their proposal was accepted by Emory's Executive Curriculum Committee with plans to implement the changes for the class of 2024 (6, 7). The creation of the Planetary Health Report Card by students at University of California, San Francisco School of Medicine and the subsequent Planetary Health Report Card Conference held online in October 2021 provided an important venue for medical students at different schools to learn from each other's experiences and gain advocacy skills (8).

Here we present the Warren Alpert Medical School of Brown University as an example of a student-driven, bottom-up approach that has led to the development of a longitudinal PH education program integrated into existing pedagogical priorities. The earliest efforts to expand PH education at the Medical School were disparate initiatives organized and led by students. In 2020, the efforts gained significant momentum when the administration sanctioned the creation of a task force dedicated to improving PH education. Composed of medical students, faculty, and administrators, the Planetary Health Task Force (PH-TF) has focused on both educating the entire student body about PH as well as creating opportunities for highly interested students to engage more deeply with these issues. In this article, we describe the student PH advocacy that led up to the creation of the task force, the curricular changes implemented to date, and the task force's ongoing work to improve PH education (Figure 1). Importantly, we focus on the role of the PH-TF in establishing student-identified PH educational priorities within the Medical School's existing pedagogical framework, known as the Nine Abilities.

To our knowledge, the PH-TF has led to one of the broadest and most successful efforts to date to integrate PH education across all 4 years of medical school in a variety of forms. Although we recognize that each medical school will need to individualize their own PH curriculum, we hope our experiences can be a template for how to incorporate PH into medical education.

Frameworks

The Medical School's PH curriculum was developed within the existing framework of the Medical School's pedagogical priorities. Since 1996 and most recently revised in 2021, the Warren Alpert Medical School has followed a competency-based curriculum which seeks to define the qualities, abilities, and knowledge that all students should have upon graduating, known as the Nine Abilities. These abilities are: (1) effective communication, (2) basic clinical skills, (3) using basic science in the practice of medicine, (4) diagnosis, prevention, and treatment, (5) lifelong learning, (6) professionalism, (7) health equity and racial justice, (8) moral reasoning and clinical ethics, and (9) clinical decision making. The competencies set prior to the 2021 revision have been described previously in (9, 10).

The PH-TF served as the key vehicle for enacting PH curricular change within the guidelines set by the Nine Abilities. The priorities for PH curricular change were selected in part based on the pre-existing student-driven initiatives that led to the creation of the PH-TF as well as the expertise of PH-TF faculty members in specific content areas. To ensure sufficient scope, the PH-TF consulted previously published frameworks

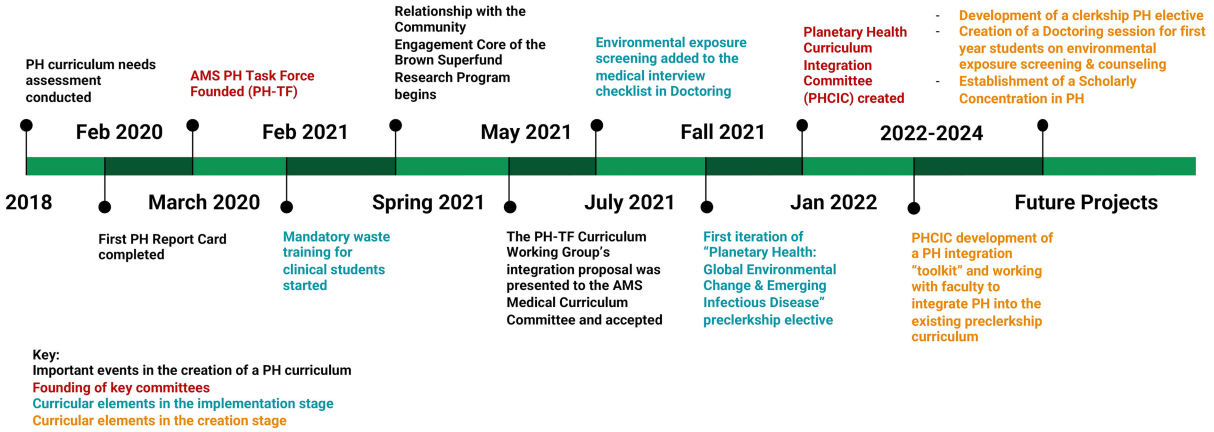

FIGURE 1
Timeline of planetary health educational initiatives at the Warren Alpert Medical School of Brown University.

for PH education including the PH learning objectives from the "Climate and Health Key Competencies for Health Professions Students" from the Global Consortium on Climate and Health Education (GCCHE) (11). This approach has enabled the PH-TF's efforts to emphasize the local priorities and interests of our community while avoiding unintentional omissions of crucial PH topics identified from national or international viewpoints.

Origins of the planetary health task force: Student-driven initiatives and the planetary health report card

Prior to the formation of the PH-TF, medical students led a variety of sporadic sustainability initiatives. On the medical school campus, student advocacy in 2019 resulted in the addition of composting and single-stream recycling. The Student Senate began requiring student group leaders to view a presentation on sustainable event-hosting and commit to following the guidelines. Given the intrinsic connection of PH to community impacts, interested students also frequently engaged with local environmental justice organizations in Rhode Island (RI). These included the Brown Agriculture Nutrition and Community Health program, a collaboration between the Brown Department of Family Medicine and a local elementary school that seeks to address disparities in access to green spaces, nutrition, and health education, as well as political advocacy with grassroots organizations such as Renew RI and Sunrise PVD, tours of the local landfill, and volunteer trips to harvest leftover crops for food banks.

In 2018, a student-led needs assessment drew attention to gaps in the Medical School curriculum regarding PH. The survey, developed by a medical student after consultation with Medical School faculty and Rhode Island Department of Health experts, was sent to all 1st-year medical students ($n = 144$) and achieved a response rate of 50.7% ($n = 73$). This survey found that 95% of first-year medical students agreed that it is important for medical providers to know about the health impacts of climate change, but only 6.8% of students felt that the Medical School provided sufficient education on climate change and health. Furthermore, only 9.6% felt confident discussing health impacts of climate change with patients and only 6.8% felt they knew ways to mitigate the health impacts of climate change (12).

While the needs assessment revealed important shortcomings in PH education, the key event that led to the consolidation of student efforts with the backing of the Medical School administration was the 2020 Planetary Health Report Card (PHRC). The PHRC is a student-driven, metric-based initiative run by the national organization Medical Students for a Sustainable Future. Its goal is to inspire PH and sustainable healthcare education engagement in medical schools across the globe. The PHRC evaluates the performance of medical schools with respect to PH using five metrics including curriculum, research, community outreach, support for student-led initiatives, and campus sustainability (8). In response to the B- grade that the Medical School received in the 2020 PHRC, the administration created the PH-TF.

Structure of the planetary health task force

The task force includes medical students, faculty, and administrators as well as Brown University Environmental Sciences faculty. The PH-TF is structured as two working groups focused on community engagement and curriculum development, which were the weakest areas according to

the Planetary Health Report Card. While the community engagement working group has had difficulty making progress due to COVID-related disruptions affecting local environmental organizations, the curriculum working group has achieved significant results over the past 2 years.

The entire curriculum working group meets on an *ad-hoc* basis ∼5 times each year. Subcommittees in charge of implementing specific initiatives meet separately, with varying frequencies.

Curriculum proposals generated by the curriculum working group that affect the entire student body are presented to the Medical Curriculum Committee (MCC) of the Medical School. If the MCC approves a proposal, proposal implementation is led by PH-TF member(s) with the greatest level of interest and expertise in the specific proposal. Depending on the scope of the proposal, this has at times required the creation of a sub-committee, such as the Curriculum Integration Committee described below in Section Integrating planetary health into pre-clerkship material. If the proposal is an initiative targeted to a subset of students interested in PH rather than the entire study body, such as an elective course, it does not necessarily need to be presented to the MCC. When proposals require the involvement of faculty outside the PH-TF, the PH-TF member(s) leading the initiative contact and coordinate with relevant faculty and course directors. To date, the PH-TF has found the faculty who lead the Medical School's pre-clerkship and clerkship courses to be very supportive of the PH-TF's goals and proposals.

Development of the planetary health core competencies through national and institutional frameworks

Tasked with incorporating a longitudinal PH education into the medical school curriculum, the PH-TF first identified a set of core PH-related skills and knowledge that all students should possess upon graduation. These were adopted from the "Climate and Health Key Competencies for Health Professions Students" from the Global Consortium on Climate and Health Education (GCCHE) to fit the Medical School curriculum (11).

One of the primary strategies for tailoring the GCCHE competencies to the curriculum was to situate the PH competencies within the pre-existing framework of the Medical School's Nine Abilities.

To demonstrate why PH education should be incorporated into the medical school curriculum, the PH-TF emphasized how the objectives of the PH curriculum furthered seven of The Nine Abilities (Table 1). Although different medical schools have different educational priorities, framing the goals of a PH education within preexisting curricular objectives emphasizes the relevance and importance of PH knowledge for future clinicians. It also highlights how PH can be efficiently woven into existing curricula rather than requiring the addition of a new and distinct subject area.

Learning environment, objectives, and format

In line with the PH curriculum's core competencies, the interventions undertaken by the PH-TF span a diverse range of learning environments and formats from traditional core classroom education to an elective course, student-directed research, and extracurricular community engagement opportunities. These diverse initiatives can be categorized into two groups: first, the interventions targeted to include the entire student body and second, the programs designed for the subset of students who desire deeper engagement with planetary health. The format and learning objectives of the specific initiatives are detailed here.

Student body-wide interventions undertaken by the planetary health task force

Integrating planetary health into pre-clerkship material

Prior to the formation of the PH-TF, isolated lectures on PH topics existed in the curriculum. The first-semester Health Systems Sciences (HSS) course included lectures on environmental justice, lead poisoning, and occupational health, but PH themes disappeared from the curriculum after the conclusion of the HSS course.

During early discussions with the PH-TF, the main concern from the Office of Medical Education about improving PH education was the limited time available to cover new topics. To solve this problem, the curriculum working group proposed to integrate PH longitudinally within the existing curriculum. Similar concerns about limited curricular space are widely shared across health professions schools and several other medical institutions have adopted a similar integrative approach to PH education designed to minimally disrupt existing curricula (13–16).

Student members of the PH-TF first reviewed the course objectives for every pre-clerkship course and identified topics that were amenable to being viewed through a PH lens. For each of these topics, students proposed specific PH-related learning objectives that could be addressed within existing lectures. Each proposed learning objective was connected to the relevant PH core competency. A selection of the learning objectives are shown in Table 2.

TABLE 1 Planetary health core competencies aligned with guiding educational principles.

The nine abilities of the medical school	Planetary health core competencies
Ability 1: Effective communication	Be able to effectively communicate with patients about the health impacts of climate change, strategies to prevent those risks, and the concept of health co-benefits of action. Demonstrate effective communication with stakeholders about climate and health topics and work collaboratively and across disciplines on climate and health issues.
Ability 2: Basic clinical skills	Learn to take an environmental history
Ability 3: Using basic science in the practice of medicine	Define climate drivers (both natural and human-caused), weather, climate change, and climate variability. Identify the health impacts of climate change and other human-driven disruptions to our natural environment.
Ability 4: Diagnosis, prevention, and treatment	Apply knowledge of the connection between habitat and biodiversity loss and infectious diseases. Apply knowledge of climate and health to clinical care of patients. Understand how to identify, prevent, and treat commonly seen health related impacts of climate change, i.e., heat stroke, asthma exacerbations, acute kidney injuries, adverse birth outcomes.
Ability 7: Health equity and racial justice	Recognize the disproportionate impact of climate change on communities of color and explain pre-existing and future health disparities rooted in environmental racism, especially in Rhode Island. Apply climate and health knowledge to improve decisions about public health services, and adapt and improve population health. Describe ways medical students and health professionals can engage in institutional, community, and political advocacy around planetary health. Describe ways that healthcare professionals and facilities can prepare for and respond to climate-related health risks.
Ability 8: Moral reasoning and clinical ethics	Appreciate the role of the healthcare industry in contributing to climate change and identify ways healthcare providers can reduce/mitigate waste and carbon emissions.

The planetary health core competencies adopted from the "Climate and Health Key Competencies for Health Professions Students" from the Global Consortium on Climate and Health Education were able to be aligned with seven of the "Nine Abilities" that guide the Medical School curriculum.

After the administration accepted this proposal in May 2021, the PH Curriculum Integration Committee (PHCIC) consisting of students, curriculum deans, and faculty experts in PH was formed within the curriculum working group to implement the proposal. The PHCIC's approach to implementation is guided by three principles: efficacy, sustainability, and minimizing disruptions to the existing curriculum. The PHCIC is currently refining the PH learning objectives and planning to incorporate them into courses using an "integration toolbox" which will provide a set format for integration of PH material. Importantly, the PHCIC is focusing on integrating material into case-based small group discussions, as teaching PH through active learning methods has been found to be critical for other institutions' success (15, 16). The PHCIC meets individually with course leaders to introduce the project and solicit feedback, thereby engaging the faculty as stakeholders in this initiative with the goal of promoting sustainability of the initiatives. The PHCIC will also oversee designing an evaluation program to assess impact and enable refinement of the curriculum changes. While this is a multi-year process, the PHCIC plans target a pilot set of the organ systems-based courses for this year's incoming medical students.

Education in environmental exposure screening and counseling

Several of the PH core competencies detailed in Table 1 require teaching students to directly address PH issues with affected patients. The PH-TF chose to situate this component of PH education within the school's Doctoring course, a 2-year clinical skills course on interviewing and physical examination skills taught during the pre-clerkship years. To this end, in fall 2021 additional environmental exposure screening questions and context were incorporated into the social history component of the patient interview checklist taught to 1st year medical students. These questions are shown in Figure 2.

In future years, the PH-TF plans to develop a dedicated class on environmental exposure screening and counseling that will be taught to all medical students during Doctoring. The session will include case simulations so students can practice environmental exposure counseling. To provide longitudinal reinforcement of these skills, the PH-TF is also currently in discussions with the family medicine clerkship director about integrating PH screening and counseling within the existing family medicine clerkship curriculum for all 3rd-year medical students.

TABLE 2 Examples of planetary health learning objectives proposed within existing preclinical course objectives.

Course	Course objective	PH learning objective	PH core competency
Brain sciences	Pathophysiology of major afflictions of the CNS and PNS	Explain the increased vulnerability to hot weather in patients with chronic neurological conditions such as Parkinson's, MS, and ALS.	Identify the health impacts of climate change and other human-driven disruptions to our natural environment.
Brain sciences	Pathophysiology of common neurologic and psychiatric disorders	Describe the effects on climate change on mental health disorders. Define "climate anxiety" and prepare to speak with a patient about climate anxiety.	Identify the health impacts of climate change and other human-driven disruptions to our natural environment. Apply knowledge of climate and health to clinical care of patients.
Microbiology and infectious disease	Epidemiology and risk factors of infectious diseases	Explain the effects of climate and land use change on vector-borne infections and emerging infectious diseases.	Apply knowledge of the connection between habitat and biodiversity loss and infectious diseases.
Cardiovascular	Risk factors and pathogenesis of common cardiovascular disorders	Identify the role of air pollution in promoting atherosclerosis and cardiovascular disease. Describe the inflammatory cascade produced by air pollution resulting in cardiovascular dysfunction.	Identify the health impacts of climate change and other human-driven disruptions to our natural environment.
Pulmonary	Risk factors and pathogenesis of common pulmonary disorders	Describe the effect that increases in temperature and ambient CO_2 concentrations has on increasing pollen production and its contribution to allergies. Identify the role that ground-level ozone pollution has on asthma exacerbations, COPD, and pulmonary infections.	Define climate drivers (both natural and human-caused), weather, climate change, and climate variability. Identify the health impacts of climate change and other human-driven disruptions to our natural environment.
Pulmonary	Risk factors and pathogenesis of common pulmonary disorders	Explain the racial and socioeconomic disparities in exposure to air pollution in relation to land use and other policies that disadvantage communities of color.	Recognize the disproportionate impact of climate change on communities of color and explain pre-existing and future health disparities rooted in environmental racism, especially in Rhode Island.
Human reproduction	Risk factors and pathogenesis of common reproductive disorders	Describe the association of air pollution and heat exposure with serious adverse pregnancy outcomes.	Identify the health impacts of climate change and other human-driven disruptions to our natural environment.
Human reproduction	Risk factors and pathogenesis of common reproductive disorders	Identify the disproportionate environmental exposures experienced by pregnant individuals living in underserved communities.	Recognize the disproportionate impact of climate change on communities of color and explain pre-existing and future health disparities rooted in environmental racism, especially in Rhode Island.

The following learning objectives are an illustrative selection of the set of learning objectives proposed by the Planetary Health Task Force to be incorporated into existing pre-clinical courses. Each learning objective falls within the scope of at least one course objective within the existing curriculum. The relevant planetary health core competencies are also presented with each learning objective. Given space constraints, this is not meant to be a comprehensive list of all topic areas within PH.

Mandatory waste training for clinical medical students

Prompted by a student-led waste audit at a local hospital, PH-TF students created a mandatory waste training for students entering clerkships. The training is designed to further Ability 8 on moral reasoning and clinical ethics by addressing healthcare impacts on the environment (Table 1), given that the healthcare system produces 10% of US greenhouse gasses and generates four billion pounds of waste each year (6). This training consists of an hour-long session for all 3rd-year medical students during pre-clerkship clinical skills training and has now been taught to two classes of students in 2021 and 2022. It teaches students about proper healthcare waste disposal and decreasing red bag waste, including hospital waste regulations, practice scenarios, and instruction in counseling patients on medical waste disposal at home. Figure 3 shows two practice scenarios from the training.

Interview Checklist

- Living Arrangements:
  - Have you ever changed or wanted to change your residence due to a health problem?
  - Is there anything about your current physical home and neighborhood that might be impacting your health?
- Current work status and occupation:
  - Are you exposed to any health hazards at work (chemicals, dust, etc.?)

Student Companion to the Medical Interview

Living arrangements	"Tell me a little about your current living situation." "Who lives at home with you?" Ask about satisfaction with housing or physical neighborhoods, including exposure to health hazards (e.g., lead, allergens/asthma triggers: mold, dust and smoke). It's important to ask about hazards to the patient's physical environment, such as pollution, extreme heat or cold (access to heat or cooling). These factors, among others, can have an important impact on health.
Current work status and occupation; exposure to health hazards	Find out if the patient is currently working and what they do for work. Ask about exposure to health hazards at work (e.g., chemicals, asbestos, prolonged sun exposure, heavy machinery/power tool use, repetitive injuries, etc.). You can also ask about the use of protective equipment at work and whether they feel they are being adequately protected. Sometimes this section can also include questions about education level/training.

FIGURE 2
Environmental exposure screening questions incorporated into the social history section of the patient interview checklist taught to first year medical students. Additional context was provided in the Student Companion to the Medical Interview, a medical interview guide available to all students.

In Family Medicine clinic, you just performed a speculum exam and maybe even helped insert your first IUD (yay!).

Where do your gloves go:

Red bag waste?
Or solid waste?

Answer: Solid waste! If not dripping or saturated in blood or vaginal secretions

After surgery, you're busy un-velcroing the suction tubes from the drapes so that the drapes can go into solid waste. The PA asks why you're doing that.

What do you say?

Key points that you can bring up:

1. Based on state regulations, **the main things that should go into red bag are things that are dripping or soaking in blood.**
2. Red bag waste can cost the hospital up to **10x more** than white bag waste
3. Disposal of red bag waste is much worse for the environment than solid waste.
4. Things that can go into regular trash at home (poopy diapers, bloody tampons) can also go into regular trash at the hospital.

FIGURE 3
Examples of practice scenarios from the waste disposal training delivered to all medical students entering clerkships.

Initiatives to facilitate deeper student engagement in planetary health

Planetary health elective courses

Although much of the PH curriculum at the Medical School has been designed to reach all medical students, the PH-TF has also created multiple opportunities for students with strong interests in PH to develop additional knowledge and skills. One such opportunity comes *via* PH elective courses. At the Warren Alpert Medical School of Brown University, pre-clerkship electives are offered to 1st- and 2nd-year students. Pre-clerkship electives may be organized by

students and either taught by faculty or led by students alongside a faculty advisor. The Medical School also offers electives for clinical students in their third and 4th years, which are typically organized and led by faculty. The PH-TF created a pre-clerkship PH elective that was taught in 2021 and a clinical elective is being developed for the 2022–23 academic year.

Prior to the formation of the PH-TF, a pre-clerkship elective on "Climate Change and Health" was offered to 1st- and 2nd-year medical students in fall 2019. The course exposed students to heat-related morbidity and mortality, changing infectious disease patterns, and the impacts of extreme weather events on human health through lectures, a final project, and community service. Although the COVID-19 pandemic disrupted this elective, the PH-TF revived the elective in fall 2021. Titled Planetary Health: Global Environmental Change and Emerging Infectious Disease, this version of the course took a more focused approach to one facet of PH. Over eight sessions, clinicians, ecologists, and public health experts introduced students to the dynamics of infectious disease emergence resulting from climate change, land-use change, and increased human interaction with wildlife. For a final project, students wrote op-eds about the effects of climate change on human health and were offered guidance to publish their work (17). The elective garnered significant interest in fall 2021 and has been renewed for fall 2022.

PH-TF members are currently crafting a clinical PH elective for 3rd- and 4th-year medical students. This elective's goal is to build on the foundation of pre-clerkship PH knowledge to develop student leaders in PH. This elective will follow an asynchronous curriculum that explores PH education, policy, and clinical impacts. The asynchronous nature of the elective will allow students independence to pursue a specific topic of interest related to education, advocacy, or research within the field of PH under the mentorship of faculty.

Facilitating student research in planetary health

Another goal of the PH-TF is to encourage student PH-related research in order to fulfill the PH competencies within Abilities 3 and 7 (see Table 1). Prior to the creation of the PH-TF, small groups of driven medical students had already found and created opportunities to engage in PH research. These efforts have resulted in several publications including waste audits in local hospital emergency rooms and a retrospective study on the impact of summer temperatures on Emergency Medical Services (EMS) utilization (18–21). Ongoing student PH research projects include surveys to quantify the carbon footprint of residency interview travel and Rhode Island EMS and assess hospital food waste as well as a retrospective study on the impact of temperatures at discharge on surgical patient readmissions.

However, a significant challenge for students interested in PH research is the lack of a centralized program devoted to PH research at the Medical School and its affiliated healthcare systems. Medical students currently rely on word-of-mouth to find research mentors with expertise in PH. Compared to other research areas such as sepsis or aging, the Medical School and its affiliated hospital systems have fewer principal investigators engaged in PH research. Recently, the decision of the *Rhode Island Medical Journal* to dedicate an issue to climate change and health helped draw the attention of local researchers and physicians to these issues (22). While hiring new faculty or creating a centralized research initiative dedicated to PH is beyond the scope of the PH-TF, the Medical School can still make progress by directly assisting students interested in PH research as well as drawing the attention of the student body to the potential for scholarship in this area.

To this end, the Medical School administration recently announced a new opportunity for a rising 3rd- or 4th-year medical student to spend a fully funded gap year focused on PH research. The selected student will have the opportunity to sit on the PH-TF and contribute to the task force's initiatives.

In addition, the PH-TF plans to create a new Scholarly Concentration (SC) in Planetary Health. The SC program is a longitudinal commitment to a rigorous independent scholarly project across all 4 years of medical school. Projects are undertaken under the mentorship of a Brown faculty member and further educational and mentorship opportunities are provided by the program directors of each SC. Students choose to participate in the SC program on an elective basis and undergo a competitive application process, with ∼25% of the student body selected to participate. As of 2022, there are 12 Scholarly Concentrations at the Medical School, ranging from traditional biomedical research in the Translational Research in Medicine SC to more socially oriented domains such as the Caring for Underserved Communities SC or the Medical Humanities and Ethics SC.

A SC in Planetary Health would serve as a vehicle to consolidate available research opportunities and connect students to relevant faculty. The PH-TF plans to design the SC to help medical students take advantage of resources available in the broader Brown University community by including researchers at Brown's School of Public Health and the Institute at Brown for the Environment and Society. By providing dedicated training in research methods relevant to PH, the SC would enable medical school graduates to advance scholarship in this field throughout their careers.

Engaging with and learning from the community

Community engagement is both an important part of medical education and an intrinsic part of the PH movement. While the COVID-19 pandemic negatively

impacted many local environmental organizations, the PH-TF's community engagement working group plans to deepen existing partnerships between medical students and the Community Engagement Core of the Brown Superfund Research Program, an initiative that focuses on academic-government-community partnerships to address PH and remediation issues in RI.

Results to date

The creation of the PH-TF resulted in a more comprehensive, cohesive, and longitudinal PH curriculum. To date a variety of initiatives have been successfully enacted including: (1) various efforts to integrate PH longitudinally within the existing pre-clinical medical curriculum including additions to the medical interview checklist in the Doctoring course and, through the establishment of the PHCIC and resulting interest from course leaders, the addition of a dedicated lecture on air pollution in the 2nd-year Pulmonary course; (2) mandatory waste training for clerkship students to address healthcare impacts on the environment and discuss moral reasoning and clinical ethics; (3) an elective to introduce pre-clerkship students to infectious disease emergence in relation to global environmental change; and (4) the opportunity for a clerkship student to take a fully funded gap year involving PH research and PH-TF initiatives.

The work of the PH-TF is ongoing and the following changes are currently in the process of being implemented: (1) finalization of an integration "toolbox" by the PHCIC with plans to pilot changes for current first-year medical students when they start the organ systems-based courses in spring 2023; (2) creation of a Doctoring session on environmental exposure screening; and (3) a clerkship elective focused on PH policy and clinical impacts. In future years, the PH-TF plans to tackle additional projects including the creation of a PH scholarly concentration for research endeavors and expanding the work of the PH community engagement working group. While no formal assessments of the impact of these initiatives have been completed to date, the PHCIC plans to repeat the PH education needs assessment and use structured surveys to assess the effect of the curriculum changes that will be implemented in the 2022–23 curriculum.

Discussion of lessons learned and limitations

The approach to PH education at the Warren Alpert Medical School of Brown University has evolved over the past 5 years from a set of sporadic student initiatives into a cohesive structured task force capable of sustainably enacting significant changes over a multi-year time frame. Framing PH learning objectives within the school's established educational priorities, the Nine Abilities, was central to our success because it demonstrated that PH was integral to the mission of the Medical School. Other important factors that led to the success of this initiative include respecting limitations on curricular space by addressing PH topics at their intersection with existing material, creating connections to local environmental and hospital issues, and providing a range of opportunities for both the entire student body as well as a subset of highly interested students. The willingness of the Medical School administration to listen and respond to student concerns has been essential throughout this process.

While we appreciate that each medical school will need to tailor their approaches, we believe that some of the strategies that worked in our context will likely be generalizable to other institutions. Including students, faculty, and administrative members on the PH-TF has substantially hastened the speed with which realistic proposals can be generated and implemented because it enables all parties to communicate directly with each other from the start of the process. The strategy of inserting PH topics within the existing curriculum has succeeded for us and students at several other medical schools because it does not require significant schedule changes. [cite] It also does not overwhelm students with additional lectures nor does it require faculty members to be content experts in PH. The Planetary Health Report Card also served as a helpful starting point for student advocacy efforts that effectively caught the attention of our administration. Finally, ensuring that elective opportunities are available for the subset of students most passionate about PH has helped build relationships between PH-interested students across class years and has effectively created a pipeline for recruiting new student members to the PH-TF, reducing the difficulties associated with student body turnover.

While the curriculum working group of the PH-TF has significantly improved the quality and scope of PH education, the task force structure has its limitations. While the involvement of faculty and administration on the PH-TF has helped provide the continuity required to enact multi-year initiatives, it has still been difficult to build institutional memory about prior PH initiatives given the constant turnover of medical students and the changing schedules of students between pre-clerkship, clerkship, and post-clerkship years. The community engagement working group of the PH-TF has had difficulty making progress because the COVID-19 pandemic disrupted the activities of local environmental organizations for so many months that previous ties between medical students and those organizations were effectively severed when those medical students graduated and moved to residencies without the

chance to pass down those connections to the subsequent medical student classes.

In addition, the PH-TF's capacity to enact change has been somewhat limited by the sparsity of medical faculty members with expertise in planetary health education. The lack of a centralized program for planetary health research at the Medical School and its teaching hospitals has also made it difficult to find and recruit new faculty members. While significant research and scholarship related to planetary health occur at the Brown School of Public Health and in the environmental sciences department, the PH-TF has had difficulty coordinating with other parts of the university, in part due to the irregular and sometimes unpredictable hours required during the clinical years of medical school.

Regarding the scope of the PH core competencies, although many of the GCCHE competencies were amenable to being adapted within the framework of the Nine Abilities, some could not be included. For instance, the GCCHE competency "explain the role of subnational, national and global policy frameworks and governance structures to address health risks associated with climate change" were not included because it did not fit easily within the primarily clinical focus of the Nine Abilities. However, while the PH-TF might have difficulty arguing that such topics need to be taught to the entire study body, the elective opportunities created for students with the greatest interest in PH provide flexibility for individual students to pursue such topics if interested.

Finally, while the PH-TF plans to repeat the needs assessment and undertake surveys to assess the impact of PH education initiatives, our conclusions about the effect of the new PH education initiatives on the student body will remain speculative until these structured assessments are completed.

Despite these limitations, we hope our experiences can serve as a useful example for other medical schools interested in implementing their own PH education programs.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

AN-W, BB, JC, KM, and ML conceptualized, wrote, reviewed, and edited the manuscript. AN-W, KM, and JC created figures. SW and KDM reviewed and edited the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Evaluating strengths and opportunities for a co-created climate change curriculum: Medical student perspectives

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Introduction: Medical trainees are front-line workers in our worsening climate and health crisis. A movement is underway to teach medical students essential climate change and health content. Few evaluations of climate and health curricula exist to support ongoing curricular development, innovation, and improvement. This study explores student perspectives on climate change and health content and delivery post-implementation of a climate change and health curriculum that was co-created by students and faculty and integrated across 16 months of pre-clinical coursework at Emory University School of Medicine.

Methods: The authors conducted focus groups with the inaugural cohort of students to receive the climate and health education content at the conclusion of their preclinical curriculum. The focus groups elicited student perspectives across four domains: (i) prior perceptions of climate change and health, (ii) current attitudes about climate change and health, (iii) reflections on the existing curriculum, and (iv) opportunities for the curriculum. In this qualitative evaluation, the authors coded focus group transcripts using an inductive content analysis approach.

Results: Out of 137 eligible students in the cohort, 13 (9.5%) participated in the focus groups. Implementation strategies that students valued included contextualization and integration of climate content within existing topics and student representation through the co-creation process. Students recommended bolstering small group sessions and case-based learning to build relevant history and physical examination skills as well as creating interprofessional and community-based opportunities.

Discussion: This evaluation offers in-depth student perspectives of our climate and health curriculum. Opportunities exist to synergize climate and health education with broader transformations in medicine toward health promotion and sustainable, climate-ready healthcare. From the input of focus groups, the authors derive a framework for strengthening and extending curricular content.

KEYWORDS

climate and health education, co-creation, Planetary Health, climate health, medical students, curriculum evaluation

Introduction

Medical trainees are front-line workers in our worsening climate and health crisis. In response to the urgency of the climate crisis and the historical lack of climate change and health content in medical schools, students have motivated efforts in climate and health education (CHE) and spearheaded a movement to prepare themselves for the challenges ahead (1–3). Educating learners across the medical education spectrum about climate change and health is now recognized as an essential component of adapting the healthcare system and meeting healthcare needs in this era of climate change (4–6). Emerging CHE efforts range from isolated lectures to specialized electives and integrated curricula (7–10). Bolstered by calls from students, faculty, and professional organizations, many institutions are seeking to accelerate adoption of CHE or expand their existing CHE content and activities (11, 12).

Available literature proposes models for integrating CHE but without a consensus on best practices (13, 14). Few evaluations of implemented curricula exist and few resources elucidate learner perspectives on educational priorities and approaches to content delivery. Identifying acceptable and effective means to integrate CHE into medical curricula is a pressing need for students and faculty.

In the fall of 2020, our student and faculty team introduced a climate and health curriculum for all 139 students in the class of 2024 at Emory University School of Medicine (3). The curriculum integrates CHE across pre-clinical courses for first- and second-year students during the first 16 months, or pre-clinical coursework, of medical school (Figure 1). The role of students in envisioning and co-creating the curriculum as well as the initial learning objectives and the timeline of approval for the curriculum have been published previously (3).

Students, administrators, and lecturers were engaged to co-create and contextualize climate change and environmental health content within the foundational concepts of pre-clinical medical education. The curriculum includes both standalone lectures and integrated talking points and slides in pre-existing lectures as well as small groups discussions. In the first year of implementation, new CHE content was disseminated across lectures and small group sessions in more than 10 courses for the class of 2024. In some courses, student knowledge of CHE content was assessed through multiple choice questions at the discretion of individual course directors. This curriculum is ranked highly on the student-driven Planetary Health Report Card, which is a metric-driven evaluation tool launched in 2019 to evaluate CHE and sustainability initiatives at health professional schools (2).

At the conclusion of this pilot curriculum, we interviewed students in focus groups to better understand our first cohort's (i) prior perceptions of climate change and health, (ii) current attitudes about climate change and health for their careers, (iii) reflections on the existing curriculum, and (iv) identified opportunities for the curriculum. Participatory by nature, student focus groups extended our co-creation approach to curriculum evaluation. In this report, we present our analysis of student focus group transcripts and share perceptions and suggestions from the first cohort of students to receive our disseminated preclinical CHE curriculum.

Methods

We randomly selected second year medical students (from the class of 2024) in the fall of 2021 to participate in the focus groups. Of 139 students in the cohort, 137 were eligible to participate. Two students were excluded because they are members of the CHE curriculum team (MM and IL). We aimed to include about 10% of eligible students, or 14 students, in two focus groups of 7 each. We randomly selected 14 eligible students and sent them emails informing them of the purpose of the evaluation and inviting participation. If invited students declined or did not respond within 1 week, we sent emails to additional randomly selected students until we reached our target enrollment of 14 students. Students were offered a $10 gift card and bamboo cutlery sets for participation. We obtained funding for these incentives from the Emory University Office of Sustainability Initiatives' General Sustainability and Social Justice Fund as a part of a grant to boost student participation in curriculum co-creation and to conduct a sustainable food and composting workshop. Emory University Institutional Review Board (IRB) did not require ethics approval for this curriculum evaluation.

We created an interview guide with probing questions related to our four domains of interest: (i) prior perceptions of climate change and health, (ii) current attitudes about climate change and health for their careers, (iii) reflections on the existing curriculum, and (iv) identified opportunities for the curriculum (Supplementary material). MM and IL each moderated one of the focus groups. As peers and members of the cohort to receive the curriculum, MM and IL were selected to reduce the potential power differential between moderators and participants. The moderators allowed participants to drive the conversation, using the questions only when needed to stimulate conversation and ensure exploration of each domain. Participation was voluntary and confidential. Responses were recorded anonymously. Participants gave verbal consent for audio-recording. The duration of the two focus groups ranged from 48 to 52 min.

We transcribed the focus group recordings using an online transcription service (scribie.com) (15). Two team members (IL and BR) independently verified the transcriptions, listening to the recordings and ensuring fidelity in the automated transcription. IL and BR independently analyzed and coded the transcripts using an inductive content analysis approach (16, 17). No *a priori* codes were used. Using an open coding

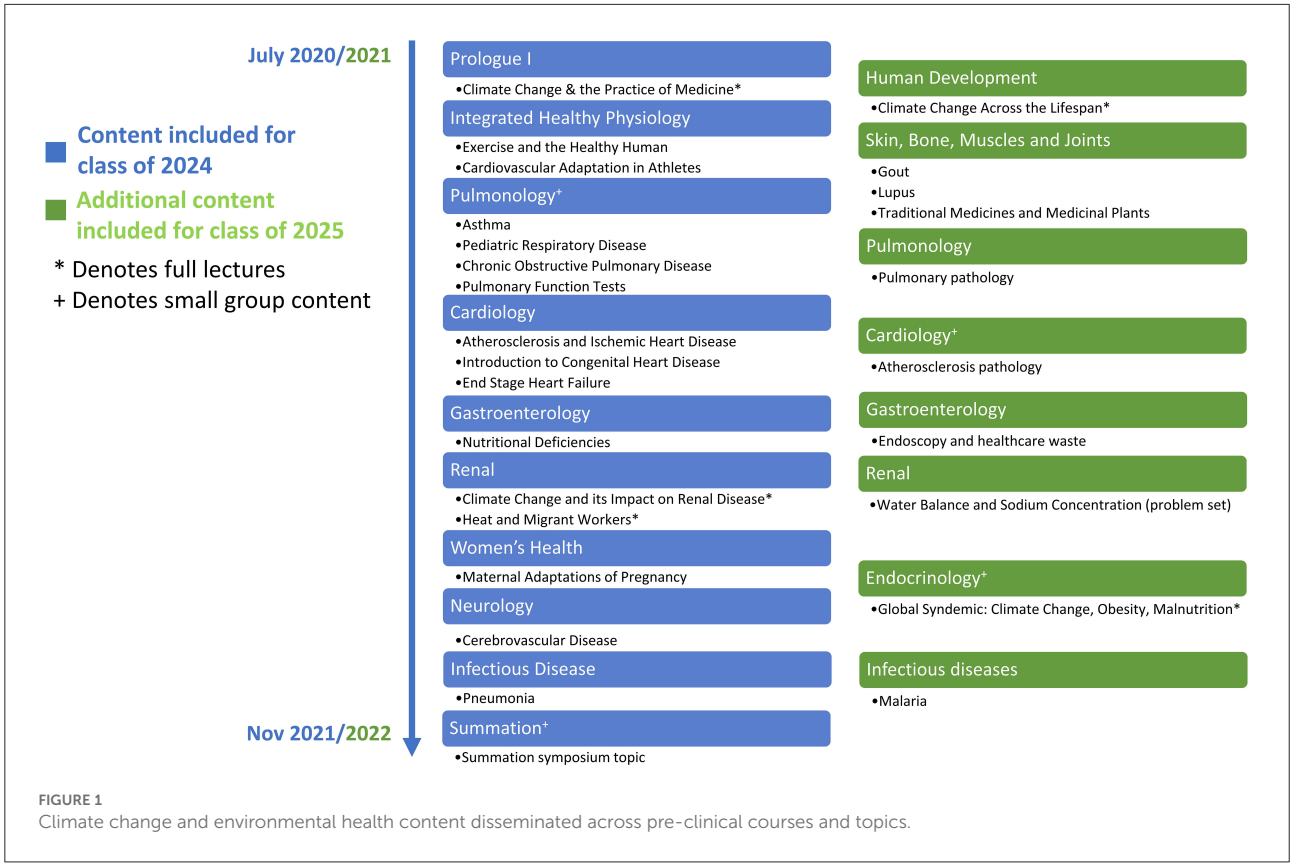

FIGURE 1
Climate change and environmental health content disseminated across pre-clinical courses and topics.

process to identify phrases of meaning in the text, IL and BR assigned codes and grouped codes under the relevant domain. IL and BR met with RP to review and refine codebooks, organize codes into themes, and revise themes through an iterative process using in-depth discussions and comparisons of thematic relationships (16).

Results

Between October 25th and November 1st, 2021, we conducted two focus groups with 6 and 7 participants, respectively. In total, 28 students were sent email invitations to participate in the focus groups. Of the 28 invited students, 14 agreed to participate, 11 had no response to two follow up emails in one week, one had a scheduling conflict, one opted not to participate because s/he did not attend lectures, and one did not want to participate with no reason stated. Of 14 students who agreed to participate, one was prevented from attending because of illness. The 13 who participated represent a sample of approximately 9.5% of the cohort to receive the inaugural disseminated CHE curriculum. Table 1 presents a summary of focus group discussions with themes, codes, and illustrative quotations (Table 1).

Domain 1: Students' prior perceptions of climate change and health

Although students had engaged to different degrees with climate change prior to medical school matriculation (e.g., in their personal life or in their community), they were largely unaware of the links between climate change and medicine. They did not need or want convincing of the "science of climate change" and were well-versed in climate change basics. They had not expected, however, that climate change would be integrated into the medical curriculum. Summarizing a common stance, one student expressed lack of knowledge on "how it related directly to patient health." Though some incorporated environmental sustainability in their personal lives (e.g., reducing single-use products) or came from undergraduate programs with a culture of sustainability, most students had not previously engaged in climate advocacy.

Domain 2: Current attitudes about climate change and health in terms of their careers as doctors

At the conclusion of our curriculum, there was broad consensus on the relevance of climate change not only to

TABLE 1 Student focus group evaluation: Perceptions of climate change and a co-created and disseminated pre-clinical climate change and health curriculum across four domains.

Themes	Codes	Quotations
Domain 1: Students' prior perceptions of climate change and health		
Missing link between climate change & medicine	Knew the science	"Knew about the science of climate change…"; "I had a broad public health view."
	Not patient health	"I don't think I knew as well about how it related directly to patient health."
	Not an expected focus in the medical curriculum	"I expected to learn about social determinants of health…but I didn't expect climate change to be a part of that."
	Important, but abstract	"I also thought of it very abstractly, almost in a different world to like, oh…worldly societal things that are important to me, and it was very separate."
Variable level of engagement	Do one's part	"I did try to…do my part…reduce single-use products and not drive as much."
	Reflecting prior exposure to sustainability	"As an undergrad…it was weaved into the curriculum or just the culture with peer health mentors that they had and a lot of sustainability efforts."
	Not an advocate	"I wouldn't say I was super big into being an advocate."
Domain 2: Current attitudes about climate change and health in terms of their careers as doctors		
Believe that climate change matters for patients and counseling	Affects history-taking	"We need to be thinking about those questions when we're talking to a patient."
	Context for exposures	"You have to take into the context what their exposures are on a daily basis."
	Useful in an upstream way	"Informing people why the situation is the way it is, is upstream to helping them decide to make change later on through their voting."
	Location/context matters	"I think just with being in the South…seeing some of the air quality difference…the warmer climate, it seems to be almost dramatic."
Working through application of climate and health knowledge in future clinical practice	Convergence of work and life	"Thinking about caring for patients while processing that personal experience [with climate disasters], it is all coming together."
	Frustration at individual limits	"One of my challenges is…I don't know if my actions will make a difference."
	Uncertain how to apply	"But one piece that's missing for me for me is like, 'What does it mean that I know this now?'"
Perceive need to engage through non-clinical activities	Advocacy	"A lot of the big changes that we need to do to fix the issue won't really happen unless we do things on a policy level."
	Research	"There's not decades or there's not centuries of research…on climate change."
Domain 3: Reflections on the existing climate change and health curriculum		
Enhanced awareness and applications in multiple domains	Medical waste	"The only one thing I can see after the case is… the post-surgery clean-up… [I] wouldn't have even looked at without…the lecture we have on how much medical waste is generated on a daily, annual basis."
	Personal and professional growth	"…[Climate change] becomes something you consider in your daily practice, too, and hopefully moving forward as a physician."
	Leadership	"It will be for the chance where we'll be in positions where we have opportunities to make an impact."
	Patient health	"One of the biggest takeaways has been the application to patients."
	Communication skills	"The most valuable part was how to talk about it."
	Health equity	"When they showed the map with the red-lining, and how it overlapped perfectly with the map of the high incidence of heatstroke and the ambient temperature being higher, I think that really impacted me…"

(Continued)

TABLE 1 (Continued)

Themes	Codes	Quotations
Approach to content delivery matters	Meet the needs of different learners	"For 95% of the class, having key takeaway points is gonna do the trick . . . [but] one of the goals. . . is to inspire that 5% to do more. . . because we're gonna need that 5%, right?"
	Provide examples	"The more concrete an example or practical solution that they can give in those lectures is most meaningful."
	Integrate seamlessly	"[When content] is weaved in and out through all the different lectures, it helps to kind of make it into more easily digestible bits. And also you can see more clearly how it impacts all these different areas of health."
	Provide a frame/anchor	"It becomes a thing that helps you remember the other thing."
	Faculty attitudes matter	"If the lecturer doesn't care, we can feel it."
	Focus on facts rather than politics	"I really like how . . . it wasn't. . . there to sway people on climate change . . . instead. . . the focus of the lecture is more so like, this is climate change, this is why it's happening, this what we need to do."
Perceived as more intuitive or deprioritized	Content is intuitive	"Part of it felt a little bit intuitive or kind of, 'Oh, I probably know what they're gonna say,'"
	Traditional medical learning takes priority	"I care about this stuff, and. . . early on, when we were overwhelmed with anatomy, it was like, I am not even looking at this PowerPoint."
Domain 4: Student-identified opportunities for the curriculum		
Opportunities in non-didactic spaces	History and physical	"Maybe redoing how we take physical exams incorporating more questions. . . and incorporating more environmental risk factors in the questions we ask."
	Translate to rotations	"If I'm a primary care doctor, how this gets integrated into my decision-making."
	Case reports	"Having that tied to a case would be just engaging and nice."
	Community learning	"Incorporating some opportunities. . . [with] organizations that might be doing this work."
	Small group	"I would really like to see climate change being more integrated into a small group. I'm also not a lecture watcher."
	Include students	"If you invited students to give presentations on topics they cared about. . . people would be more engaged."
	Career development	"Things to think about when you're looking at a residency, or an employer down the line, about if these are really important values to you."
Role and modalities of assessments	Reflections	"Reflections. . . would allow people to kind of explore what they find interesting..."
	Student motivation	"Including test questions would probably not really motivate people."
	Perceived yield	"It's like, that's not gonna be on step, that's not gonna be on the test."

public health but also to medicine. Some students identified specific ways that the content can be applied to patient care, especially to patient counseling and history-taking, with one noting, "We need to be thinking about those questions when we're talking to a patient." Others still grappled with the application of climate change and health knowledge to clinical encounters, struggling with how they will translate the pathophysiologic concepts they had learned in the classroom to patient histories, clinical assessments, and care plans.

Students discussed the ways in which the curriculum influenced their own perceptions of their roles as health professionals. They perceived a need for physicians to engage in non-clinical realms, voicing the importance of more research and solutions at a policy level to address the climate crisis. One student expressed hopelessness, stating, "I don't know if my actions will make a difference." Building upon the theme of individual constraints, upstream and policy changes were mentioned at several points as requisites to undergird the actions of individuals.

Domain 3: Reflections on the existing climate change and health curriculum

Three themes emerged as students reflected on the preclinical climate and health curriculum. First, students agreed that the curriculum opened their eyes to climate change and health challenges (e.g., medical waste, patient health, and health equity) and avenues through which they could address these (e.g., by contributing to personal and professional growth as well as leadership and communication skills). Reflecting on medical waste, one student opined, "I've gone to two surgeries now where the only thing I can see after the case is over is all of the post-surgery clean-up." The transcendence of climate change across personal and professional realms was noted: "[Climate change] becomes something that you consider in your daily [personal] practice, too, and hopefully moving forward as a physician."

Second, students' preference was for content to be "weaved in and out through all the different lectures." This integrated delivery method helped them to see "how it [climate change] impacts all these different areas of health." While we aimed to contextualize our curriculum and anchor CHE within existing preclinical topics, for some students, CHE served as the more tangible scaffold for traditional medical concepts that otherwise seemed abstract or less immediately relevant: "A thing that helps you remember the other thing." Students recalled the relationship of climate change with familiar social determinants of health, while appreciating climate-driven pathology, physiological changes to the body, and the myriad threats of climate-related exposures relevant across the organ system-based courses.

Students especially liked "concrete examples" linked to solutions and conversations about risk factors. As an example, "[Learning] about heat stroke and migrant workers…seemed like a very tangible thing…and also it taught us some direct things that we can encourage our patients…to take as precautions." Students deemed faculty enthusiasm was crucial: "If the lecturer doesn't care, we can feel it." They reflected that the curriculum should meet the needs of different learners, most of whom will want to know the foundational concepts, but some of whom will want to engage more deeply in research or advocacy or envision the subject as the future focus of their career. A student stated that although key takeaway points will suffice for many, "one of the goals…is to inspire that 5% to do more…because we're gonna need that 5%, right?"

Third, when students compared the CHE curriculum with core, traditional preclinical topics, many noted that anatomy and physiology take priority. This prioritization was not because the CHE curriculum was considered unimportant but due to time pressures. Students felt "overwhelmed with anatomy" and a "need to focus… on learning the physiology" to succeed. Others were less likely to pay attention to or study the integrated slides with CHE because they felt that the content might be more intuitive, reflecting a sentiment, "Oh, I probably know what they are going to say."

Domain 4: Student-identified opportunities for the curriculum

The majority of the preclinical CHE curriculum was lecture-based, and students proposed alternatives for more effective CHE content integration. Their ideas included incorporating content within the history and physical examination skills curriculum, 3rd and 4th year clinical clerkships, community learning opportunities, case-based learning, additional small group sessions, and research and advocacy opportunities. Students also requested space for career guidance: "Things to think about when you're looking at a residency or an employer down the line," a manifestation of the importance of this topic for many. Students embraced the co-creation model and suggested further inclusion of peers in delivering content.

When asked directly about assessment modalities and whether their motivation to learn the content depended upon its incorporation in standardized medical licensing exams, students were not in agreement. Some felt that the topic lends itself well to reflection pieces or testing modalities other than multiple-choice questions. Some expressed the opinion that CHE is important (because of the urgency of the climate crisis) independent of its representation on tests. One noted that "including test questions probably would not really motivate people." Another took a different stance, stating that content "that's not gonna be on the test," will not get studied.

Discussion

While students in these focus groups matriculated to medical school without awareness of the importance of climate change to medicine, our disseminated and co-created pre-clinical curriculum addressed this gap. Students explicitly valued strategies for CHE implementation: co-creating the curriculum, contextualizing CHE within existing topics emphasized in medical school, and integrating content throughout the curriculum.

Our curriculum leveraged these approaches due to practical considerations–saving time in a tight curriculum and updating the evidence base across organ systems. The student perspective offers added justification for building cohesion between CHE and pathophysiology, pharmacology, and traditional medical school topics: The contextualization becomes bidirectional. The CHE curriculum lends real-world meaning to the intensive and often unfamiliar concepts students learn in pre-clinical years.

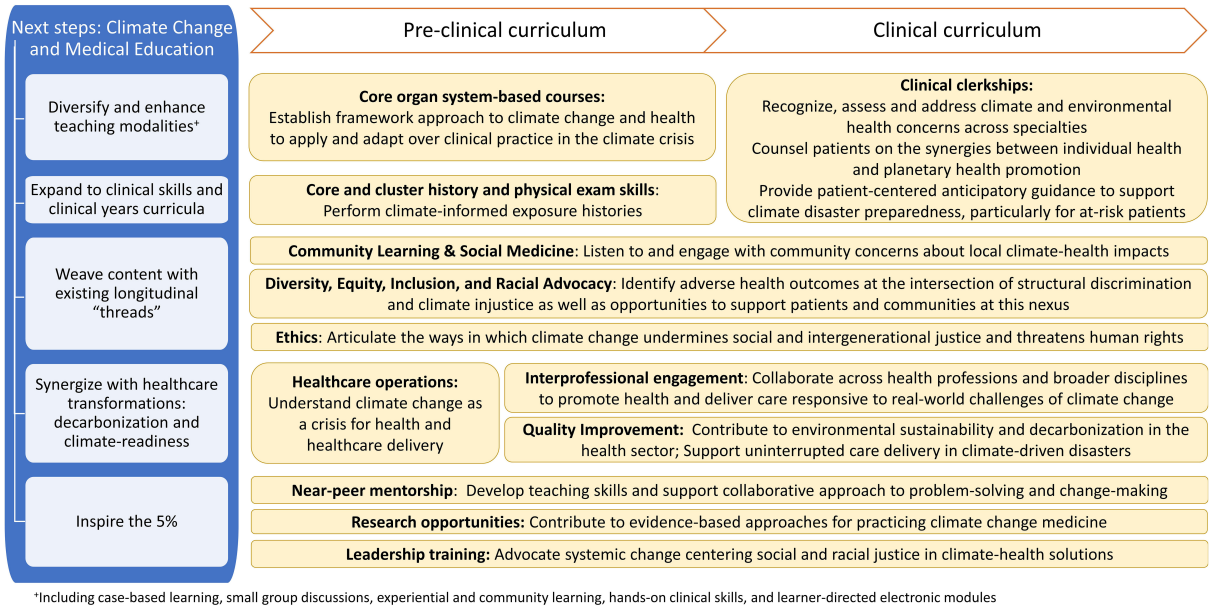

FIGURE 2
Climate change and environmental health in medical education: Curricular opportunities and learner outcomes informed by student perspectives. +including case-based learning, small group discussions, experiential and community learning, hands-on clinical skills, and learner-directed electronic modules.

Integrating CHE into the curriculum also serves the needs of exceedingly practical students seeking to fulfill well-established and rigorous criteria to advance to the next stage on their journey of becoming a doctor. Not unique to CHE, the challenges of teaching students in lecture settings and incorporating structural determinants of health in the curriculum are well-documented (18, 19). Students overwhelmed by the quantity of information in lectures prefer a shift to clinical skills applications. This preference offers an important opportunity for CHE: Recognizing, assessing, and addressing climate-health impacts are vital skills for safeguarding patients and adapting health care in the climate crisis. Building on student input in these focus groups, Figure 2 summarizes next steps for our curriculum.

Many of our students acknowledged the burden of climate change in their future professional and personal lives, with comments indicating some level of climate grief and anxiety. Many also felt powerless to address environmental injustice and structural roots of health disparity. Giving students space for discussion and reflection, avenues for experiential learning and community engagement, tangible solutions that they can apply in clinical encounters, and strategies for effective advocacy may be important to support student mental health and well-being. That students valued the opportunity to provide input and requested even more engagement suggests that co-creation of CHE may enhance student buy-in.

Although students were randomized, our focus groups included relatively few participants. Despite much overlap in themes, the focus groups may not have reached thematic saturation and their views may not fully represent our cohort. The timing of these retrospective focus groups also may have resulted in recall bias. On the brink of dedicated study for the United States Medical Licensing Examination (USMLE) Step 1, students participated at a time of increased anxiety about test preparation and relatively little exposure to patient care. Finally, the perspectives offered by students in this study are ultimately responses to a specific CHE curriculum at one institution as part of a curriculum evaluation that may not be generalizable elsewhere.

Nevertheless, this evaluation offers in-depth student perspectives post-implementation of our CHE curriculum on *what* content students value and *how* they prefer to receive this content. These insights may benefit others seeking to create, implement and evaluate their own CHE curricula. The co-creation model is particularly suited to the important and urgent topic of climate change and health. The synergies of CHE with secure and sustainable care delivery as well levers of disease prevention—in this case climate and environmental exposures—offer many applications in the clinical years of medical school. Challenges remain, but the potential of CHE movements to influence transformation in medical education and healthcare delivery is real, pressing, and still largely untapped.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval was not required for this study in accordance with the local legislation and institutional requirements. Written informed consent from the program evaluation focus group participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

All authors contributed to the design of the focus groups and this curricular evaluation. EL, BR, and RP co-created this curriculum. MM and IL created the focus group evaluation interview guide with mentorship from BR, EL, and RP. MM and IL conducted the focus groups. BR and IL analyzed the focus groups with RP. BR, IL, and RP drafted the manuscript. All authors reviewed and revised the manuscript. All authors agree to be accountable for the content of the work.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor declared a shared affiliation with one of the authors EL at the time of review.

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Supplementary material

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An authentic learner-centered planetary health assignment: A five-year evaluation of student choices to address Sustainable Development Goal 13 (*Climate Action*)

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A Code Red has been declared for the planet and human health. Climate change (e.g., increasing temperatures, adverse weather events, rising sea levels) threatens the planet's already declining ecosystems. Without urgent action, all of Earth's inhabitants face an existential threat. Health professions education should therefore prepare learners to not only practice in a changing world, but authentic educational activities should also develop competencies for global and planetary citizenship. Planetary health has been integrated across the five-year Bond University (Australia) medical curriculum. It begins in the second week of Year 1 and ends with a session on Environmentally Sustainable Healthcare in the General Practice rotation in the final year. The purpose of this article is to describe the outcomes of the first 5 years (2018–2022) of a learner-centered planetary health assignment, underpinned by the 2030 United Nations (UN) Sustainable Development Goals (SDGs), in the second year of a five-year medical program. Using systems and/or design thinking with a focus on SDG13 (*Climate Action*) plus a second SDG of choice, self-selected teams of 4–6 students submit a protocol (with feedback) to develop a deliverable "product" for an intended audience. Data analysis of the first 5 years of implementation found that the most frequently selected SDGs in addition to SDG13 were: SDG12 *Sustainable Production and Consumption* (41% of teams), mostly relating to healthcare emissions and waste; SDG3 *Health and Well-being* (22%), generally involving the impact of air pollution; and SDG6 *Clean Water and Sanitation* (15%). A survey at the concluding conference garnered student feedback across various criteria. The planetary health assignment is authentic in that teams provide solutions to address climate change. Where appropriate, final "products" are sent to local or federal ministers for consideration (e.g., policy proposals) or integrated into the curriculum (e.g., learning modules). We believe that the competencies, attitudes, and values fostered through engagement with planetary health. Throughout the medical program, as evidenced by their evaluations, stands students in

good stead to be change agents, not only in clinical practice but in society. An awareness has been created about the need for planetary citizenship in addition to global citizenship.

KEYWORDS

Sustainable Development Goals, climate change, global citizenship, planetary health, sustainable healthcare education, medicine, planetary citizenship, health science

Introduction

Background and rationale for the educational activity innovation

A Code Red has been declared for the planet and human health (1–4). Climate change (e.g., increasing temperatures, adverse weather events, rising sea levels) threatens the planet's already declining ecosystems. Without urgent action, all of Earth's inhabitants face an existential threat. Health professions education should therefore prepare learners to not only practice in a changing world, but authentic educational activities should also develop competencies for global and planetary citizenship.

Health professionals work at the "coalface" of the impacts of a changing climate, dealing, for example, with heat stress from abnormally high temperatures, smoke inhalation from wildfires, and malnutrition and starvation as a result of droughts and floods. At the November 2021 Congress of the Parties (COP26), for the first time, health was placed at the center of the climate conversation, with global health professionals offering 10 recommendations for a healthy future (5). But, in delivering healthcare, healthcare systems in many countries "do harm" to people and the environment—locally, nationally, and internationally—through upstream requirements and activities (e.g., mining of natural resources for equipment, water usage for drug development, and manufacture) and downstream greenhouse gas (GHG) emissions, waste, and pollution (6, 7). Australia's healthcare system contributes about 7% (global average = 4.4%) of national emissions (8), making it a top four *per capita* emitter (6), driven largely by coal- and gas-based energy and reliance on single-use items (8). The net-zero trajectory for the Australian healthcare sector, largely through mitigation, has thus been identified as "steep" (9). But as trusted professionals (10), all health professions, and by implication, all health professionals, should be environmentally accountable for their personal and professional activities (11). Such citizenship requires, amongst other competencies, systems and design thinking, as well as collective action and leadership. Health professions education thus has a responsibility to graduate individuals who are prepared to take action in a changing world (12) in which existing inequities will be exacerbated in a warming climate (13). They also should be able to educate patients, for example, about the co-benefits (to self, community, and the planet) of exercise (e.g., walking or cycling to work) and sustainable diets (e.g., reducing red meat intake; increasing dietary fruit and vegetables) (14). Healthcare professionals thus have a duty to advocate for larger-scale institutional, political, and economic change to address the health inequity and environmental challenges that have arisen from historic and ongoing systemic injustices (15).

The United Nations (UN) 2030 Sustainable Development Goals (SDGs) comprise a set of 17 interrelated Goals with Targets and Indicators that promote equitable actions for a sustainable future. In higher education, the Sustainable Development Solutions Network's (SDSN) 2017 guide for Australia, New Zealand, and the Pacific region (16), and the more recent, "Accelerating Education for the SDGs in Universities" guide (17), provide frameworks and case studies to support SDG implementation in universities. In the United States, the Association for the Advancement of Sustainability in Higher Education (AASHE) has incorporated the SDGs into its STARS program, developing campus metrics for reporting SDGs in terms of operations and curricula (18), while The Times Higher Education Impact Rankings publish global performance tables which assess universities against the SDGs (19).

The SDG framework can inform health professions education (20). The common generic Indicator 4.7.1 for SDGs 4 (*Quality Education*), 12 (*Sustainable Production and Consumption*), and 13 (*Climate Action*)—*Global citizenship education and education for sustainable development are mainstreamed in national education policies, curricula, teacher education, and student assessment* (20, 21)—can be applied to health professions education. The UN defines global citizenship as "the umbrella term for social, political, environmental, and economic actions of globally minded individuals on a worldwide scale" (20). Implementing the SDGs, including global citizenship, in higher education is, however, not without its challenges, ranging from poor sustainability literacy and a lack of support from management (18). The concept of global citizenship has also been contested (22), and global citizenship education challenged for potentially masking national or local responsibilities (23). However, we live in an interconnected world, and what happens in one country or region can have

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global impacts. Global carbon inequality is one such example. In calculating this inequality from 1990 to 2019, Chancel (24) reported that in 2019, the top 10% of the world's population emitted 48% of the total carbon emissions, while the bottom 50% contributed only 12% of the emissions. With carbon emissions a significant contributor to our changing climate, the brunt of which is borne by the poorest countries such as Afghanistan and Bangladesh (25), global citizenship is a necessary educational outcome (26).

It is worth noting, however, that the SDGs are now 7 years old and with the dire state of many of the planet's ecosystems, some of those who advocated for global citizenship as a competency are now calling for a paradigm shift, e.g., from "global nursing" to "planetary nursing" (26–28). Calls for planetary health integration in medical education (29) are being translated into action, such as a recent *Frontiers in Public Health* publication describing a student-driven planetary health curriculum (30). Global citizenship (social focus) can now be supplemented with planetary citizenship (environmental focus). For Turner, "identifying as a planetary citizen means seeking to understand humanity's environmental footprint and trying to do something about it. The aggregate effect of planetary citizenship across multiple levels of organization (individual, civil society, national, global) will lead to purposeful change at the planetary scale" (31).

This submission describes the outcomes of a second-year learner-centered planetary health assignment in a five-year Doctor of Medicine (MD) program at Bond University, Gold Coast, Australia, after 5 years of implementation (2018–2022) (32). Underpinned by SDG13 (*Climate Action*), self-selected teams of 4–6 students submit a protocol (with feedback) for a proposed "product" (creative output designed to deliver a message to a particular audience), which they then develop and submit. Five pairs of academic graders select their best two products ($n = 10$), voting for the Academics' Choice Award. The teams are then invited to pitch their product (5 min) to their peers, who choose the People's Choice winner and runner-up.

Pedagogical framework, principles, and competencies

The planetary health assignment is underpinned by four primary considerations: *Global citizenship* (a Bond University graduate attribute and an Indicator for several SDGs), the *SDGs* (including ecological justice), *teamwork*, and *learner-centeredness* (33).

Global citizenship

Bond University has three graduate attributes (Figure 1): Graduates need to be *capable individuals*, *effective collaborators*, and *global citizens* (34). As global citizens, graduates should thus take responsibility for their actions and understand the need for personal accountability. They should also employ integrity, professionalism, and ethical decision-making in all aspects of their enterprise. Viewed through a planetary health lens, graduates should therefore be accountable for their environmental footprints, personally and professionally, as individuals and as health professionals, recognizing the impacts locally, nationally, and globally. Considering the deteriorating state of the global (35) and the Australian natural environment (36), and considering the above-average environmental footprint of the Australian healthcare sector (6), environmental accountability in the health professions is paramount. In addition, with Australia being the second dirtiest *per capita* economy in the world (37), all Australians have a personal responsibility to mitigate their footprint.

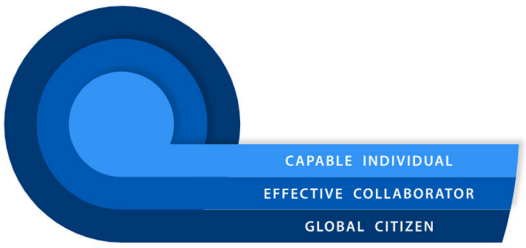

FIGURE 1
Bond University graduate attributes: capable individual, effective collaborator, and global citizen (34).

The SDGs, specifically SDG13 (*Climate Action*), including ecological justice

In 2019, Bond University became a signatory to the SDGs. Both prior to this and subsequently in response to the agreement, academics are integrating these Global Goals into various educational programs across the University. Considering the range of current environmental threats to human health (e.g., heat, smoke inhalation, deteriorating ecosystems, etc.), ensuring that all health professional students are prepared to practice (and take action) is an educational priority. For this planetary health assignment, SDG13 (*Climate Action*) is the focus, supported by at least one other SDG of choice.

Early in Year 1, Bond medical students are introduced to how "planetary health" has been integrated across the five-year Medical Program. Over the past few years, planetary health integration in medical education has been student-driven [e.g., Planetary Health Report Card (38, 39)], with a recent example of such a planetary health curriculum being that of Warren

Alpert Medical School (30). While planetary health can be viewed through several lenses, with Bond University located in Australia, where First Nations Peoples were the traditional custodians of all of Australia's ecosystems for about 65,000 years before colonization by European settlers began, we have applied an Indigenous lens to planetary health. Students are provided with this Redvers (40) description: "Planetary health as a "field" is primarily a Western construct as Indigenous Traditional Knowledge systems have no clear separation of self or that of the community and the ecosystem at large. This means that the meaning and application of planetary health are directly rooted in community values based on protocols for living in harmony with all that have existed for thousands of years."

With rich Traditional Knowledges and an Aboriginal and Torres Strait Islander *Social and Emotional Well-being Framework* (41), and connection to "Country" an integral part of this Framework, ecological justice is embedded not only in this planetary health assignment but also as a scheduled session in the same semester. Ecological justice holds that non-human beings such as animals and plants also have entitlements such as an adequate habitat, which is in line with Indigenous views of First or Natural Laws (42).

The SDGs recognize that a range of factors, from colonization, unequal development, and unjust wealth inequalities have not only marginalized many but have also come at the expense of our natural environment. Under the slogan of "Leave No-one Behind," the SDGs aim to eradicate poverty and hunger, reduce inequality within and among states, and provide a "plan of action for people, planet, and prosperity" (33) by prioritizing Indigenous knowledge systems and advancing education for women sustainably. Ecological sustainability and environmental protection are not achievable without addressing people's basic needs and ensuring a more equitable (which has not been the case to date) sharing of the planet's limited resources so that people can fulfill their potential in a healthy environment.

"Leaving no-one behind" and eliminating poverty depends, however, on protecting land rights, eliminating gender and racial inequalities, and recognizing the interdependence of human well-being and healthy, optimally biodiverse ecosystems. The ecological justice movement thus extends environmental justice by ascribing rights to land, species, and ecosystems (43). The right of an ecosystem to be protected against ecocide is of particular significance. Recent examples of ecological justice in action include the legal recognition of the personhood of the Whanganui River in New Zealand and Mutuhekau Shipu (Magpie River) in Canada (44).

Teamwork

Teamwork is fundamental for safe and high-quality healthcare (45), and learning to work as a member of a team is a key skill in health professions education. While health professionals may not always be able to choose their team members, for this learner-centered planetary health assignment, students were free to do so. For most small group work in the Program, they are assigned to teams.

Learner-centeredness

Learner-centeredness is a key consideration of this planetary health assignment (46, 47). With the only stipulation of the assignment that of using SDG13 (*Climate Action*) Targets and Indicators to address pressing issues, students had choices in terms of:

- Forming teams (4–6 students), electing a team leader, and agreeing on a team name,
- Choosing at least one additional SDG (with Targets and Indicators),
- Choosing an "issue" (problem identification),
- Selecting an appropriate audience, and,
- Deciding on the message delivery format, i.e., a product (submitted for grading).

Learning environment

Planetary health is integrated across the five-year curriculum in the Bond University MD Program. It begins in the second week of the first year when students are introduced to the key principles (e.g., the SDGs, definitions, planetary boundaries, etc.) of planetary health (*Introduction to Planetary Health*) that frame the longitudinal curriculum integration in terms of environmental sustainability, reconnecting with and protecting and restoring our natural environment. The same week, students are guided through the rationale for adopting an *Eco-biopsychosocial Model of Health and Well-being*, framed by a strong and nested sustainability model (48). Year 2 builds on these foundations and includes the planetary health assignment currently described as well as an ecological justice session. In Year 3, elements of sustainable healthcare are integrated into patient scenarios, e.g., environmental footprint of anesthetic gases, multidose inhalers, and radiological imaging. Environmentally sustainable healthcare spirals into the Year 5 General Practice rotation, with a session during which students explore their experiences of sustainability (or lack thereof) in clinical practice. In addition, some students choose to complete a 12-week Planetary Health subject offered in a Master of Healthcare Innovation for their MD Project that runs across Years 4 and 5.

Below, we provide further details relating to the design and measured outcomes of this planetary health assignment which is assigned 10% of the year grade.

Assignment learning aims and outcomes

The main aims of the assignment include teams applying at least two SDGs (SDG13, plus at least one other SDG of choice) to a planetary health "issue" they identify and use systems and/or design thinking to develop a product for a specific audience to address the identified problem. A self-study Storyline 360 (Articulate Global, New York, USA) module available on the learning management system outlines design and systems thinking and provides examples of how these "thinkings" have been applied to healthcare. With choice being a focus of this learner-centered assignment, several second-year Learning Outcomes can be applied, primarily in three of the four Medical Program domains: Health and Society (HS), Science and Scholarship (SS), and Professionalism and Leadership (PL) as listed below:

- **HS04:** Outline the range and scope of health promotion and disease prevention programs and evaluate them using knowledge of human behavior.
- **HS09:** Explain common population health screening and prevention approaches, including the use of technology.
- **SS16:** Examine evidence-based approaches to diagnosis, prognosis, and risk.
- **PL02:** Apply the principles of autonomy, beneficence, non-maleficence, and justice to patient care and problem-solving.
- **PL05:** Foster a duty of care while promoting social justice and resource stewardship.
- **PL13:** Demonstrate behaviors in accordance with codes and policies that define legal, ethical, and professional responsibilities.
- **PL14:** Demonstrate the competencies to think critically and logically, using initiative and the best available evidence when facing challenges, solving problems, and making decisions.
- **PL15:** Explain how lifestyle and professional activities may have a negative impact on others locally and globally.

Pedagogical format: Three graded components

Initially (2018–2020), the planetary health assignment contributed 3% of the year grade. In line with a transition to more programmatic assessment (49), the assignment now (2021–2022) contributes 10% of the year grade. There are currently three graded components: A proposal (4%), a product (5%), and a reflective critique (1%). Proposals are submitted at the end of Week 3 in the middle 12-week semester in a three-semester academic year. Products and reflective critiques are submitted at the end of Week 8. Selected teams pitch their products in Week 11.

Proposal, product, and reflective critique grading

Five pairs of markers comprising Medical Program academics, supported by Higher Degree Research students who are tutors in the Program, are responsible for grading the proposals, products, and reflective critiques. Each pair is responsible for overseeing 7–8 teams. In terms of grading proposals, each member of the academic pair independently grades the proposals using the assigned rubric based on Boyer's expanded scholarship criteria (50) before meeting to collate and upload their written feedback to individual teams via the learning management system. The grading rubric assesses proposals in terms of providing clear goals for the product, including a well-researched and referenced literature review, appropriately applying systems and/or design thinking, and feasibility of the proposed product in the time allocated, the articulated benefit and impact of the proposed product, and the quality of the written submission. Teams can discuss this feedback with their graders should clarification be required. No marks are assigned at this stage. The same grading process is followed for the products and the reflective critiques. The products are assessed on whether, based on feedback received, the team has created a quality product (e.g., error-free, engaging, properly referenced, etc.) that is appropriate for the intended audience. The quality of their reflection (reflective critique) is also assessed. In Week 10, academics meet to discuss the grading of all three components (inter-rater reliability). Each pair nominates two teams (based on product quality and appropriateness) to make a 5-min pitch to their peers at a conference in Week 11. Academics vote for the Academics' Choice Award (first place and runner-up). Following the team pitches, the cohort votes for the People's Choice Award. Certificates are awarded to the four winning teams. The Medical Program then donates AUS$50 to the four teams' chosen environmental organizations.

Self-reported personal and professional development

Immediately following the People's Choice Award voting, students anonymously respond to seven statements which evaluate whether intended and advertised outcomes have been met. They report on their awareness of the impact of a changing environment, their responsibility (values, attitudes) in mitigating and advocating in this regard and they also indicate

whether the assignment has contributed to the development of a range of skills.

This team-based, learner-centered planetary health assignment is innovative in that it encourages learners to think globally in terms of the impact of their personal and future professional actions, and, using the SDGs, engages them in proposing solutions to climate change. This submission thus aims to answer the following question: *Did this planetary health assignment, designed to engage teams of learners to "take action" on a pressing global issue (climate change), meet the intended outcomes?*

Ethics

Ethics for the study was approved by the Bond University Human Research Ethics Committee (CM03517).

Results

The data archived over the 2018–2022 period ($n = 162$ teams) were analyzed to identify trends in terms of the planetary health "issues," the second SDG selected to target alongside SDG13 (*Climate Action*), the intended audience, and the final product format.

Main "issues" identified

Figure 2 depicts the planetary health "issues" identified over the five-year period (2018–2022). Collectively across the 5 years ($n = 162$ teams), waste (35.4% of all teams), pollution (31.1%), and poor health (19.3%) were the most frequently identified "issues." The subcategories addressed under the issue of waste ($n = 57$ teams) included healthcare (82.5%), food (14%), and general household waste (3.5%). On a year-by-year basis, waste was the most common "issue" identified in 2018 (30% of 30 teams), 2021 (55.9% of 34 teams), and 2022 (50% of 36 teams) while pollution was the most frequently identified issue in 2019 (43.8% of 32 teams) and 2020 (44.8% of 30 teams). Types of pollution ($n = 50$ teams) included air (32%), land (28%), water (26%), and GHG emissions (14%). Poor health ($n = 32$ teams) was the second most common issue identified in 2020 (20.7%) and 2022 (27.8%), which addressed topics such as poor lifestyle (e.g., diet and exercise for 40.6% of these teams), communicable disease (25.0%), mental health (21.9%), anti-microbial resistance (6.3%), sexual health (3.1%), and hand hygiene (3.1%).

Second SDG selected

As described earlier, the primary aim of the assignment was for teams to use SDG13 (*Climate Action*) to advocate for action on climate change. Over the 5 years, the most selected additional SDGs were:

- SDG12 (*Sustainable Production and Consumption*) −41% of teams, mostly relating to healthcare emissions and waste
- SDG3 (*Health and Well-being*) −22%, involving the impact of air pollution
- SDG6 (*Clean Water and Sanitation*) −15% (Figure 3).

There was reasonable consistency across the 5 years, although SDG12 selection increased in the last 2 years, accounting for 62% (2021) and 53% (2022) of team choices. There were no significant differences in terms of the additional SDG selected across the cohorts (Kruskal-Wallis test with Dunn's multiple comparison assessment).

In terms of the least selected SDGs, no teams selected SDG1 (*No Poverty*) and SDG10 (*Reduced Inequalities*) over the 5 years. SDG8 (*Decent Work and Economic Growth*) was selected by one team in 2021 and SDG16 (*Peace, Justice, Strong Institutions*) by one team in 2018. Two teams selected SDG17 (*Partnership for the Goals*) in 2018. It is worth noting that a few teams did choose a third SDG to fully address the intended scope of their "product." These have not been included in the analysis. An example of this would be SDG5 (*Gender Equality*), in addition to SDG12 in relation to environmentally friendly feminine hygiene products.

Intended audience and product format

The "issues" identified influenced who the intended audience was and hence the format of the product. Table 1 provides the composite data for the intended audiences and the product delivery format for the 5 years. The most targeted audiences were local, state, or federal governments (24.7% of teams), healthcare professionals (i.e., doctors, nurses, pharmacists) (24.1%), and the public (21.6%). In 2018, just over one-third of teams chose governments as their target audience, while in 2021, 41% of teams chose healthcare professionals as their target audience.

Across the 5 years, the most frequent product formats were video (26.7%), information pamphlets (18.6%), and written proposals (16.8%). The trend across the 5 years suggests the development of digital skills, with a decrease in slideshow presentations and information pamphlets, and an increase in more sophisticated digital skills such as creating websites, videos, and "apps." Interestingly, there was a resurgence of written proposals in 2022 (25.0%), following a decline in 2019 and 2021.

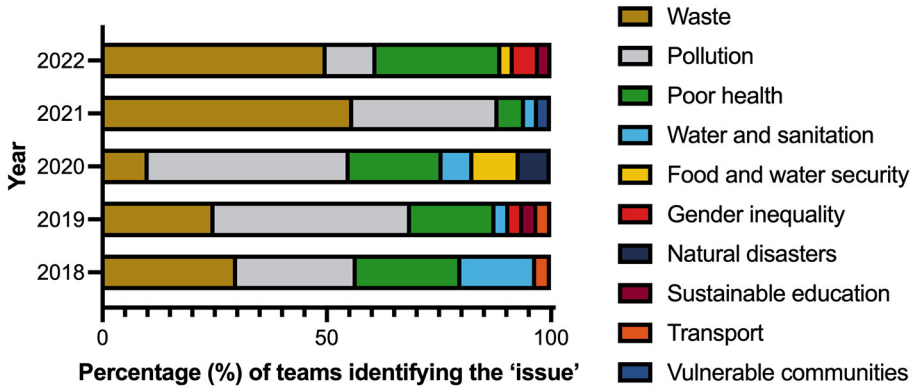

FIGURE 2
Percentage of teams identifying a range of "issues" across a five-year period (2018–2022, *n* teams = 162: 2018 = 30, 2019 = 32, 2020 = 30, 2021 = 34, 2022 = 36).

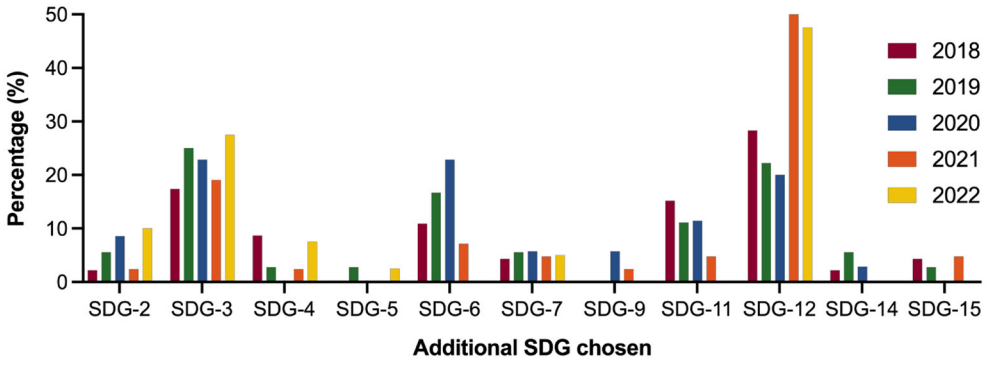

FIGURE 3
Second SDG (% of teams in each cohort) selected for the five-year period (2018–2022, *n* teams = 162: 2018 = 30, 2019 = 32, 2020 = 30, 2021 = 34, 2022 = 36). As all teams had to use SDG13, data for this goal is not included.

Self-reported personal and professional development

Table 2 summarizes learners' self-reported personal and professional development after completing the assignment. The average response rate for the five-year period was 51.6% (of the total 788 students completing the assignment). Overwhelmingly, students reported personal and professional development in terms of their awareness of the environment as a determinant of health and their responsibility to "take action" on climate change. Their responses also indicated an improvement in a range of skills, such as teamwork (80.8%), information-handling (72.8%), problem-solving (71.2%), and digital technology (62.0%).

Discussion

Although the warning bells about climate change and health rang many years ago, with Costello and colleagues warning in 2009 that climate change was the greatest threat to human health, potentially undoing the last 50 years of progress (51), medical education has generally been slow to include global health issues such as climate change and air pollution in the curriculum. A 2019–2020 International Federation of Medical Students' Associations (IFMSA) survey of over 2,800 medical schools in 112 countries found that few medical curricula had included climate change (15%) or air pollution (11%) (39). In response to these curricular omissions, medical students have been proactive in setting up organizations (e.g., Medical Students for a Sustainable Future, M4SF) (52) and developing

TABLE 1 Intended audience and product format for the five-year period (2018–2022).

Audience	Frequency per year (%)					
	Overall ($n = 162$)	2018 ($n = 30$)	2019 ($n = 32$)	2020 ($n = 30$)	2021 ($n = 34$)	2022 ($n = 36$)
Government	24.7	36.7	25.0	26.7	8.8	27.8
Healthcare professionals	24.1	23.3	15.6	16.7	41.2	22.2
Public	21.6	23.3	21.9	23.3	26.5	13.9
University	19.1	6.7	21.9	26.7	14.7	25
Schools	3.1	10	3.1	0.0	0.0	2.8
Pharmaceutical companies	2.5	0.0	0.0	0.0	2.9	8.3
Vulnerable populations	2.5	0.0	3.1	0.0	2.9	0.0
Non-profit organization	1.2	0.0	6.3	0.0	0.0	0.0
Farmers	1.2	0.0	3.1	0.0	2.9	0.0
Product format						
Video	26.7	13.3	28.1	20.0	41.2	27.8
Information pamphlet	18.6	16.7	31.3	36.7	8.8	2.8
Written proposal	16.8	36.7	9.4	6.7	8.8	25.0
Slideshow presentation	15.5	26.7	18.8	20.0	11.8	2.8
Website	14.3	3.3	9.4	6.7	17.6	30.6
Mobile app	6.2	3.3	0.0	6.7	8.8	11.1
Podcast	1.9	0.0	3.1	3.3	2.9	0.0

n = number of teams with 4–6 students per team.

TABLE 2 Self-reported awareness of environmental responsibility and skills development by completing the planetary health assignment (2018–2022).

	Agree (%)	Not sure (%)	Disagree (%)	n (2018–2022)
***Values, behavior, and attitudes:* This assignment has…**				
Made me more aware of the relationship between the environment and health and well-being	83.1	10.1	6.8	268
Made me think how I can personally reduce my environmental footprint (i.e., be part of the solution by mitigating)	83.0	9.8	7.2	240
Made me aware of my future role as a health professional (i.e., advocacy, education about environmental factors affecting health)	83.8	10.6	5.6	224
***Skills development:* This assignment has developed my ….**				
Teamwork skills	80.8	14.1	5.1	230
Information-handling skills	72.8	19.6	7.6	217
Problem-solving skills	71.2	17.3	11.5	207
IT and/or technology skills	62.0	26.3	11.7	247

n = individual students.

curricular frameworks and learning outcomes (53), as well as producing training manuals and issuing policy statements (e.g. IFMSA) (54). In 2019, medical students developed the Planetary Health Report Card, a self-evaluation tool comprising five metrics to guide universities and health professions schools' self-audits to identify areas requiring attention (38).

As concerned academics, we recognized the need to graduate Australian doctors suitably equipped to deal with the

consequences of rising temperatures and adverse weather events, who also need to be sensitive to the impacts on marginalized (therefore requiring prioritization) individuals and populations in an already unequal world. It seemed appropriate then in 2018 to use the SDGs (also referred to as the Global Goals for collective action, i.e., global citizenship) to underpin the planetary health assignment. With climate change a pressing global issue not only for people but also for the planet, SDG13 (*Climate Action*) framed the assignment. The authentic assessment was also designed to include a range of activities that would allow students to not only increase their knowledge and develop skills [e.g., problem-solving, systems thinking (55)] but which would also foster the acquisition of values and attitudes (e.g., civil responsibility) to be able to "take climate action" both in their personal lives as global citizens, but also collectively as future health professionals. These students' future professional body, the Australian Medical Association (56), in conjunction with an advocacy group, Doctors for the Environment Australia, recently released a communique, *Governments and the healthcare sector must lead on climate change*, advocating an 80% reduction in carbon emissions by 2030 and a net-zero Australian healthcare system by 2040. This is a major undertaking considering that the Australian healthcare system was listed as a top four *per capita* emitter in 2019 (7). A steep decarbonization trajectory is thus required (9).

Practical implications: Were the intended outcomes met?

In describing the measured outcomes after 5 years of implementation of an authentic, team-based, learner-centered planetary health assignment completed by second-year students in the Bond University Medical Program, the key question to be answered is: *Did this planetary health assignment, designed to engage teams of learners to "take action" on a pressing global issue (climate change), meet the intended outcomes?* Considering that the students were studying medicine, the outcomes in terms of the "issues" identified, and the SDGs selected over the 5 years of implementation are not surprising: Waste (mostly in healthcare), pollution and poor health led to SDG12 (*Sustainable Production and Consumption*) being the most frequently identified secondary SDG, followed by SDG3 (*Good Health and Well-being*), and SDG6 (*Clean Water and Sanitation*). More sustainable production and reduced consumption would lead to less waste and less pollution (e.g., cleaner air) and hence improved health outcomes. In terms of SDG6, "taking action" generally related to addressing "issues" in communities most likely to be impacted, such as in the Solomon Islands and remote Australia (Indigenous communities), where, as future Year 5 students, their MD capstone healthcare immersion would provide opportunities for advocacy. Further evidence of advocacy involved "taking action" in the form of creating informational videos, websites, and writing proposals directed at individuals or groups in positions of power, i.e., local and national government ministers and healthcare professionals, to take note of and hopefully respond.

Using self-reported data on the impact of the assignment across the 5 years, more than 80% of the students who responded reported a heightened awareness of the relationship between the environment and health and well-being, how they could personally reduce their environmental footprint (i.e., be part of the solution by mitigating), and that their future health professional roles would require advocating for action. Again, these findings align not only with global citizenship as a Bond University graduate attribute (20) but also as an outcome of several SDGs (15, 16), and reflect planetary citizenship.

Students reported improvement in a range of skills relevant to their future clinical practice: Teamwork (80.8%), information-handling (72.8%), problem-solving (71.2%), and information technology (IT) (62.0%). These self-reported improvements align with other Bond University graduate attributes of becoming *capable individuals* and *effective collaborators* who show strong interpersonal skills, can lead or contribute in effective teams, create, think critically, problem solve, and demonstrate information literacy (34). An interesting find was that only 62% of students reported IT (digital technology) skills improvement. There are several likely explanations. One might be that not all teams chose to develop products requiring these skills, e.g., compare writing a policy proposal with developing a website. With technology now embedded in many medical curricula (57, 58), such as the need for these students to develop a website the previous semester, many already might consider themselves to be "digitally literate." In addition, the COVID-19 pandemic accelerated this literacy as remote learning during lockdowns required the adaptation of lecture delivery, assignments, and assessment (59). There are reported benefits from remote delivery formats (60), although this often requires upskilling of both faculty and students (57).

This assignment is unique in the Bond Medical Program (and probably in many medical curricula) in several respects:

- The learner-centered design allows students to make several choices, including team members. Mostly during their medical studies, for convenience, individuals are assigned to groups.
- It is authentic in that learners tackle a real-world pressing global issue (climate change) using a global framework (UN SDGs, with Targets and Indicators) for "taking action." Using the SDGs exposes students not only to the concept of environmental sustainability, but also provides an opportunity to reflect on global inequity from a position

of "privilege" as students living and studying in a wealthy country with a large *per capita* footprint individually and in their future profession.
- It is skills-based, from problem-solving to communication, and includes systems and design (61) thinking, both of which have been identified as key skills in healthcare (62). All other skills built into the assignment are important in healthcare.
- Teams receive feedback on their first submission (their proposals), which they can apply immediately in the development of their second submission (their products), leading to high quality outputs. Generally, in assignments, feedback is not provided until after submission.
- Teams create fit-for-purpose products which can be sent to the intended audience, e.g., a policy document to a minister of health or a website available to the public.

Lessons learned

From our perspective as educators, this assignment, although labor-intensive, is an extremely hopeful exercise, and proof-positive that we can educate and support students to engage in harm reduction by addressing systemic inequity and taking care of the planet. While some students may already be advocates and ecological change agents, most will discover these concepts through the longitudinal integration of planetary health in their curriculum. Many will, however, require institutional support and a proper grounding in the dynamics of climate change, ecological justice, and the socio-economic determinants driving the current crisis. When provided, such as with this Year 2 assignment, our findings suggest that a number of teams have advocated for change on pressing issues by addressing their concerns and suggestions to politicians or other individuals who have the power to change the *status quo*. As health professions educators, our findings also offer considerable reason for hope. In addition to improving the understanding of the determinants of health for themselves and their future patients, we believe that our students have also gained an understanding of how healthcare currently "does harm" by contributing to both upstream (production; manufacture) and downstream (waste; pollution) damage to ecosystems and to communities who are culturally and spiritually connected to land or Country. We believe that many learners have developed an increased understanding of the need to treat the natural world, other species, and other cultures as morally considerable. In our judgment, most now appreciate the compelling need to integrate planetary health and ecological justice principles into their future work as health professionals.

Based on our findings, we are of the opinion that this planetary health assignment, as part of longitudinal planetary health curriculum integration, supports students to not just be global citizens but also to be planetary citizens, developing the knowledge, skills, values, and attitudes to tackle the Code Red crisis that all of Earth's inhabitants are facing (2–4). Our approach not only aligns with but extends the Bond University graduate outcomes (20) and the SDG education Targets (15, 16).

Future directions

At this point, our conclusions are based on self-reported development of values and attitudes involving environmental responsibility, advocacy, and skill development. It would be valuable to ascertain whether this assignment (as part of longitudinal planetary health integration) leads to real changes in environmental attitudes and behaviors (rather than perceptions of change) over a longer period.

While the 2030 SDGs embody global citizenship, in the 7 years since the SDGs were created, we believe that citizenship should be extended to the planetary level, involving ecological justice (31). In the Bond University Medical Program, "planetary health" is integrated using an Indigenous lens, which embodies environmental stewardship in line with Natural or First Laws and Traditional Knowledges (42, 63). This is particularly important considering the poor state of Australia's ecosystems. First Nations Peoples ways of knowing, being, and doing are thus vital for sustaining and restoring Australia's declining ecosystems (36).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics for the study was approved by the Bond University Human Research Ethics Committee (CM03517). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

MM: conceptualization, methodology, and project administration. MM, CP, VV, JS, NM, DB, RM, BC, and CM: validation, investigation, and reviewing and editing the publication. MM, CP, JS, NM, and CM: formal analysis. MM, CP, NM, and CM: data curation. MM, CP, NM, RM, BC, and CM: writing the publication. MM,

CP, JS, and CM: visualization and figures. MM and CM: supervision. All authors approved the final manuscript for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Working toward a transdisciplinary approach to teaching and learning planetary health–A collective reflection

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Background: In order to educate the next generation of leaders to work at reverting the damaging effects of the Anthropocene, there is an increasing need to incorporate more environmental-related aspects in all teaching programmes, including the health-related. Planetary health is a complex field which can benefit from a transdisciplinary pedagogical approach. The aim of this research was to evaluate an approach working toward transdisciplinarity applied to a course of Planetary Health taught at the Bachelor degree Global Responsibility & Leadership of the University of Groningen through substantive feedback and reflections from the students.

Methods: By the end of the course, a focus group was conducted with the students inviting them to reflect on the different aspects of the pedagogical approach, evaluating their effectiveness. A thematic analysis was conducted on the transcribed focus group.

Results: The students appreciated the added value of working toward a transdisciplinary approach and peer-to-peer learning and teaching adopted in the Planetary Health course, as a way of enhancing their learning experience. They pointed out the need of incorporating a transcultural approach into the transdisciplinary one, as a way not only to improve their learning experience, but also to enrich the transdisciplinarity itself.

Conclusion: Incorporating a process toward transdisciplinary and transcultural teaching of planetary health into undergraduate programmes was found to be of added value. The peer-to-peer horizontal learning opportunities were seen as a way for taking advantage of the collaborative, informal teaching and community building serving the overall scope of the course.

KEYWORDS

transdisciplinarity, innovative teaching, planetary health, thematic analysis, focus group, pedagogy, transcultural approach

Introduction

Our planet is rapidly changing. We have entered a new era, the Anthropocene, characterized by the impact of human activities on the planet and every living species on it (1). Anthropogenic activities and their consequences such as climate change, biodiversity loss, land use change, and pollution threaten human health directly and indirectly (2). They have an impact on the natural environment we depend on (e.g., air quality, arable land, temperature), and they are directly responsible for the increase of mental health, infectious diseases, non-communicable diseases, physical trauma, displacement and malnutrition, all major global public health concerns (1, 2).

In order to revert the trends and limit the damages caused during the Anthropocene, strong international political will is needed; however, economic interests often compete with environmental stances (3). For sustainable changes in the long term, the new generation, already very sensitive to the topic (4), needs to be educated to evaluate, understand, and ponder the intricate net of consequences that human activity has on the health of humans and the planet. Concepts like One Health and Ecohealth were developed, focussing on the interaction between animal, human and ecosystem health (5). Simultaneously, the field of Global Health emerged, concerned with improving health and achieving health equity for all people worldwide (6). Following these concepts and building upon the inter- and transdisciplinary work that has been done in those disciplines, a new concept was developed that combined them all: Planetary Health. Planetary health is defined as "the health of human civilization and the state of the natural systems on which it depends" (7), bit is also referred to as a "solution-oriented, transdisciplinary field and a social movement focused on analyzing and addressing the impacts of human disruptions to Earth's natural systems on human health and all life on Earth" (8).

In comparison to other approaches related to environmental health, planetary health is not a fully developed concept, but it has been gaining traction due to its introduction of the importance of sustainability, as well as inclusion of factors such as gender and socioeconomic background (5). Because of its importance and its comprehensive approach, interest in planetary health education has been increasing across different disciplines, institutions, and world areas (1, 9). Importantly, a distinctive factor of the study of planetary health, is the complexity of the problems it aims to investigate. The investigation of such complexities relies on the expertise coming from several different disciplines to unpack, understand, and analyse individual problems and their extended network of interaction. This naturally requires going beyond the disciplinary approach, and instead implementing new, more permeable approaches suitable for this field complexity.

Throughout this paper we refer to the concepts of *multidisciplinarity* as the approach that draws on knowledge from different disciplines, allowing knowledge to remain within their boundaries; *interdisciplinarity* as the process of analyzing, synthesizing and harmonizing links between disciplines into a coordinated and coherent whole; and *transdisciplinarity* as the ultimate integration of the natural, social and health sciences in a humanities context, allowing (academic and non-academic) disciplines to transcend their traditional boundaries (10). Aware of the existence of multiple definitions, these were chosen as developed in an evidence-based manner from health and education studies (10).

It was previously suggested that transdisciplinary in teaching and learning is a key pedagogical approach for specific fields characterized by intrinsic complexity and at the intersection of traditional disciplinary fields (11–13). Planetary health would be perfectly suited to be studied with a transdisciplinary approach. This in fact allows transcending disciplinary boundaries and creating a major reconfiguration of disciplinary divisions within a systemic, global and integrated perspective (14, 15). This approach is particularly suited to address contemporary challenges and includes the idea of extended cross-discipline peer-review. Ideally, stakeholders from outside the academic field would also contribute to the construction of knowledge and co-create, together with scientists, practical solutions to social problems (16, 17). Even though the stakeholder aspect was not specifically included in the present approach, it remains transdisciplinary in essence as it starts from the complexity unpacking it into simpler issues, and adds the cultural dimension to the pure encounter of disciplines. To what extent an academic approach working toward transdisciplinarity in Planetary health is suited for any level of teaching, and how it is enriched by classes of students coming from different backgrounds remain important topics to be studied.

As such, this research aims at evaluating an academic approach working toward transdisciplinarity to teaching and learning Planetary health by applying it to the case study of a newly developed Planetary Health course within the BSc Global Responsibility & Leadership at University of Groningen and inviting the students to collectively reflect on its merit.

Methods

BSc global responsibility and leadership

The Global Responsibility & Leadership (GRL) bachelor program at University of Groningen, is an interdisciplinary and international bachelor whose curricula is founded on the sustainable development goals (SDG's), and modeled following the liberal arts and sciences philosophy, featuring the main motto "global challenges, local solutions." As such, the programme offers a broad as well as in-depth academic

training, with a strong focus on social responsibility and (personal) leadership (18). The three-year undergraduate degree is structured into a series of mandatory introductory courses of a selection of six different areas of scholarship (traditionally described as disciplines) and an extensive skill-based training in year one, forming the shared academic core, or foundation year. In the second and third years, student follow elective courses which are divided into three main majors that students can choose from: Responsible Humanity, Responsible Governance and Responsible Planet. The teaching and learning environment is fundamentally learned focused: classes are small-scale with typically up to a maximum of 25 students per class, and teacher act as coaches who facilitate discussion and critical thinking.

The planetary health course

The planetary health course is a 9-week elective module designed as an overarching course open to third year students from any track and belonging to any major. As students in this course have already completed 2 years of study, they have started building slightly different academic backgrounds. This allowed subdividing the students by background in order to prompt a disciplinary encounter of peer-to-peer learning.

The course has been designed using an approach working toward transdisciplinarity. It focused on interconnectedness of issues, and how these generate intricate systems to be analyzed in all their complexity. The learning outcomes of the course were:

1. Describe the main determinants of the complex interaction between human and planetary health.
2. Examine various theoretical concepts in light of their application to planetary health determinants.
3. Apply an inter/transdisciplinary approach in practice by fruitfully interacting with expert from different fields.
4. Generate an evidence-based analysis of a complex issue in planetary health applying the principles of system dynamics.
5. Reflect on the deep meaning of the connection between humans and nature.
6. Present a planetary health-related seminar with an interdisciplinary team to a wider academic audience, and discuss its content.

The taught component of the module was structured around six abstract concepts (equilibrium, scarcity, common good, tipping point, belonging and risk), which set the main themes of each week. These served as a starting point for multiple disciplinary reflections on planetary health.

The course also combined vertical and horizontal learning. Vertical teaching included expanding on each one of the abstract concepts with two lectures given by two experts from two different disciplines; for example the topic of "belonging" included one lecture entitled "Acceptance, belonging, and Agency," an overview of social science research on migration, with particular emphasis on solastalgia (19), and another entitled "The epigenetic Landscape" tackling the concept of belonging from a biomedical perspective exploring the environmental hallmark on the human genome (20). Horizontal teaching was promoted with student-led sessions. Twice during the course, students with a specific background (social, environmental, or governance) were asked to deepen their knowledge on a topic, and plan as well as lead an entire session teaching that topic to their peers. This included circulating any preparation material, and conducting any formative assessment, if needed.

This course was designed to transcend the academic boundaries of individual disciplines creating a shared knowledge and understanding of reality, generating space for deeper reflection. For example, it presented students with complex problem to unpack in all their complexity working on the interactions of individual disciplinary issues. Further, students and teachers were explicitly prompted to transcend their disciplinary fields entering a no-man-land of dialogue and potential cross-fertilization. Finally the teaching space opened the door to broader reflections on the topic addressed, from cultural meanings to activism. The course, however, did not yet managed to meet all the standards of what is commonly defined as transdisciplinarity, as it did not include any societal stakeholders into its current structure. For this reason in this paper we describe this approach as working toward transdisciplinarity.

The course was run for the first time from November 2021 to January 2022, a total of eight students participated, four from Responsible Governance, three from Responsible Humanity, and one from Responsible Planet (Table 1).

TABLE 1 Participants' characteristics (*N* = number of participants).

		N
Background (tracks)	Humanities	3
	Governance	4
	Environment	1
Sex	Male	2
	Female	6
Nationality	Western European	6
	Asian	1
	South American	1

Focus group

By the end of the course, students were invited to participate in a focus group to share in-depth feedback on their experience,

and in particular to reflect on the course approach working toward transdisciplinarity. Ethical approval was obtained from the Ethical Committee of the faculty, all eight students participated in the focus group. The session lasted about 1.5 h. The focus group was led by a senior medical student (CD) who did not participate in the design or concept of the course but attended only the last sessions, who was doing an internship within the Department of Sustainable Health. During the focus group, the following two main themes were identified and addressed, on which the students elaborated extensively

- The relative contribution of the approach working toward transdisciplinarity in enriching the learning environment.
- The learning environment: experiences on the vertical (academic expert to student) and the horizontal (student to student) learning process in terms of quantity and quality of learning.

Any new important topic arisen during the focus group was considered and analyzed accordingly. The focus group was video recorded, after asking permission of all the participants, and the recording was transcribed using the free software program OtterAI (21).

Thematic analysis

In order to analyse the content of the collective reflection captured during the focus group, a thematic analysis was used. This was conducted following Braun & Clarke's 6-step framework (22). Initial codes were generated by 3 researchers (CD, JSD, RO) independently. A combination of open and closed coding was used, some pre-set codes based on the questions asked in the focus group were used, but others were also developed and others modified as the researchers worked through the transcription. All coding was done by hand. The initial codes were then combined and grouped in themes and subthemes. In the next section, the results will be presented by theme merged in three main sections, and illustrated with relevant quotes.

Results

The focus group transcription was categorized into 4 main themes with 13 subthemes and 25 codes with 29 sub-codes (Figure 1). These were initially analyzed separately, and subsequently re-grouped into three main sections: working toward transdisciplinarity in planetary health, transculturality in relation to transdisciplinarity, and teaching and learning environment (including points for improvement). Quotes are reported without any reference to the characteristics of the responder in order to prevent their potential identification, given the limited number of participants in the focus group. Overall the students participating in the focus group produced the points of the discussion in a collaborative way, and no major disagreements worth mentioning were recorded. As such, in the results, the opinions of the participants are referred to as a unique collective source.

Working toward transdisciplinarity in planetary health

A few important key characteristics of the learning process working toward transdisciplinarity brought up in the focus group were that it was strictly collaborative and that it implied a slower learning pace. According to the students, in this class learning was not something that could be achieved on one's own, it needed to be in a group. Moreover, it was a slower learning process compared to disciplinary learning, but it gave a broader, and more comprehensive perspective in the end. They also felt they needed to accept that the complexity of the problem posed meant that there was not always an answer to every question, differently from other courses they had attended. Overall the students considered the approach working toward transdisciplinarity not as an end goal, but as a tool that they could use on complex issues and learn with.

The students also stressed the importance of coming to the course with some disciplinary background knowledge relevant to Planetary health, which they felt only partially to have. They stressed the importance of multiple disciplinary backgrounds as contributors to increase the efficiency of learning in a context working toward transdisciplinarity. Finding the balance in the education system between disciplinary and transdisciplinary learning was felt as key.

> *"I think everyone would value having an interdisciplinary approach, but then again* it *comes into my mind this collective thing of learning about each other, and you need the foundation."*

This argument implicitly prompted a reflection on when it is appropriate to start using a transdisciplinary approach in higher education. When was the disciplinary knowledge enough to enable it? While for one student, the transdisciplinary approach came too early in their bachelor programme, causing her to feel she lacked the background knowledge for the Planetary Health course, all other students agreed that early implementation was better.

> *"But I think it* [the transdisciplinary approach] *really helps our education. And . . . I like it and I think it's good that we implement it early on in the bachelors already."*

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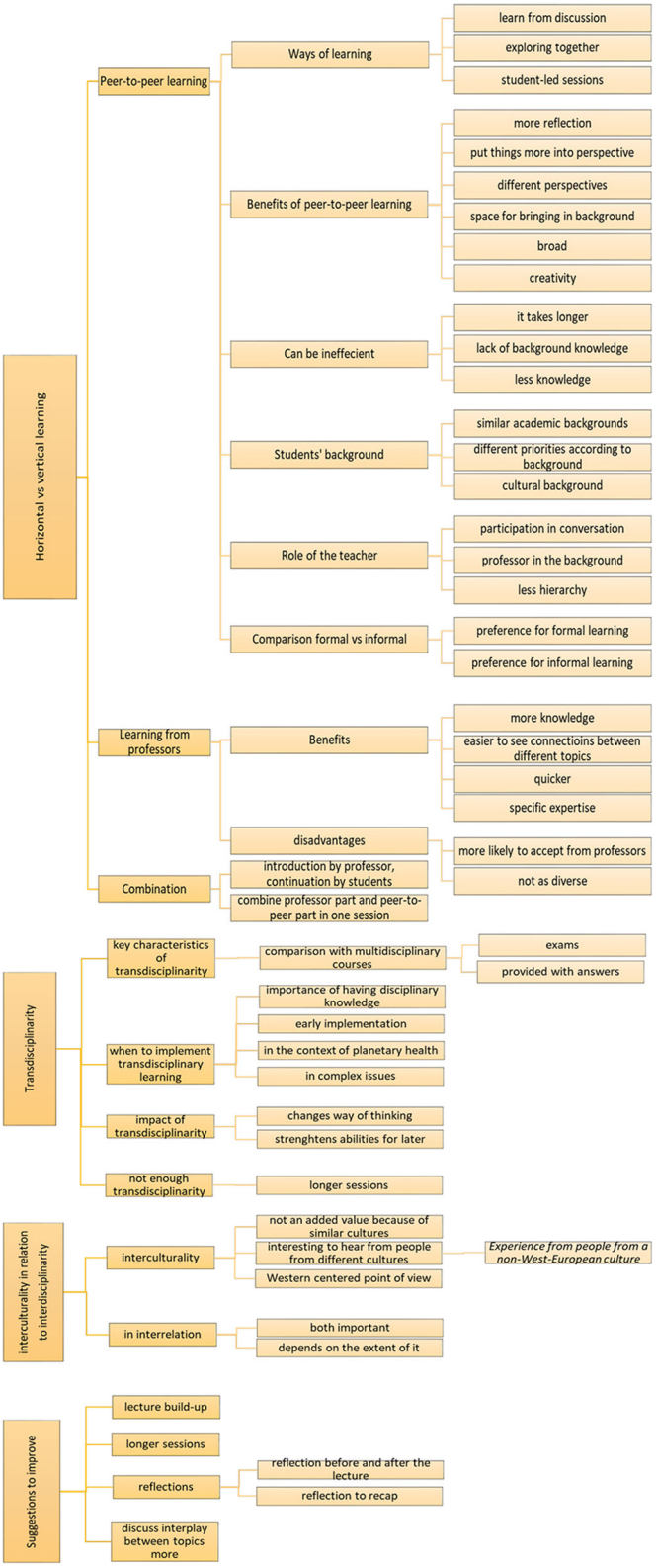

FIGURE 1
Overview of the themes, subthemes and codes used for the thematic analysis.

All students agreed that gradually increasing the level of transdisciplinarity throughout the education trajectory could be a useful way to implement it early on but still have room for gaining the disciplinary knowledge one needs as a foundation.

Early implementation was also perceived to be good because transdisciplinary learning was felt as a way of strengthening students' abilities for later on in the education, changing their way of thinking. Students felt they gained more perspectives, started thinking more holistically, they were more open-minded, and this changed the way they dealt with problems.

> *"So I think … what this approach does* [the transdisciplinary approach], *is it gets your gears turning, … it gets you thinking, it gets you analyzing, that's …, I think, the most integral part to it."*

The specific approach working toward transdisciplinarity implemented in the Planetary health course where students from all majors were invited to participate was felt as a particular important addition to the Bachelor. It was also noted how, especially in the context of planetary health, transdisciplinarity was a valuable approach to address complex issues and learn about them.

> *"For complex issues, it makes most sense to use an interdisciplinary approach because they are so … complex, they affect different areas of life. So it makes a lot of sense to use an interdisciplinary approach for complex issues."*

The nature of a genuine transdisciplinarity in this course was questioned by the students as the backgrounds were felt not to be different enough. In addition, the students found there to be less than desirable cross-over or connection between the many topics covered.

> *"We had a lot of different topics, but … sometimes it felt that they still stayed a little bit within their own side."*

A suggested way to increase the transdisciplinarity of the course was to have longer sessions to discuss the interplay between the topics more in depth. The students noted that time-wise the discussions often got cut, and interesting thoughts were lost after the session. Pace was also deemed very important by the students as they felt it was easier to follow the train of thought when every argument was built slowly.

> *"Because especially in this interdisciplinary context, I sometimes after the session, I suddenly realize, … this is a very good point, or this is a very interesting perspective, I wonder what the rest thinks about this. But then, because the next session is already on a different topic again, then that* it *gets lost."*

Transculturality in relation to transdisciplinarity

The students in the course did not only have a slightly different academic background, but also different cultural backgrounds. In this section, results on the relative perceived importance of both these aspects and how they influenced the learning environment is reported. The topic of transculturality was not prompted by the conductor of the focus group but came up in the discussion; it was therefore analyzed as a new topic, accordingly.

Both transculturality and transdisciplinarity were regarded as very important for the learning environment. The students acknowledged that the more backgrounds and cultures were different among the participants in a discussion, the more they learnt from these other perspectives. In this particular case, most but not all the students came from Western-European countries, so interculturality was present, but limited.

> *"It was very interesting to hear from the people that were from very different areas in the world to hear what they had to add from there."*

The students noted that transculturality was also limited in the literature list for this course; most papers concerned studies in western countries and were published in western journals. However, all students noted how it was really of added value to hear the perspectives of the students and guest lecturers that came from different areas of the world.

Importantly, some of the students raised the point that when discussing transdisciplinarity, it meant encounters with disciplines defined in a Western context. How transdisciplinarity and different disciplines are dealt with in different cultures was not included into the course. This contributed to narrowing the concept of transdisciplinarity tackling it purely from a Western hemisphere/global North perspective.

> *"Interdisciplinarity, I never really realized that up until now, but of course, we think is still in the disciplines as in the westernized university structure, and we take those disciplines and then we try to link those so that the concept of how we live interdisciplinarity, or how we deal with the topic is also really, culturally based in how we structure our universities, that's true."*

This is deemed to be particularly important for Planetary Health where the intimate relationship between humans and nature is an integral part of the picture, and where some individual and collective values and traditions and the intrinsic position of nature in human life is deeply different across cultures.

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Teaching and learning environment

Overall, the students agreed that creating this multidirectional learning environment with both horizontal and vertical learning combined was an important part of transdisciplinary teaching in the Planetary health course. When comparing peer-to-peer learning with learning from academic experts, the biggest differences according to the students were the efficiency of the learning process and the amount of knowledge students gain. Students perceived academic experts to have more knowledge and expertise and that they could bring that knowledge across in a quicker way. They could also point out connections between different points more easily.

> *"… learning from a professor content wise is a bit more efficient, like you get more content in a shorter period."*

Sometimes peer-to-peer learning felt less efficient. It is a slower journey, it took longer because peers often lacked in-depth background knowledge on topics and overall they gained less new knowledge than when learning from academic experts.

> *"You're sort of lacking the basis and often you get discussions that are where we're all discussing about something we still don't really grasp."*
>
> *"It takes so much longer to get to a point where you have something like concrete knowledge."*

Nonetheless, the benefits of peer-to-peer learning compared to learning from academic experts were that students felt as if they were more prone to critically reflect on what had been said, while when information comes from academic experts, they were more likely to directly accept it.

> *"Learning from peers is more talking to each other, and maybe even like, disagree or, yeah, critically, critically reflect on it."*

With peer-to-peer learning, students mostly learnt through discussions with their peers while they were exploring new topics together. Students found this a good way of learning.

> *"And I learned so much in that course, just from all this, discussing."*

Students were also exposed to multiple different perspectives together in peer-to-peer learning, which added more diversity than learning from academic experts. They noted that in more vertical settings, even when academic teachers were really conscious about the coexistence of multiple perspectives and tried to approach a topic from different angles, they were not always successful in conveying multiple points of view in a balanced way, as was the case with regards to peer-to-peer learning.

> "[in peer-to-peer learning] *there's generally more diversity in perspectives and in ways to approach a topic."*
>
> *"Sitting there hearing from people from different backgrounds on a topic that they prepared I think I would also say that was more valuable."*

Furthermore, the students felt there was more space to bring in creativity and their own background in peer-to-peer learning, both cultural and academic. Those backgrounds and different perspectives that every student brought in, were what made the student-led sessions so interesting to follow for other students.

> *"Everyone prioritizes different things and emphasizes different things in what they want to learn."*

According to some students, ideally, the horizontal and vertical learning would be combined in one session: with an introduction by an academic expert first, to lay the basis and gain the knowledge and have a more efficient peer-to-peer discussion after that.

> *"But maybe I would even think about not having that in two separate sessions, but combining that in one session. so, you first have half an hour more lecture type by for example, the professor and then[...] have the rest of the hour a student led session, so not have the whole one and a half hours by students, but combine like the lecture by the professor with the peer to peer part a bit more."*

The role of the teacher during this peer-to-peer discussion was more in the background, but with some interventions in the discussion. By taking part in the conversation, on the same level as the students, students noted that teachers could provide a different perspective or some more in depth knowledge, without a hierarchical structure, benefiting the overall learning environment.

> *"There's not this one professor that is higher up."*

In general having more reflection time and time to recap was suggested by some students as needed to improve the learning environment, because many topics and many points of view were discussed making it hard to remember everything and keep a balanced overview.

> *"I wish we would have had a little bit more because then the knowledge can stay even more in your brain because you like recap and remember, but also you get to process it and see how other people have processed."*

Co-teaching by more than one professor was also seen as very fruitful. When two or more experts were present in one session and the discussion developed among students and experts was seen as maximizing transdisciplinary learning, witnessing a real-life interplay between the topics.

> *"Having half an hour by one expert and half an hour by the other and then have a shared discussion both with students and also active involvement of both these lecturers is really really valuable."*

Overall, the students expressed appreciation for the course, which was evaluated well.

Discussion

This research evaluated an innovative approach working toward transdisciplinarity teaching in the course of Planetary Health in the BSc Global Responsibility & Leadership through substantive feedback and reflections from the students collected in a focus group. Overall, having an approach working toward transdisciplinarity in the planetary health course was perceived as beneficial for the learning process of this complex field. Creating a multidirectional learning environment without a hierarchical structure improved the learning environment. Combining horizontal learning in which students learn mostly *via* discussions with peers and vertical learning in which academic experts, preferably *via* co-teaching, give students essential new knowledge needed for these discussions in a more efficient way, was key to maximizing the gaining of new knowledge and perspectives. Peer-to-peer learning and teaching was already reported as a way of improving students' critical thinking, learning autonomy, motivation, collaborative and communicative skills (13, 23); however, less evidence is available on the advantage of this technique when students from different disciplinary backgrounds are merged in one class. Importantly, students pointed out that they felt that this type of learning was possible only in a group. This implied that they regarded the experience not merely as an encounter of different disciplines as in an interdisciplinary approach, but valued the role of the interaction and cross-fertilization of disciplines, which means working toward a more substantial transdisciplinary approach.

Another important factor highlighted in the present study is that planetary health is not only a transdisciplinary field, but should also be seen as an intercultural field, with the notion that these are not two separate concepts but are complementary and interconnected. In this respect, transculturality could also promote the further evolution of transdisciplinarity by embracing disciplines beyond the traditional western approach (24). For example, spirituality in the relationship between human and environment is often not included in the complexity of planetary health studies. Nonetheless, in some indigenous communities of the Amazon forest the reality is perceived as an integrated entity of the environment, the society, the culture, the economy and the religion, without real ontological differences between them (25). Transculturality in Planetary health, therefore, not only deals with the co-existence of different cultures in the class, and often cultural differences between students origins and the place where learning takes place (26). It also needs to be accounted for in the peer-to-peer learning, team working, and problem solving typical of this discipline, and it needs to enrich the discipline content itself.

The students participating in the present research stressed the value of having a interdisciplinary and transdisciplinary courses in their university program, but also acknowledged the need for disciplinary knowledge as a foundation. Finding the right balance between enough disciplinary knowledge and early implementation of transdisciplinarity is challenging. To do so, devoting 10% of the teaching time in each discipline to transdisciplinarity was proposed in the literature, as well as having a transdisciplinary department in every university that could act as a network of all disciplines (27). Among the benefits of early implementation of transdisciplinarity there is a change in the way of thinking of the students and the teachers alike (28). Approaching problems from different perspectives, finding common language with other disciplines and more holistic thinking are skills very useful for professionals in every field, elements which are commonly not taught in conventional education (28).

Moreover, the creation of a multidirectional teaching and learning environment not only benefits the learning process but also presents an opportunity to shift (higher) education away from a top down model toward a more participatory model, where peers and lecturers can learn in partnership. A number of supervised time slots dedicated to recap previous sessions, essential learning points, and reflections was suggested by this group of students as a way to acknowledge a slower learning process improving students' ownership of the process itself.

The potential benefit of including transdisciplinary and transcultural planetary health courses in all fields of education, from professional like medicine, engineering, or law, to all natural and social science as well as liberal arts, is evident (29). At present, it is particularly striking that the subject of planetary health is barely included in medical curricula, public health curricula, or other health professionals' education. Research shows that internationally, only 15% of medical schools worldwide have incorporated climate change and health in their curriculum (30). While medical students and student associations are advocating for integration of planetary health in the curricula, medical education is slow to respond. Medical students would gain vital clinical skills by appreciating the interconnectedness of human health and environment, but also start to think more critically about the healthcare systems they work in (31).

Ideally all educational programmes would have combined courses to engage in a truly transdisciplinary approach,

breaking with the disciplinary structure of the universities. This would contribute to training the next generation of leaders with increased sensitivity to environmental matters, and their complexity.

A further degree of complexity which is intrinsic to some definition of transdisciplinarity also includes collaboration with different stakeholders outside the scientific field who contribute to the construction of knowledge and the co-creation of practical solutions to social problems (16, 17). In order to achieve this, it is important to introduce the shift toward a transdisciplinary approach to science starting from the early education years. In this way, students would be well-equipped to collaborate across fields to produce knowledge and innovation with social relevance (32, 33). This can represent a further step to promote transdisciplinarity in Planetary health with a concrete and task-oriented approach.

Strengths and limitations of the study

The main strength of the present study is that it is based on an innovative teaching method, heavily relying on an approach working toward transdisciplinary, intercultural and peer-to-peer learning, that has not yet been described in the literature. In addition, a characteristic particular to the study was that it was conducted within a bachelor programme primarily constituted out of people who identify as women in a field such as leadership, commonly dominated by men. This can be seen both as negative, due to lack of equal representation, and as positive, since it provides a unique perspective. The variety of the teacher's academic backgrounds on the other hans was an important strength of this study, as this really fostered an inter- and trans-disciplinary thinking.

The limited number of participants in the study undoubtedly constitutes a limitation. With only eight students in the course and participating into the focus group, it is hard to draw major conclusions or generalize our findings. Further, we only had one focus group and no individual follow-up interviews. This could influence the findings, as answers in groups can be influenced by others. In addition, the course leader (VG) attended the focus group as an observer, this might have inhibited some overt criticism of the course and some of the most critical reflections. It is worth noticing, though, that no further point was raised in relation to the course in the anonymous evaluation of the students which was due after the focus group. Collecting reflections through focus groups might imply some reciprocal influence on the content of the reflection, limiting the opportunity for original thought among participants. While this is true, it was interesting to hear different voices also on themes raised by the students themselves. Another important aspect is that the horizontal learning in this course was not truly built on different disciplinary backgrounds as students came from different majors yet with similar foundation education, and a pilot course we sis not yet manage to include an element of stakeholder involvement which is often associated with transdisciplinary learning. Therefore, the unique disciplinary knowledge every student had was limited and voices from outside of academia were not included, which is why it could be argued that our approach was only "quasi-transdisciplinary." Given these limitations, it is very difficult to generalize these results. Instead, they should serve as a guide to prompt further innovative teaching ideas and to prompt additional reflection on adopting transdisciplinary approaches in the teaching and learning of planetary health.

Conclusion

In conclusion, this study supported the notion of incorporating transdisciplinary and transcultural teaching of planetary health into undergraduate programmes as an added value, even when the primary focus is not on public health. The peer-to-peer horizontal learning opportunities within the module were seen as a way for taking advantage of the collaborative, informal teaching and community building serving the overall scope of the course. Moving beyond a pilot as the one we have described, future steps would be to incorporate external stakeholders in the educational environment in order to not only work toward but fully apply transdisciplinary teaching and learning in planetary health.

Data availability statement

The transcript of the full data supporting the conclusions can be made available by the authors, upon request. The original recording cannot be shared to protect the privacy of participants.

Ethics statement

The study was approved by the Ethical Committee of Campus Fryslân. All participants signed an informed consent before taking part. All participants were given the final copy of the paper before submission and given the opportunity to object the content of the paper.

Author contributions

VG and CD: study concept and design. CD, JS, and RO: analysis and interpretation of data. CD and JS: drafting of the manuscript. CD, VG, and RO: data collection. VG, DM, and IZ: critical revision of the manuscript for important intellectual content. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Climate and health education: A critical review at one medical school

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Introduction: As medical schools continue to improve and refine their undergraduate curricula, they are also redefining the roadmap for preparing future generations of physicians. Climate change is a critical topic to integrate into medical education. This period of change for undergraduate medical education coincides with a surge in interest and design efforts for climate and health curricula in health professional education, but this nascent field has yet to be solidly institutionalized. To continue to grow the number of medical students who achieve competency in the effects of climate change on individual health and the health of the planet during their training, we must examine what has worked to date and continue to shift our approach as curricular changes are implemented for feasibility and relevancy.

Objective and methods: In the present study, we assessed the "climate and health" content at one northeastern U.S. medical school that is undergoing an overhaul of their entire curriculum to explore strategies to deliver more robust climate health education in the context of the educational redesign. We conducted 1) a retrospective review of the now four-year-old initiative to investigate the sustainability of the original content, and 2) semi-structured interviews with lecturers, course directors, and medical education coordinators involved in implementation, and with faculty tasked with developing the upcoming curricular redesign.

Results and discussion: Of the original implementation plan, the content was still present in nine of the 14 lectures. Themes determined from our conversations with involved faculty included the need for 1) a shared vision throughout the content arc, 2) further professional development for faculty, and 3) involvement of summative assessment for students and the content itself to ensure longevity. The interviews also highlighted the importance of developing climate-specific resources that fit within the school's new curricular priorities. This critical review can serve as a case study in curriculum to inform other schools undergoing similar changes.

KEYWORDS

climate change, curriculum, education, medicine, curricular redesign

1. Introduction

The overarching objective of undergraduate medical education curricula is to provide students with the scientific knowledge and practical skills to be accomplished and responsible physicians (1). Historically, medical school curricula undergo frequent content, format, and faculty changes as well as periodic large scale reorganization (2), which is currently happening across the country (3). Prominent trends throughout the present curricular developments include condensing the early coursework and introducing more content on social science and policy (4) and structural determinants of health (5, 6). The driving forces for these changes include Association of American Medical Colleges (AAMC), Liaison Committee on Medical Education (LCME), and United States Medical Licensing Evaluation (USMLE) pressures and student demand (7–13).

Climate change is one of the large societal issues being integrated into some medical school curricula. Climate change has been on the radar of the general public for years but has only slowly gained traction as a political, social, and medical crisis. The effects of climate change on health come from both the indirect impacts of exacerbating inequities in SDOH, with the earliest and most prominent effects of climate change affecting those in low income and disadvantaged communities (14), and the direct impacts of heat, extreme weather events, pollution, wildfires, and other phenomena. Infants and young children, older adults, and people with disabilities are also among the most vulnerable to the effects of climate change. A breadth of research shows the direct clinical impacts of climate change in all medical disciplines [cardiac health, (15); pulmonary health, (16); renal health, (17); infectious disease, (18, 19); psychiatry, (20); emergency medicine, (21); pediatrics, (22, 23); gynecology, (24)], but this research has not translated to inclusion into medical school curricula at the same rate. In a survey conducted by the International Federation of Medical Students associations, only 15% of the 2,817 medical schools included climate change in their curricula (25). In recent years, groups within medical schools have worked to build and adapt curricular initiatives that reflect the nature of climate change as a societal issue and a direct threat to health. Various methods for implementation have been adapted: Emory University and the Icahn School of Medicine at Mount Sinai (ISMMS) have adopted a disseminated design with climate change and health content spread throughout pre-clerkship courses and small group discussions (26), Queen's University Belfast, Stanford, and UC-Berkeley UCSF Joint Medical Program have an elective-based approach, and Georgetown School of Medicine and Harvard Medical School offer clinical scenario exercises to expose students to the practical applications of climate change (27). Because climate change results in pervasive, universal, and ever worsening health problems, it remains crucial to educate the students who will be responsible for human health on its impacts.

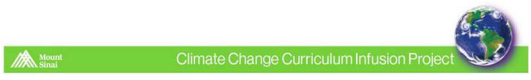

FIGURE 1
The CCCIP banner that appeared on each of the pre-prepared slides (26).

We are in a critical period for understanding curricular initiatives in climate change and health to ensure their sustainability. The ISMMS MD program is undergoing a curricular reform across all facets of the educational program. The climate change curriculum infusion project (CCCIP) is the initiative that has coordinated the introduction of climate change content at ISMMS since 2018. The student-led, faculty supported group responsible for the inception of the project designed stand-alone slides, each with a recognizable banner (Figure 1), to be incorporated in 14 lectures across six courses in the first 2 years of the pre-clerkship curriculum (26). Two rounds of student feedback ($n = 74$) of the CCCIP concluded that the content was appropriate in the courses (88%) and important to their medical education (83%). The feedback also indicated that students did not remember the content well (78%) and that the climate-related content at ISMMS did not match their expectations [62%; (26)].

The goal of the present study is to explore a nationally relevant case study of the ISMMS' climate change content as it relates to a drastic curricular redesign. We aim to assess the CCCIP implementation from the perspective of the ISMMS faculty, understand the challenges to implementing the content as presented, and assess ways to improve the success and sustainability of the information in the new conceptual framework.

2. Methods

2.1. Retrospective review of CCCIP

2.1.1. Study design and data collection

The first component of this study was a retrospective review of CCCIP content continuity. We identified the lectures where CCCIP content was originally accepted by course directors and lecturers by following the CCCIP records (26) from the inception of the program. Medical administrators at ISMMS granted us access to the *Blackboard* course websites for all courses from the 2020–2021 and 2021–2022 academic years identified to have lectures with CCCIP material. With the timetabled lectures from 2018 as a guide, these courses were

systematically reviewed to identify where CCCIP content was still being used.

2.1.2. Data analysis

Lectures where we found slides with the CCCIP banner were counted as lectures where the content was still present. The data for both years of content were recorded and helped to inform the second component of the study.

2.2. Assessment of faculty experience

2.2.1. Study design and data collection

The second component of the study aimed to gather faculty feedback on the CCCIP. To better understand faculty experience with CCCIP implementation, a mixed methods interview-based exploratory study was designed. The study was deemed exempt by the Mount Sinai Institutional Review Board (IRB). Inclusion criteria were based on participation in the original CCCIP. Eligible faculty members included lecturers who were tasked with delivering CCCIP content, course directors for courses where CCCIP content was included, and medical education leadership. Two separate semi-structured interview guides were created, one for lecturers and course directors directly involved in the CCCIP and one for medical education faculty who had knowledge of the aims of the content implementation and who are involved in the current curriculum redesign. The guides were designed by consulting studies with similar lenses of curriculum implementation (10, 28–30) and by reviewing literature on qualitative research methods (31).

Eligible faculty members (nine lecturers, of whom five are also course directors, and six leaders in medical education) were emailed with information about the study, the research information sheet, and a request to schedule a 30-min interview. Once a time slot was selected, a calendar invitation was sent to the faculty member with a HIPAA-compliant videoconference *Zoom* link. Zoom sessions were run by one interview lead and notes were taken concurrently by another researcher. After obtaining consent, each session was recorded for note-taking purposes. Interview questions included three introductory questions related to the interviewee's field of practice, ten baseline questions regarding lecture content and delivery for lecturers and course directors, and seven baseline questions regarding curriculum design and sustainability for medical education faculty and those involved in the curricular redesign team (Table 1). Following the conclusion of the interviews, the recordings were reviewed by the research lead to supplement the notes, as needed. Once the final data were organized, recordings were permanently discarded and data were stripped of all identifiers.

2.2.2. Data analysis

Interviews were reviewed and characterized throughout data collection. Qualitative interview data were coded by a single coder using an inductive approach (32). During analysis of individual interview transcripts, ideas in each interview were noted and subsequently added to a separate spreadsheet. The same spreadsheet was used to organize ideas from every interview and served as an initial codebook. Analyses were checked by a second, independent coder. The additional coder chose three interviews to code at random, after which the two coders reviewed the independently generated codes for consistency. Once all interviews were coded, results were refined and synthesized into broader thematic determinations. Quantitative, Likert-style questions were assessed using parametric summary statistics.

3. Results

3.1. Retrospective review of CCCIP content

In the CCCIP, content was initially (2018) planned for a total of 14 lectures across 6 courses (26). In the retrospective review of these lectures from 2020 to 2022, we found that the content was present in nine lectures (64%) across five courses (Table 2). The number and content of CCCIP lecture slides used in each lecture changed from year to year depending on lecturer preference. Interviews with course faculty revealed that CCCIP content was implemented in one lecture not originally included (Alzheimer's disease, *Brain and Behavior Course*). Content that was originally planned for another lecture (asthma, *Pulmonary Pathophysiology course*) was used initially, but was removed prior to the 2020–2021 academic year and therefore not included in this review.

3.2. Assessment of faculty experience

Interviews were conducted with seven of the nine recruited lecturers (including four of the five course directors) and with two of the six faculty members in medical education leadership. Faculty members were given unique identifiers A-I. The semi-structured interviews revealed several common ideas that were then organized into three major thematic umbrellas with regard to ensuring sustainable content development: (1) the necessity of centralization and a shared vision; (2) adequate professional development; and (3) assessment of student learning and of the content itself (Table 3). Coding comparisons revealed high inter-rater reliability. Barriers to general curriculum development and re-design had a high degree of consistency with those felt by the faculty involved in the CCCIP.

TABLE 1 Closed and open interview questions for the semi-structured interviews for the climate content evaluation.

Introductory questions	
	What is your field of practice—clinical practice and/or medical education focus?
	Do you feel that Climate Change is important in your field of medicine?
	Follow-up: How important (1–5, 5 being critically important)
	Is your specialty addressing climate change as a health issue?
Baseline questions for lecturers/course directors	
	Was the CCCIP information integrated in your lecture/s?
	Follow-up: Did the CCCIP slides feel like a natural fit with your existing slides?
	Did the CCCIP information come up in any other part of the course?
	Do you plan to continue to include the CCCIP information in your lecture/s?
	How comfortable were you in teaching the climate change content in your course? (1–5, 5 being very comfortable)
	Follow-up: Are there steps we can take to help faculty feel more empowered to teach this aspect of the curriculum?
	Do you believe that the students engaged with this aspect of the course content?
	Did you find anything particularly helpful in implementing this content?
	Did you face any challenges when implementing this content?
	How can we better support you in successfully implementing climate change in medicine material?
	With the upcoming curriculum redesign, do you see a place for cross-cutting topic threads like climate change and other SDOH?
	Do you have any further ideas for more successful implementation of this information?
Baseline questions for medical education faculty	
	What was your role in implementation of the CCCIP project?
	From your view in medical education, do you believe that the lectures given have impacted the way that the students view the impacts of climate change in medicine?
	How can we help our faculty to feel empowered to teach this content?
	Do you feel like there is room and opportunity to improve the CCCIP?
	What would you say, if any, are the institutional barriers to creating and implementing thematic course content across multiple courses?
	How can we approach sustainability of the course content delivery as lecturers and course directors may change?
	With the upcoming curriculum redesign, do you see a place for cross-cutting topic threads like climate change and other SDOH?

3.2.1. Shared vision

The most commonly cited challenge was the lack of centralization in terms of the organization of the content arc and access of the contributors and participants to the full plan. When the CCCIP began, permission was granted from course directors to include the slides into their course. Slides were given to individual lecturers to integrate into their existing content, but participants noted a lack of knowledge of the "bigger picture." Several faculty expressed the need for more visible leadership as well as an overt curricular map to provide context and to motivate them to present the material in a meaningful way. For example, one lecturer/course director (study participant C) noted that they "never heard if the content was implemented in other courses" and another lecturer (study participant E) thought that knowing what had been taught so far would make it easier to contextualize their piece of the curricular thread in relation to what had been taught about the topic in previous courses.

Themes discerned from conversations with faculty specifically involved in the upcoming curriculum redesign echoed similar themes to the lecturers and course directors. They further highlighted the need for comprehensive resources for proposed curriculum enhancements, with designs that involve a full educational arc:

> "It's so critical that we have a curriculum map and an inventory of where [the content] is taught and where it is assessed. It needs to be big picture: What's the arc?

TABLE 2 Results of the retrospective (2020–2022) review of CCCIP inclusion, presented in chronological order of content delivery through the 2 years of the pre-clerkship curriculum.

Course	Lecture topic for which the CCCIP was planned	School year of lecture presentation	CCCIP slides present in 2020–2021?	CCCIP slides present in 2021–2022?
The Art and Science of Medicine				
	Course introduction	Year 1	Yes, as a separate resource	Yes
	Obtaining an effective social history	Year 1	Yes	Yes
	Social determinants of health	Year 1	No	No
Immunology				
	Immunology of allergic responses	Year 1	Yes	Yes
Medical Microbiology				
	Bacterial biology and mechanisms	Year 1	Yes	Yes
	Bacterial GI pathogens	Year 1	Yes	Yes
	Vector-borne and zoonotic bacterial infections	Year 1	Yes	Yes
	Viral vector-borne infections and zoonoses	Year 1	Yes	Yes
	Global perspective	Year 1	Yes	Yes
Brain and Behavior: Neurology, Neuroanatomy, and Psychiatry				
	Child development	Year 2	No	No
	ADHD and autism	Year 2	No	No
	Nutritional and metabolic disorders of the CNS	Year 2	Lecture not given	Lecture not given
	Alzheimer's disease*	Year 2	Yes	Yes
Pulmonary Pathophysiology				
	Asthma	Year 2	No	No
Cardiovascular Pathophysiology				
	Cardiovascular disorders	Year 2	Lecture not given	Lecture not given

*CCCIP content for the Alzheimer's disease lecture was not originally reported in Kligler et al. (26), but was identified as a lecture with Information about the lecture topics having CCCIP lecture slides prepared for them is taken from Kligler et al. (26). This review investigated the presence of these lectures in the 2020–2021 and 2021–2022 curricula. CCCIP content by institutional memory and verified in interviews with course faculty.

> Where do we start from? And Where are we going?…Do folks have learning objectives throughout? Do we have assessments? Are there questions on any exams related to this? This is a very important database of information to have as you think through the curriculum going forward… Where is it actually meaningful?... It really is figuring out how do we ensure the long term retention of it for the students."
>
> - Medical education leadership (study participant I).

3.2.2. Faculty development

All but one of the interviewed faculty members agreed that climate change is important in their field, and in medicine in general (average = 3.75 on 5-point Likert scale; SD = 1.0206, median = 3.75). Reasons for this importance ranged from direct impacts on patient health, such as weather events impacting the ability of patients to receive care, to indirect impacts involving SDOH, with one lecturer/course director (study participant A) noting "people's social circumstances greatly affect whether they need intensive care." Those that described lower degrees of importance of climate change in their field noted that, to their knowledge, the question of its impact had not yet been addressed. Lecturers had various reasons for agreeing to include information about climate change and health in their material. Lecturers with connections to climate change outside of the CCCIP generally felt more comfort in developing the material. Some faculty had a personal interest in climate change: one lecturer/course director (study participant F) cited family members who work directly in the field and act as climate

TABLE 3 Codebook from faculty interviews with lecturers and course directors.

Identified theme*	Definition	Responses comprising the thematic designations: enablers of implementation	Responses comprising the thematic designation: challenges to implementation
Shared vision	The ability for all contributors and participants to see and understand the full arc of the content, including learning objectives, location of content, and assessment milestones.		Lack of centralized content arc
Faculty development	Educational support for faculty in increasing their ability to successfully deliver necessary content.	Faculty interest in climate change: personal reasons	Lack of faculty expertise
		Faculty interest in climate change: visibility during clinical practice	Fit of CCCIP content: forced
		Fit of CCCIP content: natural	
		Drivers for implementation: student involvement	
		Drivers for implementation: faculty buy-in	
Assessment	Measurable results of both student learning, in the form of summative assessment, and the content implementation, in the form of satisfying institutional or accreditation requirements.		Lack of summative assessment
			Lack of time and space in the curriculum

*Responses throughout interviews that touched on similar concepts were grouped together in "Identified themes."

change activists while another lecturer (study participant B) cited personal fears about the climate crisis outside of their occupation. Other faculty became invested in the health impacts of climate change through seeing it in their work. For example, one lecturer explained

> "I think . . . in my education [climate change] didn't play any role, so I think it was really when I was working on the ground and I was seeing the effect. . . I was seeing malaria epidemics were happening where, according to the books, they shouldn't have happened. . . [Climate change became important] when I really had contact with it and really saw the consequences."
>
> Lecturer (study participant D).

The role of students came up as an important topic throughout the interviews. One lecturer/course director (study participant C) noted that students in this generation "are more attuned to and more concerned with these issues," making climate change a comfortable and important topic to bring into lectures. The idea of students as drivers of content development was consistent throughout almost every interview. Many faculty cited the CCCIP initiative as essential in reminding faculty that these topics are important. One lecturer (study participant D) stated that "what you are doing is like lobbying, you just have to continue lobbying" and another lecturer (study participant B) noted that being brought the material by the research group was the first time they had thought about climate change as it relates to their field. Interviewees also identified buy-in from medical education faculty as an essential driver for content development and reform. Some faculty participants explained that support from higher level administrators would make them feel that the new content is necessary, that there is a network of support, and that their labor involved in curricular development is valued.

Comfort and expertise with climate change and health was variable across the lecturers (average = 3.50 on 5-point Likert scale; SD = 1.643, median = 4.0). Limited faculty development and time were noted as a substantial challenge for those who were less comfortable with the topic itself, noting a lack of "bandwidth in the midst of the course to incorporate new material" and that there was "no support, no one in charge was giving a presentation" (lecturer, study participant E) during the CCCIP. Expansion of faculty development around climate change and SDOH through experiences such as an educational development session, written faculty guide, annual event with expert speakers, or a learning module for faculty were cited as ways to improve faculty comfort.

The challenge of faculty expertise on climate change was also identified as a factor in feedback on the efficacy of the pre-made CCCIP slides. While about half of faculty members

felt that the CCCIP information fit "very well" into their existing course material, others noted that the slides felt "a little disjointed" or "like a post-script for the lecture rather than something that nicely tied it together" (lecturer/course director, study participant G). Positive attributes of the slides themselves included the recognizability of the banner (Figure 1) and the clarity of having info-graphic style slides. Faculty members had differing opinions about whether having the pre-made slides was helpful in incorporating the new information, or if providing the slides was a barrier to feeling ownership and confidence in the material. One lecturer (study participant E) believed that the pre-made slides were helpful noting that if we "had not given [them] the slides, [they] probably would not have included it" but that the ease of having slides allowed them to avoid exploring the topic further and including the concept in their own words, making the slide more of a "shortsighted solution." Overall, faculty motivation appears to be heterogeneous with lack of personal education as a substantial barrier to successful and motivated implementation.

3.2.3. Assessment

Assessment is a reflection of both student learning, in the form of summative assessment, and of the content implementation, in the form of institutional or accreditation requirements. Having these quantifiable assessments increases the pressure on institutions to include curricular topics and increases the pressure on students to internalize the content. The need for these outcomes in the success of any curriculum is clear when considering the frequently cited challenge of time and space constraints in medical education. One lecturer (study participant D) explained this challenge, saying "I think the problem is that medicine is always growing, but the time we have face to face with students never grows." Faculty on the medical education leadership team (study participant H) echoed this idea with the notion that "there are many topics that people are passionate about, but [when something is added] something has to come out." The upcoming curriculum reform plan for ISMMS includes changes to the mode of instruction, moving away from lecture-based learning toward more engaged learning modalities, which anticipates all courses having to confront the challenge of curricular space and prioritization:

> "Everybody is going to have to pull out what's been most critical… we are going to have to figure out how we fit those into small group discussions and case-based discussions…[we have to figure out if there] is stuff with climate change that is …self-taught that we can still require [and] assess, but …in a way where the students are not going to gloss over it."
>
> - Medical education leadership (study participant I).

Guidelines in the form of institutional requirements and summative assessment shape what continues to be included in medical education. None of the CCCIP information was included in course assessments to date. Several faculty members noted lack of assessment both at the school and the USMLE level as barriers to advocating for further development in this content area. Most faculty agreed that assessment is an important tool for learning. One lecturer/course director (study participant C) stated, "assessments should reflect what we think is most important for students to learn and to understand and I think that if we are not assessing that content that that's sending a message that it is maybe not that important." In terms of a message of importance coming from governing bodies of medical education, faculty cited the student and educator fixation on the NBME boards to dictate was content is emphasized:

> "There's so much major biomedical content that you have to have to get you ready for step 1 and the clinicals…a lot of this other [material]... the touchy-feely side of medicine…gets lost a bit."
>
> - Medical education leadership (study participant I).
>
> "we're not going to get any points for it…for accreditation because we're not assessing it. We're just saying we did something, but we really didn't do it. We didn't go through it in a meaningful way."
>
> - Medical education leadership (study participant I).

4. Discussion

The results of the retrospective review portion of this study show the longevity of the prior climate content integration at ISMMS, and the qualitative interview portion of this study serves to help cultivate an understanding of the reasons behind its mixed successes and failures. A majority of the CCCIP content that was created in 2018 was carried through to the 2021–2022 curriculum, but not all of it. This is consistent with the changing nature of curriculum and educational priorities (2). Two interesting changes to the pre-made CCCIP content noted in the interviews were 1) the removal from one lecture after having been in place the years prior, and 2) the addition of content to a lecture where it was not originally planned to be. First considerations of the removal of the content from a lecture may suggest that the content was deemed unimportant, but based on our conversations with lecturers, it may more likely reflect discomfort with the material and curricular time constraints. In a survey of 84 international health professional schools and programs, 71% of respondents indicated that they encountered challenges to instituting climate change content in their curriculum, with 24% indicating lack of teaching materials and expertise and 29% indicating no available space in the core

curriculum, similar to challenges identified in our conversations (30). On the other hand, addition of climate related content into an unplanned lecture may point to a sustainable impact of the CCCIP initiative on the faculty themselves. Teaching and learning are often thought to be intertwined processes that happen simultaneously and symbiotically (33). Teaching the CCCIP material may in turn serve to make the lecturer more aware and interested in the topic. This is consistent with the idea that the CCCIP initiative and the student involvement in the curriculum helped to drive content implementation that was present across multiple interviews. The idea of student lead initiatives as drivers of change in medical education is present both in institutions initiating climate change education (34–36) and across additional domains of educational reform, outreach services, and advocacy groups as students engage in extracurricular activities and research throughout their medical education (8, 37, 38). Student-faculty partnerships are integral to the development and sustainability of curricular changes and accountability in the health sector (36). While students may be able to take on some of the required work in facilitating learning, including creating learning materials, teaching their peers, and leading faculty development, the investment of faculty support, clinical expertise, and status in the institution is continuously necessary for the longevity of the initiative (35). When medical education and faculty embrace students as partners, they are able to become more invested in shaping their own education.

Active collaborations to organize student and faculty advocacy efforts can aid in the creation and development of future curricula at ISMMS and other institutions. International organizations (International Medical Education Collaboration on Climate and Sustainability, IMECCS; and the Global Consortium on Climate and Health Education, GCCHE), international initiatives (Planetary Health Report Card, PHRC; and the Association of Medical Education in Europe's Consensus Statement, AMEE), and national student networks (Medical Students for a Sustainable Future, MS4SF) offer extensive and overlapping resources for guidance on advocating for inclusion of content, content development, and an in-depth content repository of content (summarized in Figure 2).

Three key barriers to successful and sustainable content integration in the CCCIP arose from conversations with faculty: Lack of a shared vision for the content arc, inadequate faculty development, and failure to incorporate assessment. These essential elements of content design were echoed by the medical education faculty preparing to implement the new curriculum. The overall challenges faced by the ISMMS faculty in implementing the CCCIP curriculum match those seen in other institutions (30). When looking across institutions, it is clear that the efforts to improve an institution's climate literacy is never without its challenges. The PHRC provides an interesting look into the relative efficacy of climate curricula and additional aspects of sustainability and climate consciousness at different institutions. The results of the first year (2019–2020) of the PHRC indicated that zero out of the 13 participating institutions received an "A" grade (80% of possible points) and the results of the second year (2020–2021) indicated that only one institution, Emory University (Atlanta, GA, USA) out of 62 medical schools in five countries received an "A-" (40). These results indicate that significant improvement is still needed across all participating institutions (41).

Overall, we found that a transparent and intentional approach to implementation involving accessible content mapping, faculty education, and formal assessment of related content may help to improve the overall knowledge base of the institution and its students. These findings are consistent with the some of the important points in the six-step approach to curriculum development in medical education. The six-steps include "performing a needs assessment, determining and prioritizing content, writing goals and objectives, selecting teaching/educational strategies, implementation of the curriculum, and evaluation and application of lessons learned" (42, 43). Without clear content mapping with a shared vision, faculty development, and formal assessment, these steps cannot be met.

Following the upcoming shift away from primarily lecture-based education, aspects of how content is best delivered at ISMMS, including climate change and health education, may need to be re-thought. As this research explores the CCCIP at ISMMS as it relates to the imminent curricular redesign, it can have national relevance as a case study for other medical schools. Institutions aiming to integrate climate and health education, and advocacy groups with hopes of empowering their institutions to do so, must be able to develop and promote these content initiatives in the context of wider curriculum development.

LCME guidelines create unique opportunities for climate change and other topics surrounding SDOH to provide enhancement of real-world applications of the scientific basis of medical education (13). With these guidelines, there has been a growing interest in teaching SDOH in medical education (44), a change that can both serve to highlight the importance of these issues in health and health inequity, and help to fulfill the accreditation requirements of the institution. While climate change impacts and exacerbates existing inequities of SDOH (*What is Climate Change?*), the reality of climate change as a present and imminent threat to the health and lives of the population may be better stressed by separating it from SDOH and focusing on ecologic determinants of health, such as air and ocean pollution, global warming, and declining biodiversity (45). This approach is also more holistic in examining the impact of the health of the planet on human and community wellbeing at a systems level, including more comprehensive factors, such as "ecological, social, cultural, and intergenerational determinants of health" and encouraging participation of community, policy, and indigenous programs outside of the health sector to inform perspectives (45). As the emphasis of medical curricula shifts to

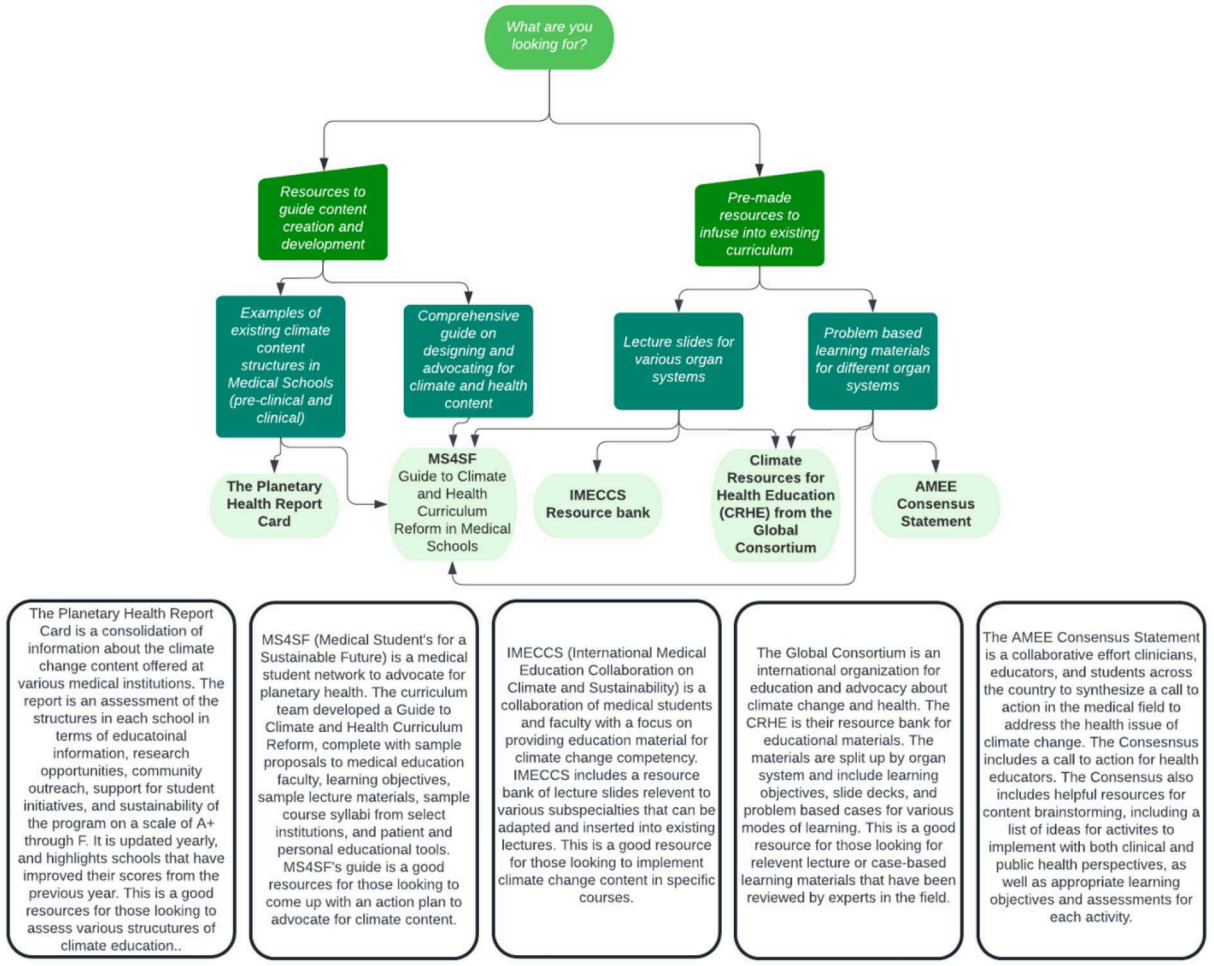

FIGURE 2
A guide for the various available resources for climate change content development and implementation [graphic created by Lucy Greenwald with information sourced from https://phreportcard.org/, https://ms4sf.org/, https://www.imeccs.org/, https://climatehealthed.org/, and (39)].

highlight the patient in context, individuals' social and physical environments play an even larger role in health (46).

At ISMMS, the LCME guided "societal problems" will be integrated in six threads throughout the curricular arc. These threads have already been chosen as an extension of the named priorities of the institution: Scholarly Discovery, Advocacy, Social Justice and Anti-Oppression, Healthcare Delivery Science, Medical Decision-Making, and Leadership and Professional Identity Formation. Climate change is included under the umbrella of "Advocacy, Social Justice, and Anti-Oppression." Some possibilities for the future of the CCCIP include a pre-clerkship informal extra-curricular elective, a clerkship elective course, generating fully developed problem-based learning cases to be integrated in pre-curriculum courses, and continued advocacy for climate literacy of all faculty at the institution, integrating faculty development across subspecialties.

4.1. Limitations

The major limitation of this study was that we reviewed only one medical school's climate content. Additionally, we only reviewed the content from faculty involved in the first 2 years of the pre-clinical curriculum. Additional institutions and inclusion of faculty with greater diversity of educator experiences of climate content would be needed to make the conclusions generalizable to the public. Nevertheless, we were able to have meaningful conversations with faculty at each level of leadership in the curriculum that provided valuable information to consider.

5. Conclusions

From the retrospective review and qualitative interviews with faculty involved with delivering climate change content,

we identified key steps that are needed to implement successful and sustainable curricula. It is necessary to stay active and continue to build fully realized curricula with the help of available resources, especially in the current period of reviewing and revitalizing medical education. Advocates must engage medical education deans and faculty to assure that there is higher-level understanding of the importance of this education. Further advocacy must extend beyond the institutional level to national networks of decision makers in medical education standards (USMLE, LCME, and AAMC). Climate and health literacy must be on the radar of all those with the power to make curricular decisions for the benefit of all current and future physicians and patients. Providers have direct access to communities, and therefore unique opportunities to recognize climate change and prepare patients for its effects. As respected members of society who are first-hand witnesses to the effects of the crisis, physicians must take active roles in preventing its worst effects by advocating for more robust climate action—specifically reducing healthcare sector carbon emissions and building climate resilient health systems. As a society we have begun to become numb to the devastating effects of catastrophes that we encounter every day (47). We must remember that climate change is here, it is impacting our health, and it is accelerating.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Ethics statement

Studies involving human participants are reviewed and approved by the Icahn School of Medicine at Mount Sinai IRB. This study was reviewed by the IRB and deemed exempt. The participants were provided the study information and gave verbal consent prior to the start of the interviews.

Author contributions

LG, OB, and PS conceived of the research idea and participated in data collection and analysis. LG wrote the manuscript with supervision from PS and editing from OB. CH provided expertise in LCME and accreditation requirements and reviewed and edited the manuscript. All authors discussed the results and helped shape the final product.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Improving the capacity and diversity of local public health workforce to address climate impacts to health through community partnerships and problem-based learning

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All aspects of society are affected by our changing climate. Individuals and communities experience the health impacts associated with climate change most every day, whether or not they realize it. Increasing both the knowledge and capacity to respond to the health impacts of climate change will be imperative for future public health leaders. This manuscript will highlight three case studies in how problem-based learning was used by California State University, East Bay's Department of Public Health undergraduate students to address climate change issues for local community and government organizations. The results from problem-based learning collaborations between undergraduate students and community and government organizations have been mutually beneficial and increased the knowledge and workforce capacity of climate and health in the San Francisco Bay Area. The authors believe the use of problem-based learning is an effective model to achieve these goals. Both the students and the community benefit from these experiences and results of projects that enhance an organization's ability to prepare for and respond to climate change in their communities.

KEYWORDS

climate change, health, undergraduate, problem-based learning, workforce

Introduction

Global climate change continues to have significant impacts on human health. All aspects of society are affected by our changing climate (1). Individuals and communities experience the health impacts associated with climate change in their everyday lives ranging from direct exposure to extreme heat events, to rising food prices due to droughts in agricultural regions. Although the connection between climate and health has been studied and documented extensively, there continues to be a disconnect among individuals about how climate change impacts people directly in the here and now (2, 3). There has been little coordination among institutions of higher learning and development of programs to address this need (4). Only recently, formalized curriculum and programs have been established, particularly in schools and programs of public health (5–7). Many of the significant advancements in medical school education around the topic of climate and health have been advocated and requested by medical students (8, 9). However, these efforts have been quite sporadic and limited for undergraduate students and their education (10). Given the continued threat of climate change on society, particularly on human health, it will be imperative that not only clinicians but all health professionals be educated on this topic. Improvements in climate literacy, particularly when it

comes to climate change impacts to health, are needed among both the larger population and public health professionals (11). One important way of improving climate literacy is through our formal education systems: K-12, undergraduate, and graduate programs. In particular, emphasis should be placed on climate and health education among pre-professionals in healthcare, public health, and other allied health fields due to the lasting impacts of changing climate on the health of individuals. Increasing both the knowledge and capacity to respond to the health impacts of climate change will be imperative for future public health leaders. Substantive investment in basic climate knowledge and climate change impacts to human health will be needed to advance our preparation for and response to climate hazards. Next to clinicians, public health professionals provide trusted voices and essential roles in combating the negative health impacts of climate change (12). To achieve this, it will be important to expand climate and health education into institutions of higher education, particularly at the undergraduate level where a significant portion of public health and allied health professionals obtain their education (13). It is also important to realize that this expansion cannot happen overnight. These changes may require new degree pathways, curricula, or pedagogical methods to inform and reinforce knowledge for climate and health education.

It is of utmost importance to integrate climate and health education into course and program learning objectives. In addition, rather than having a standalone course that provides a broad overview of climate change, engaging with climate and health related content in courses that pertain to social determinants of health, epidemiological methods, or health communication promotes deeper understanding of the specific ways that climate change influences health. Traditionally, undergraduate education has been centered on content based lectures from instructor to students, with assessment *via* quizzes and tests and a greater emphasis on knowledge assimilation and recall. Students often have a few discussion based courses where the exchange and clarification of content involving critical analysis and thinking occurs between instructor and students (14) in the classroom or *via* reflective essays and assignments. However, outside of internships or service-learning courses (i.e., courses that have an academic component in the classroom and an applied learning component outside the classroom), undergraduate students are likely to have participated in predominantly classroom learning during their college education.

To address the complex issues associated with climate change and to better prepare future leaders a more "hands-on" approach is needed to advance critical thinking and problem solving for issues related to climate change. One approach to increasing knowledge and action is through problem-based learning (PBL), which allows students to engage in "real-world" problem-solving opportunities through collaborative work with mentors and stakeholders which can be practiced in the classroom or through hands-on approaches in community settings (15). PBL has been shown to increase learning outcomes and long-term knowledge retention compared to traditional pedagogical methods (16). PBL has been used most often in medical education and law school with only a few examples of successful implementation in undergraduate public health education. Students and practitioners of public health have an opportunity to get involved in issues that impact local communities by engaging in PBL that provides applicable skills and knowledge to better address complex health issues associated with climate impacts. This manuscript will highlight three case studies in how hands-on problem-based learning was used by Cal State East Bay's Department of Public Health undergraduate students to address climate change issues for local community and government organizations.

Context

Cal State East Bay is one of the most racially and ethnically diverse campuses in the US. It is also designated a Hispanic Serving Institution and Asian Americans and Native American Pacific Islanders Serving Institution. The Department of Public Health's student body reflects the University's student body as well as that of the surrounding community. The Department is committed to social justice and it values engagement and building collaborative partnerships between faculty, students, and community organizations. The climate crisis is of particular concern for vulnerable communities who are likely to bear the greatest burden. The Public Health capstone course in the Department of Public Health at Cal State East Bay, which is also the culminating course in the Problem Based Learning 3-course series, provides students with opportunities to work closely with community partners. In this culminating experience, leaders from community organizations identify a substantial health challenge or issue they are facing and work collaboratively with course instructors to formulate problems that students, in teams of six, advance solutions toward using their cumulative knowledge and lived experiences. This experience helps students integrate their public health knowledge and build on their critical thinking, problem solving, and team building skills. The Department of Public Health has partnered with over 15 organizations over the past 4 years and provided capacity, services, and knowledge to the community and public health organizations all while furthering the education and skills for undergraduate public health students. Some examples of projects include increasing awareness and capacity in the local health department for LGBTQ+ family planning, developing outreach and communication plans to get non-native English speakers vaccinated against COVID-19, and improving community knowledge on the benefits of urban agriculture and increased access to health foods in urban food deserts, etc. Increasingly though, climate change has been at the forefront of topics that organizations want to address, but have traditionally lacked the knowledge and/or capacity to achieve their desired outcomes. Faculty in the Department of Public Health has used this opportunity to engage with community partners to integrate climate and health issues in the capstone class. Three projects completed in the last year are detailed below.

Details: Community case studies on climate and health education

Case study—City of Oakland emergency services

The Department of Public Health at Cal State East Bay and the Communities of Oakland Respond to Emergencies (CORE) program, run by the City of Oakland in California have had a standing partnership for educating students at Cal State East Bay on emergency preparedness. The CORE program is a locally organized version of the Federal Emergency Management Agency's

(FEMA's) Community Emergency Response Team (CERT) program. In the spring semester of 2019, CORE partnered with students from the Department of Public Health's capstone course. The students were tasked with adding workforce capacity and subject matter expertise to support CORE's program for Oakland. For background, the CORE program was partnering with the local Red Cross to assess the state of Oakland's emergency shelter system. This was in response to the devastating 2018 wildfire season, which included the deadly Camp Fire where 85 people lost their lives and was the deadliest wildfire season in recent California history (17). Because the California wildfire season is getting longer and the frequency, size, and intensity of wildfires are increasing, emergency preparedness programs like CORE need to be ready to house evacuated and displaced populations. The CORE program relies on volunteer relief organizations like the Red Cross to facilitate and support evacuation centers, though CORE manages the administrative process of securing buildings to use as evacuation shelters.

Students used the National Shelter System database (NSS) to identify shelter locations, performed site visits, and used criteria in the Shelter Facility Survey developed by the Red Cross to identify deficiencies and areas for improvement needed for the shelter to house communities impacted by hazards and disasters. Many of these shelters had not been inspected for over a decade and most did not meet the criteria outlined in the Shelter Facility Survey. With this data students were tasked with assessing the specific needs of the population of Oakland through analysis of census data and other socioeconomic indicators such as disability status, homelessness, and medical vulnerabilities. This analysis was combined with a geospatial analysis of high risk locations associated with climate hazards, such as wildfires and flooding events, and the specific locations of shelters to assess needs of the community.

Students developed a recommendation report from the data gathered from the survey, the analysis of secondary data from socioeconomic indicators, along with the geospatial analysis. The students then presented this report which identified recommendations on increasing shelter capacity, accessibility, and safety and improving dedicated funding to shelter systems to the CORE program and the Red Cross. This product provided guidance to CORE and the Red Cross to develop actionable tasks to ultimately address improvements. Two students who worked on this capstone project were hired as contractors soon after the course was completed to work on these shelter improvement projects.

Case study—Community collaboration and climate vulnerabilities

The Department of Public Health at Cal State East Bay worked with the University of California San Francisco (UCSF) and community groups in the Bayview-Hunters Point (BVHP) neighborhood of San Francisco. UCSF is a large medical university that does not have undergraduate programs. Most academic programs at UCSF are clinically based with some Masters programs in Public Health. UCSF is also situated at the border of the BVHP neighborhood. This community carries most of the burden of San Francisco's pollution. Located in southeast San Francisco, residents are surrounded by considerable environmental threats, including a superfund site known as the US Navy's Hunters Point Naval Shipyard. In the spring semester of 2022, UCSF and BVHP formed a working group to leverage resources in hopes of addressing challenges that the neighborhood has been facing. Students from Cal State East Bay's Department of Public Health capstone course were enlisted to provide capacity and subject matter expertise to initiate projects and lay the foundation for collaborations that were needed to address environmental and climate issues the community was interested in addressing.

The first task of the project was centered on recommendations on how to bring UCSF, BVHP, and the City of San Francisco together to address community concerns since each group had been working on their own within this neighborhood. It was felt by residents that no one was listening to them and that UCSF and the City of San Francisco had their own agenda for the neighborhood without thought of community members, particularly around land use and urban development. Additionally, there were trust issues between the community and UCSF and how environmental clean-up operations were going because of incidents of falsified environmental reports and conflicts of interest among subject matter experts from UCSF (18, 19). Similar recommendations were needed to build an effective community advisory council at the city level. While there was an appointed advisory council, there was limited communication between community members and the advisory council.

The second task was to assess the community vulnerability to climate hazards. Bayview-Hunters Point has a long history of environmental pollution and community groups have been concerned about how current and impending climate hazards such as heat waves and sea-level rise would impact these polluted sites and the residents. Using a vulnerability assessment framework, students developed a report on the current and future climate impacts to BVHP. In order to successfully use this information, the other projects focused on communication and outreach plans for BVHP to engage with government officials and UCSF to initiate discussions on how to build climate resilience within the community. A plan was developed on a more equitable community advisory council between the main stakeholders in the BVHP community, the City of San Francisco and other government agencies that had oversight into climate adaptation and resiliency in this location. These products and plans facilitated community engagement on climate adaptation and resiliency planning within the BVHP community. It allowed the community to have additional resources and evidence to advocate for these changes. This opportunity provided UCSF with a community-based view point on how collaborations and partnerships can work among the BVHP community.

Case study—City of Hayward environmental justice and climate action plan

In the spring semester of 2022, the City of Hayward was in the process of updating components of its General Plan, a planning document that provides a city or county with a policy framework to guide decision-making related to land use, growth and development, safety, and open space conservation. In particular, one of the updates was the creation of an Environmental Justice Element, which is a set of goals and policies that addresses health risks in disadvantaged communities and prioritizes improvements to achieve more equitable engagement with better health outcomes. One of the goals of the

City of Hayward was to engage with community members to identify problems that have previously been left unaddressed. Working in the intersection of Environmental Justice and Public Health, Cal State East Bay students were tasked with helping the City of Hayward on four focus areas: (1) Access to clean air, (2) Access to healthy foods, (3) Access to safe and sanitary housing; and (4) Access to physical activity and recreation. Each of these projects is described in greater detail below.

One student team completed basic research to have a fundamental understanding of the problem associated with pollution burden. In 2021, Alameda County did not meet state standards for air pollutants PM2.5 and Ozone. As with many cities in Alameda County, the city of Hayward has a relatively high amount of PM2.5 in relation to other California census tracts. The student team explored the CalEnviroScreen tool to visualize the impact of traffic and pollution on the City of Hayward. They also created a survey on resident's knowledge about air pollution and administered it to residents, and incorporated the results to create policy recommendations for the City of Hayward.

The second team looked into "Access to healthy food" as a key determinant of positive health outcomes and adequate quality of life. Historically, low-income communities and communities of color have been disproportionately impacted by lack of access to healthier foods. After initial research on food access and food insecurity, the student group used the Policy Map tool to visualize SNAP retail locations and percentage of families receiving food stamps/SNAP benefits in Hayward. They created a campaign to raise awareness about the CalFresh/EBT/Pandemic EBT (electronic benefits) programs available at the Hayward Farmer's Market and surveyed residents about their access to nutritious food choices. Using these results, the team submitted policy recommendations for the City of Hayward.

The quality of housing in a community has a direct health impact on the people who reside within those homes. Low-income households disproportionately experience severe housing problems. These housing problems include physical defects to a unit, overcrowded conditions, and housing cost burden. In Hayward, ~80 percent of extremely low-income and 75 percent of very low-income households had one or more housing problems. The third student team working on this topic surveyed residents in Hayward about their living situation. They created a campaign to raise awareness about existing rebate programs for Hayward residents to create healthier homes and lower their energy bills. The student team recommended policies that might improve Hayward residents' access to safe and sanitary housing after researching existing policies that have been brought to City of Hayward City Council and reviewing policy measures that have been successfully implemented in other jurisdictions.

Access to public facilities and resources is a critical environmental determinant of health. According to the California Department of Parks and Recreation's Park Access Tool, 76 percent of residents in Hayward live in areas with <3 acres of parks or open space per 1,000 residents. This indicates that 76 percent of residents in Hayward live in underserved areas for park access. The fourth student team created a resource matrix of services, programs, and offerings including parks, recreation centers, community programs, walking/hiking trails, bike paths, and other active transportation. They created a survey to understand how residents utilize the current services, programs, and offerings, as well as what they wish were different and any suggestions they may have. Based on the resource matrix and survey, the group provided policy recommendations to the City of Hayward to improve access to physical activity and recreation.

Discussion

The results from problem-based learning and hands-on collaborations between undergraduate students and community and government organizations have been mutually beneficial and increased the knowledge and workforce capacity of climate and health work in the San Francisco Bay Area. This benefits students by giving them an opportunity to apply their topical knowledge to practical public health issues related to climate change. It also expands student knowledge on the implications that climate change will have on human health and the systemic issues this will likely cause to our public health and health care systems. By having climate and health program learning outcomes for undergraduates in Public Health majors, it helps to increase knowledge and workforce capacity to address current and future climate and health issues. In the case studies discussed, the immediate result for students has been either a paid internship or full-time employment opportunity for students to transition into the public health workforce, continuing or advancing projects on climate and health.

Partner organizations in these case studies were unable to initiate or complete projects because of the lack of knowledge, workers, or other resources. As climate hazards increase in frequency and intensity, local government and community-based organizations that serve impacted communities need to improve adaptive and resiliency measures. We know from past studies that providing public health services centered on climate change have been lacking. A survey from the National Association of County and City Health Officials (NACCHO) indicated that 80% of local health department directors said climate change is impacting their work but they lack expertise in their agency to respond and that the lack of resources prevented effecting programming in this area (20). Job postings mentioning "climate change" and "public health" have been increasing (21), though the question to ask is have we prepared our public health students and workforce to meet this demand?

While 2022 brought about advances in both Federal funding, through the Build Back Better Act and Infrastructure Investment and Jobs Act, and a number of sweeping climate measures in the state of California, knowledgeable workers will be needed to help fulfill these commitments to climate adaptation, mitigation, and resiliency. In the case studies discussed, the partnerships between Cal State East Bay's Department of Public Health, and local government and community organizations exemplify how knowledge and capacity from undergraduate students in Public Health were able to fulfill the needs of partner organizations on the topic of climate and health. The results of these projects have allowed partner organizations to either completely achieve their goals or move them closer to meeting these goals.

The authors believe that the use of problem-based learning, as a practical application, and community partnerships that contribute to improving the capacity and knowledge that address health threats associated with climate change is a key factor in preparing future public health leadership to equip communities for climate change. Additionally, having climate and health learning objectives

in undergraduate programs will help to sustain student knowledge as they progress through their programs and majors. For the Department of Public Health at Cal State East Bay, this is made possible by dedicated and strong leadership for climate and health education among the faculty. Most public health and health-related undergraduate majors do not have requirements through accreditation bodies for climate and health topics, and recent assessments of courses and programs on climate change and health education are for graduate programs (22, 23). Though organizations like APHA and Columbia University's Global Consortium of Climate and Health Education have called for such and developed their own competencies. As noted above, there has been substantive engagement from medical students to include climate and health topics in medical school education, though there has not been an organized approach for public health, particularly at the undergraduate level. While there is an accrediting body for undergraduate and graduate public health programs, the Council on Education for Public Health (CEPH), curriculum and competencies do not require the topic of climate change to be addressed as CEPH allows programs the flexibility of having different topical material, like climate change and health, be introduced into skills-based competencies (24).

The Department of Public Health at Cal State East Bay has been successful in building partnerships with local government agencies and community organizations. This foundation has strengthened the problem-based learning curriculum used for climate and health education and can be a model for other public health programs. The program is still evolving and refining its approach is not without its challenges. First, as with other undergraduate programs, students are still building expertise in their areas of study. The authors found that students would benefit from more topical content on climate and health to help navigate them through the research portion of the problem-based learning projects. Adding required readings and resources can help with the process and add more clarity and knowledge for students. Second, clear expectations on the deliverables are needed, facilitated by the partner organization. When final deliverables were not clearly structured with specific goals and milestones, students had difficulty developing final products and reaching conclusions. Third, problem-based learning can be resource intensive in a large undergraduate program, as a low student-faculty ratio is needed to successfully guide students in their group projects. Similarly, problem-based learning is not often used at the undergraduate level and devoting time and resources to help students become comfortable with this pedagogical method is resource intensive.

As climate change continues to impact the health of individuals and communities, effective preparedness and responses will be needed to protect human health. The authors believe that integrating climate and health education in the undergraduate education of Public Health majors is a key factor for increasing both community and workforce knowledge on these topics. Additionally, the authors believe the use of problem-based learning is an effective model to achieve these goals. Both the students and the community benefit from these experiences and results of projects that enhance an organization's ability to prepare for and respond to climate change in their communities. The authors acknowledge that this requires strong leadership and the necessary knowledge of the faculty and university, but the benefits to increasing the public health workforce with climate and health educated workers will be substantially beneficial given our current and future outlook on local and global impacts of climate change.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Climate and health capacity building for health professionals in the Caribbean: A pilot course

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Climate change is a reality in the Caribbean and its effects are already harming health, yet the health workforce capacity to implement climate mitigation and adaptation measures is lacking. From March-May of 2022, a free, live-virtual, evidence and competency based 10-week climate and health course targeted toward health risks in the Caribbean was deployed to: (1) increase communication about climate and health, (2) equip health professionals with knowledge and skills that could be readily incorporated into practice, and (3) engage health professionals with climate and health initiatives within their communities. Participants in this course came from 37 countries, 10 different health-related fields, and five different general places of work. Longitudinal surveys revealed significant changes in health professional communication, engagement and application of climate and health knowledge and skills. Live-virtual, evidence and competency-based courses, regional-specific courses have the potential to change health professional behaviors toward addressing climate impacts on health.

KEYWORDS

climate and health education, health profession courses, Caribbean, vulnerability, evaluation

Introduction

Climate change is a health issue that affects morbidity, mortality, and society's abilities to deliver healthcare and support healthy living. The effects of climate change are already harming health in the Caribbean region and impacts will only intensify in the coming years (1). Within the region, heat waves, hurricanes and rainstorms are becoming more deadly (2), disease outbreaks last longer and are seen in new regions (3–6), wildfire smoke and Saharan dust reduces air quality (7, 8), and food and water security are threatened by extreme weather and floods (9). The Caribbean community of nations, all classified as Small Island Developing States (SIDS), will face escalating risks with the changing climate, placing the provision of health care and the prevention of communicable and non-communicable diseases in jeopardy. The Caribbean SIDS include low-lying coastal countries like Guyana, Suriname, and Belize which share similar sustainable development challenges, including small populations, limited resources, and susceptibility to climate change.

The ability to preserve and protect health in the Caribbean is further complicated by insufficient research into the substantive health impacts from climate change in the region and a lack of evidence-based actions to prevent and prepare against these health impacts (10). Furthermore, while climate change adversely impacts health in many ways, the health system globally contributes an estimated 4.4% of global carbon emissions, with energy generation and distribution being the largest contributor. Switching to renewables such as solar power in health facilities would help reduce operational costs, cut carbon emissions, and ensure continuity of critical patient care services in the event of extreme weather and blackouts. There is an imperative for quick action on many fronts: to prevent climate change at its source by reducing heat-trapping greenhouse gas emissions; to increase the research base regarding the impacts of climate change on the health of Caribbean populations, to recognize, prevent and respond to climate-health impacts at individual and population levels; to build climate resilient and low carbon health systems and to communicate effectively about these issues for the sake of safeguarding human health.

Health professionals occupy a critical position in the response to climate change. First, they are charged with protecting individual and community health in the face of multiple new and compounding health risks that will become more costly and complicated to address as time goes on. For example, Public Health professionals will be tasked with creating vulnerability assessments to and performing impacts assessments resulting from climate-related events. Clinical health professionals will increasingly care for patients whose disease processes are caused or accelerated by climate change and will be tasked with counseling and treating these individuals as well as readying healthcare systems to cope with increasing burdens of disease (11).

Second, health professional expertise must be brought to bear on cross-sectoral solutions to the climate crisis, and to articulate climate risks and solutions to patients, the public and policy makers. Third, the institutional knowledge of health professionals is indispensable in modifying health systems and communities to become both resilient to climate threats and environmentally sustainable (12). However, as climate change is currently outside of the traditional training and continual professional development of the health workforce, few have the skills and expertise to effectively fill these critical new health professional roles that are essential to protect health in the face of the climate crisis.

Several Caribbean ministries of health, in partnership with the World Health Organization, have performed national climate vulnerability assessments and identified training health professionals, as a means to strengthen health systems, a priority (13–16). Furthermore, researchers, students, and other professionals have identified a need for improved climate and health education in professional training. (17). However, there have been limited efforts to standardize content or ensure that educational efforts change practical actions, especially in the Caribbean region. To address this gap, The Caribbean Climate and Health Responder Course was developed through a partnership between EarthMedic and EarthNurse (EM&EN), the Caribbean Institute for Meteorology and Hydrology and the Global Consortium on Climate and Health Education (GCCHE), with an aim to increase climate and health knowledge, skills, communication, and action that reflect the crucial emerging roles of health professionals within the Caribbean.

Specifically, the goal of this course was to: (1) Increase health professional communication about climate and health, (2) equip health professionals with knowledge and skills that could be readily incorporated into practice, and (3) engage health professionals with climate and health initiatives within their communities. To evaluate the effectiveness of the course in meeting the stated goals, we conducted a longitudinal study of course participants, to evaluate whether the 15-h live-virtual course has the potential to increase health professional capacity to address climate and health threats.

Methods

Program structure

The curricular foundation of this educational initiative was the GCCHE core competencies for health professionals (18), a set of highly-vetted global educational standards which cover climate and health analytic skills and knowledge, communication and collaboration, policy, and public health and clinical practice competencies (17). These competencies were divided into 10 discrete modules (see Appendix 1), each with predetermined learning objectives, which were adapted from the GCCHE competencies by regional experts to meet specific climate and health risks in the Caribbean. The course consisted of two parts:

1) Weekly 60-min core didactic lectures followed by 30 min of moderated question and answer.
2) Bi-monthly, interactive, 90-min "skills and practice" sessions.

All lectures were delivered by local and regional climate and health experts and had accompanying online reading and learning resources. Prior to the course, the expert faculty received a 1-h orientation to the curriculum and the expectations of the course participants. In addition to the 10 core didactic sessions, participants had the option to participate in bi-monthly "skills and practice" sessions, structured around clinical cases, climate tools, communication and leadership strategies, and teaching tools (Appendix 1). On enrollment, all participants received the course syllabus, a resource bank and recommended readings for each session and lecture slides, to jumpstart their climate and health practice. Participants who successfully completed 70% of the didactic training sessions (at least seven sessions) and passed a short test at the end of the 10-week training (with a score of 70% or greater), received a *Climate and Health Responder Certificate of Participation.* Continuing Medical Education Credit was provided by the American Association of Continuing Education (AACME) through the Trinidad and Tobago Medical Association.

Intended audience

This educational initiative aimed to engage physicians, nurses, allied health professionals, national or local public health workers, hospital administrators, health system leaders, health educators, policymakers, environmental health professionals and government officials. Members of these groups were invited to

participate through outreach *via* email and social media to both individuals and groups representing these professions. Outreach and promotion were also done through a promotional video sent to direct contacts with presidents of medical and nursing associations, Chief Medical officers of nation-states within the Caribbean community, regional academic universities, and Pan American Health Organization offices. Regional and global outreach was done through organizations with a focus on health, including the Caribbean Public Health Agency (CARPHA), Healthy Caribbean Coalition (HCC), Caribbean Community Climate Change Center (5Cs) and the Global Climate and Health Alliance (GCHA).

Recruitment and enrollment

All participants who registered for the course were invited to enroll in the longitudinal study. A pre-course survey was sent *via* email on the first day of the course, using the Qualtrics platform, to all course participants using contact information obtained through Zoom registration. Survey participation was entirely voluntary, however, to increase follow-up, reminders were sent *via* Qualtrics to non-responders. On the last day of the course, all registrants who attended at least one session were sent an email through Qualtrics inviting them to participate in a post-course survey. Response data was collected in Qualtrics and was anonymized before being analyzed. Demographic information (country of residence, occupation, place of work) for each participant who enrolled in the study was obtained from registration information. Only those who attended $\geq$1 class (demonstrated through Zoom attendance) were counted as "Registered." Study protocol was approved by Columbia University Institutional Review Board (AAAR4912).

Course participation

Course participation was recorded in Zoom and made available to the study team following each session. Participation was counted regardless of the duration of attendance for each session. Each session was recorded and immediately posted following each session. Individual asynchronous participation or viewing of course was not tracked.

Survey description

The longitudinal survey was structured to assess the effectiveness of this training course in affecting professional behavior related to climate and health communication, application of climate and health knowledge skills and engagement or action to address climate and health risks to health.

Communication

Survey participants were assessed before and after the course to the degree to which they communicated with patients, community members, and colleagues about the risks of climate change to health. Multiple choice options of frequently, sometimes, rarely, and never were presented.

Application

Survey participants were assessed before and after the course regarding the degree to which they incorporated climate change and health knowledge and skills in their professional work environment. Multiple choice options of frequently, sometimes, rarely, and never were presented.

Engagement

Survey participants were asked before and after the course how confident they felt that they could engage with a climate and health initiative within their community, institution, or professional area of practice. Multiple choice options of very confident, somewhat confident, not very confident, and definitely not confident were presented.

Post-survey questionnaire

The post-course questionnaire included further questions asking for participants to reflect on the effectiveness of the course, how the course may change their practice, their ability to lead adaptation and mitigation initiatives in their communities, and their ability to train other professionals on climate change and health impacts among others (see Appendix 2).

Analysis

All data from registration, course participation, and both pre- and post-surveys were organized and analyzed using R Studio. For each longitudinal survey question, we calculated the percent change in response for each of the predetermined multiple-choice responses. The number of respondents to each possible answer and total number of respondents was used to calculate percent responses to each question in the pre- and post-surveys. Following these calculations, the pre-course survey percentages and participant numbers were subtracted from post-course survey percentages and participant numbers for each question. This was listed as the "Change" in question and represents the impact of the course on participant responses. Only survey participants who completed both surveys were included in the analysis.

Results

Demographics and participation

Participants in this course came from 37 countries, 10 different health-related fields, and five different general places of work (Tables 1–3). The majority of the registered participants were from Jamaica, the United States of America, Trinidad and Tobago, Guyana and the Bahamas. The most common professions represented were physicians and

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TABLE 1 Country of residence of course registrants and survey participants.

Country	Registered	Survey participants	Country	Registered	Survey participants
Jamaica	124	10	Peru	3	0
United States	116	19	Dominica	2	0
Trinidad and Tobago	84	18	Australia	1	1
Guyana	72	15	Cayman Islands	1	1
Bahamas	50	12	Nepal	1	1
Antigua and Barbuda	45	9	Argentina	1	0
Barbados	44	8	Bolivia	1	0
Saint Lucia	34	6	Columbia	1	0
Suriname	28	10	Ecuador	1	0
Grenada	20	6	Fiji	1	0
Haiti	20	1	Jordan	1	0
Puerto Rico	13	3	Malaysia	1	0
Belize	12	4	Mexico	1	0
Virgin Islands (British)	8	2	Montserrat	1	0
Canada	7	1	Netherlands	1	0
United Kingdom	6	1	Nigeria	1	0
Saint Kitts and Nevis	4	1	Saint Vincent and the Grenadines	1	0
Spain	4	1	Turks and Caicos Islands	1	0
Philippines	4	0	Virgin Islands (US)	1	0
Brazil	3	0	Not available	44	2

TABLE 2 Reported occupation of course registrants and survey participants.

Occupation	Registered	Survey participants
Medic/physician	147	33
Environmental health	147	18
Other	117	15
Nurse	100	21
Student	85	15
Public health practitioner	84	14
Mental health	42	5
Emergency responder	22	3
Social worker	13	3
Retired	4	3
Pharmacist	3	2

TABLE 3 Location of work of course registrants and survey participants.

Place of Work	Registered	Survey participants
Governmental agency	335	60
Academic	153	21
Hospital	134	24
Private practice	77	16
CBO/NGO	65	11

environmental professionals, followed by nurses, and public health practitioners. Nearly half of participants worked for a governmental agency.

In total, 1, 276 individuals registered for the course. Of those, 764 attended classes (i.e., were present for at least one session) and were therefore eligible to participate in the pre-class and post-class surveys. The pre-course survey was completed by 461 participants. The post-course survey was completed by 178 participants. Only participants who completed both surveys, of which there were 132, were used in our analysis.

In Table 2, a large number of registrants listed their occupation as "Student" or "Other." Table 2 seeks to provide more insight into what these individuals may be studying or working in by listing the location of their work alongside their selected occupation.

Longitudinal survey

Communication (Q1): Compared to the beginning of the course, study participants increased the frequency with which they reported *frequently* discussing climate change and health with their patients,

TABLE 4 Longitudinal questions.

	Pre-course survey	Post-course survey	Change
Q1: How often do you talk to your patients/community members/colleagues about climate change and health?	(*n*) %	(*n*) %	(*n*) %
Frequently	(31) 23.5%	(43) 32.6%	(+12) +9.1%
Sometimes	(68) 51.5%	(65) 49.2%	(−3) −2.3%
Rarely	(23) 17.4%	(22) 16.7%	(−1) −0.8%
Never	(10) 7.6%	(2) 1.5%	(−8) −6.1%
Q2: How often do you incorporate climate change and health knowledge and skills in your work?	(*n*) %	(*n*) %	(*n*) %
Frequently	(26) 19.7%	(34) 25.8%	(+8) +6.1%
Sometimes	(52) 39.4%	(71) 53.8%	(+19) +14.4%
Rarely	(40)30.0%	(23) 17.4%	(−17) −12.9%
Never	(14)10.6%	(3) 2.3%	(−11) −8.3%
No response	N/A	(1) 0.8%	N/A
Q3: How confident are you that you can engage with a climate and health initiative (e.g. hospital green team, adaptation project, education) in your community/institution/practice?	(*n*) %	(*n*) %	(*n*) %
Very confident	(31) 23.5%	(48) 36.4%	(+17) +12.9%
Somewhat confident	(60) 45.5%	(68) 51.5%	(+8) +6.1%
Not very confident	(31) 23.5%	(12) 9.1%	(−19) −14.4%
Definitely not confident	(10) 7.6%	(3) 2.3%	(−7) −5.3%
No response	N/A	(1) 0.8%	N/A

community members, and colleagues by ≈ 9% ($n = 12$). At course completion, 81.8% ($n = 108$) of respondents reported climate and health communications either *frequently* (32.6%, $n = 34$) or *sometimes* (49.2%, $n = 65$) (Table 4).

Application (Q2): Compared to the beginning of the course, study participants reported a 20.5% increase in *frequently* (+6.1%, $n = 8$)or *sometimes* (+14.4%, $n = 19$) incorporating climate change and health knowledge and skills into their work (Table 4).

Engagement (Q3): Compared to the beginning of the course, 87.9% ($n = 116$) participants reported being *very confident* or *somewhat confident* in their ability to engage with climate and health initiatives—a 12.9% ($n = 17$) and 6.1% ($n = 8$) increase from the beginning of the course (Table 4).

End of course survey

At the end of the course, 50.8% ($n = 67$) of participants felt very prepared to have conversations (about climate change and health) with all contacts and (44.7%, $n = 59$) felt prepared in limited scenarios (Table 5). A similar number (93.9%, $n = 124$) felt that knowledge and skills gained through course participation would change their professional practice to "a large degree" (29.6%, $n = 39$) or in "some aspects" (64.4%, $n = 85$).

Participants were also asked about their ability to lead both adaptation and mitigation initiatives within their community of practice. Approximately a quarter of participants stated they "now feel confident leading [adaptation] initiatives" (25.8%, $n = 34$). A further 57.6% ($n = 76$) of participants stated that they feel more confident, but still need more knowledge and experience to serve as a leader. Responses to questions about leading mitigation initiatives were relatively similar with 22.7% ($n = 30$) stating they "now feel confident leading [mitigation] initiatives" and an additional 60.6% stating they feel more confident, but still need more knowledge and experience to serve as a leader in mitigation initiatives.

Post-course survey participants were also asked to reflect on how their confidence in training others "in at least some aspects of climate change" had changed since the initiation of the course. Respondents overwhelmingly (93.2%, $n = 123$) felt that the course had increased their confidence to some extent with 50.8% ($n = 67$) stating their "confidence has increased a great deal" and 42.4% ($n = 56$) stating their "confidence has increased slightly".

Discussion

Health professionals stand on the front lines of the climate crisis, yet many barriers prevent health professional engagement and meaningful action to mitigate the root causes of climate change and adapt their health practice to protect patients and communities, especially in vulnerable areas. Rapid knowledge dissemination, capacity building and health professional action is needed to protect patients, communities, and health systems. In this course, participants from at least 21 countries, 10 different health-related fields, and a variety of health professional settings reported significant changes in intention to communicate, apply, and engage in climate

TABLE 5 Post-course survey questions.

Q4: Do you think that this course has prepared you to speak with patients/community members about climate change and their health?	(*n*) %
Yes, I feel very prepared to have conversations with all contacts	(67) 50.8%
Yes, I feel prepared but in limited scenarios	(59) 44.7%
No, I do not feel like I have the expertise to speak with others on this subject	(5) 3.8%
No response	(1) 0.8%
Q5: Do you think that the knowledge and skills you gained from the Climate and Health Responder Course will change your professional practice?	**(*n*) %**
Yes, it will change my practice to a large degree	(39) 29.6%
Yes, it will change some aspects of my practice	(85) 64.4%
Not sure if it will change my practice	(5) 3.8%
My practice will not change	(1) 0.8%
No response	(2) 1.5%
Q6: Do you think the knowledge that you gained from the Climate and Health Responder Course has prepared you to lead climate and health ADAPTATION initiatives within your community of practice?	**(*n*) %**
Yes, I now feel confident leading initiatives	(34) 25.8%
I feel more confident, but still feel like I need more knowledge/experience to serve as a leader	(76) 57.6%
I do not feel confident to serve as a leader, but am more prepared to help in initiatives	(21) 15.9%
I do not feel confident to lead or help develop initiatives	(0) 0%
No response	(1) 0.8%
Q7: Do you think the knowledge that you gained from the Climate and Health Responder Course has prepared you to lead climate MITIGATION initiatives within your community of practice?	**(*n*) %**
Yes, I now feel confident leading initiatives	(30) 22.7%
I feel more confident, but still feel like I need more knowledge/experience to serve as a leader	(80) 60.6%
I do not feel confident to serve as a leader, but am more prepared to help in initiatives	(20) 15.2%
I do not feel confident to lead or help develop initiatives	(1) 0.8%
No response	(1) 0.8%
Q8: How confident are you now, as compared to before you took the Climate and Health Responder course, that you can train others in at least some aspects of climate change?	**(*n*) %**
My confidence has increased a great deal	(67) 50.8%
My confidence has increased slightly	(56) 42.4%
My confidence has not changed	(8) 6.1%
My confidence has decreased slightly	(0) 0%
My confidence has decreased a great deal	(0) 0%
No response	(1) 0.8%

and health discussions and activities after participating in a 10-week live-virtual course. To our knowledge this is the first study that evaluates the potential for virtual learning opportunities to engage health professionals from diverse backgrounds to respond to the climate crisis and informs future initiatives to build a global climate-ready global health workforce.

In a recent multinational study of health professional's views on climate change and health, although an overwhelming majority perceived a growing concern of health harm on their patients and in their communities, many identified barriers to action, communication, and adaptation of practice (19). Forty-one percent reported a lack of knowledge, 31% believed that engaging with the public would not make a difference, and 22% perceived little support from their peers (19). In this course, we were possibly able to overcome several of these stated obstacles, thus enabling a shift in reported engagement. Firstly, the meeting style setting of the Zoom platform allowed active participation during didactic sessions, through activation of the Chat function and the Q&A sessions, building cohesion and peer support. Secondly, skills and practice sessions were framed around specific proven actions that could be taken by health professionals to affect change locally and globally. Effective communication skills, commonly encountered case-histories and interactive resources provided the forum for overcoming inertia toward the notion that action would not make a difference. Thirdly, this course was based on a rigorous, evidence-based curriculum, yet participants were provided with ample time for questions and discussion clarifying and expanding on lessons learnt. Lastly the course considered the time-constraint of busy professionals. This barrier was highlighted by Kotcher et al. as the greatest hurdle. On-line slide decks and recorded videos of live sessions were stored as a repository for further use. Although culturally appropriate and regionally specific knowledge was not assessed in the Kocher study, we believe the availability of such materials may be a barrier. In this program, the majority of expert lecturers for this course, and the course design, was conceived of by professionals actively working in the Caribbean region. We believe that this contributed to the applicability of the knowledge and skills disseminated in the course.

The course had two other dimensions which will likely aid a stronger response. First, it was a multi-disciplinary audience, so the discussion and chats allowed cross-fertilization between professionals. Second, people with an interest in climate and health from the same country got to know each other and developed relationships which will likely enhance post course collaboration.

Strengths and limitations

The strengths of this course included: widespread engagement of health professionals from diverse backgrounds and practice environments throughout the Caribbean; strong support from regional health, climate and environmental organizations; deep engagement of experts from within the region who served as course faculty; opportunities for bi-directional engagement among course faculty and participants; and an evidence-based approach which adhered to global competencies for health professionals in responding to the climate and health crisis.

An important limitation to recognize is the self-selection of participants into the course and into the study cohort. Though the course was widely promoted and open to all health professionals, students, or interested individuals, it was primarily advertised through pre-existing organizations focused on climate and which may have inadvertently selected individuals already engaged with or particularly willing to engage in climate change and health related initiatives and education. Additionally, data collection required participants engaging in two optional surveys outside of the course which may have limited respondents to those who were particularly engaged with course material. The online Zoom format of the course also selected for individuals who had consistent internet access and were available during the time the courses were offered. In countries lacking consistent internet service or where Zoom is not enabled—potential participants were unable to engage.

Next steps and future directions

With the momentum stimulated from this course, in July of 2022, EM&EN invited course participants to take part in regionally based health professional working group to develop ideas, tools and culturally appropriate products on climate and health for practitioners, patients and communities. More than 60 participants responded and have since been active in the production of practitioner, patient and community education and capacity/literacy items, to increase knowledge and activate action plans for further research and application of services addressing climate change and health. Furthermore, the working groups are contributing to a newly launching monthly webinar series on climate change and non-communicable diseases in the Caribbean, which will launch October 27, 2022 through a partnership between EM&EN, the Global Consortium on Climate and Health Education and the Healthy Caribbean Coalition. Furthermore, we plan to repeat this survey among course participants in 6 and 12 months to assess the effectiveness of intervention to result in lasting health professional behavioral changes.

To mount a health system-wide effective response commensurate with the risks posed by climate change, which threatens to disrupt stable and secure livelihoods for all (10), health professions will need to assume new roles and responsibilities. The structure of this course was introductory in nature and geared toward reaching a broad range of health professionals. While this course facilitated an interdisciplinary approach to tackle climate and health challenges, more specific training is warranted for each health profession to continue to improve capacity. Further training is also needed to strengthen partnership skills to help "join up silos" between clinical professionals and environmental professionals, as the former sees the health impacts presenting, while the latter are in a better position to influence the environment, water quality, vector breeding, heat adaptation measures, etc.

Specifically regarding the role of health professionals, there are several opportunities for immediate action (20). First, academic institutions which train health professionals can integrate evidence-based climate and health knowledge and skills into the explicit training of all trainees. Such educational training can and should be supported by governing bodies which accredit health professional training institutions as well as provide licensing for individual professionals. Second, a parallel effort is needed to train clinical health professionals already in practice. This might be achieved through partnerships with local and regional health ministries as well as health professional societies who already routinely provide education and training to the health professional workforce. These education efforts can be incorporated into required ongoing maintenance of certification efforts. Importantly, efforts to build capacity within national health sectors to address the climate crisis are routinely incorporated into Health National Adaption Plans (H-NAPS), a subset of Nationally Determined Contributions for the United Nations Framework Convention on Climate Change, and thus might benefit from national level support.

With the success of this program, similar efforts are being initiated in other global regions through the Global Consortium on Climate and Planetary Health Education with local partners in Southeast Asia and Sub-Saharan Africa. Exceptional collaboration, knowledge sharing, and workforce capacity building are essential to tackle the complex ways in which climate change threatens health.

Conclusion

Climate change is a reality in the Caribbean that will continue to have a significant impact on human health and the health sector. Health professionals occupy a critical position in the response to climate change, including climate mitigation and adaptation, and their professional expertise and roles as health messengers are currently under-employed in our society-wide response to this crisis. Live-virtual, evidence and competency-based courses, regionally specific courses have the potential to change health professional behaviors toward addressing climate impacts on health by increasing communication, adaptation of practice and engagement in climate and health adaptation and mitigation initiatives.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CS, NH, HC, PH, KP, LD, and JH contributed to conception or design of the work, acquisition, analysis, and interpretation of data for the work. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Communication research to improve engagement with climate change and human health: A review

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Because of the world's dependence on fossil fuels, climate change and air pollution are profoundly harming both human and planetary health. Fortunately, climate solutions are also health solutions, and they present both local and global opportunities to foster cleaner, healthier, and safer communities. In this review, we briefly discuss the human health harms of climate change, climate and health solutions, and provide a thorough synthesis of social science research on climate and health communication. Through our review, we found that social science research provides an evidence-based foundation for messaging strategies that can build public and political will for climate and health solutions. Specifically, messages that convey the health harms of climate change and highlight the health benefits of climate solutions may be especially effective in building this public and political will. We also found that health professionals are trusted sources of information about climate change, and many have shown interest in engaging with the public and policymakers about the health relevance of climate change and clean energy. Together, the alignment between message strategies and the interest of highly trusted messengers strongly suggests the potential of health students and health professionals to create the conditions necessary to address climate change as a public health imperative. Therefore, our review serves as a resource for those interested in communicating about climate change and health and suggests that social scientists can continue to support practitioners with research and advice on the most effective communication strategies.

KEYWORDS

health, climate change, air pollution, fossil fuels, climate change communication, climate solutions

1. Introduction

Climate change and air pollution—both of which are primarily caused by the world's reliance on fossil fuels (i.e., coal, oil, and natural gas)—are arguably among the leading causes of morbidity and mortality worldwide, and the magnitude of these linked problems is growing rapidly (1, 2). Therefore, fossil fuel use is the world's most pressing public health problem, and decarbonizing communities and nations is one of the world's most promising public health opportunities.

Social science research is playing—and will continue to play—an important role in addressing these challenges. To demonstrate this, we begin this review by providing a brief overview of the public health emergency that is being caused by climate change and fossil fuel use and the solutions that have the potential to

quickly improve public health while also helping to stabilize the world's climate over time. After providing a description of the problem and the potential solutions and their benefits, we synthesize the social science research on how to educate the public and policymakers about the human health relevance of climate change and build public support for the policies necessary to protect human and planetary health. By doing so, we summarize an important and growing body of work, providing a resource for those interested in communicating about climate change and health and a foundation for future research.

2. The health harms of fossil fuel use, climate change, and air pollution

By adding large amounts of heat-trapping pollution—like carbon dioxide and methane—into the Earth's atmosphere during the twentieth and twenty-first centuries, the fossil fuel industry has become the primary driver of poor air quality and climate change globally (1, 2). Together, climate change and air pollution from burning fossil fuels are already harming both human and planetary health on an unprecedented scale, signaling a major public health concern.

Figure 1 summarizes the ways climate change can harm human health, including increases in heat-related illnesses and deaths; vector-, water-, and food-borne diseases; respiratory diseases due to reduced outdoor air quality; food insecurity and malnutrition; and direct and indirect physical and mental harm from extreme weather events and wildfires (3). The geographic range, frequency, and severity of these impacts are projected to continue to grow if preventive actions are not taken (3). Importantly, these health harms disproportionately affect people in low-income and minority communities, exacerbating existing health disparities and inequities like access to clean air and water (3).

According to the latest reports by the Fourth U.S. National Climate Assessment (NCA4), the Intergovernmental Panel on Climate Change (IPCC), and the 2022 Lancet Countdown on Health and Climate Change, climate-related health impacts

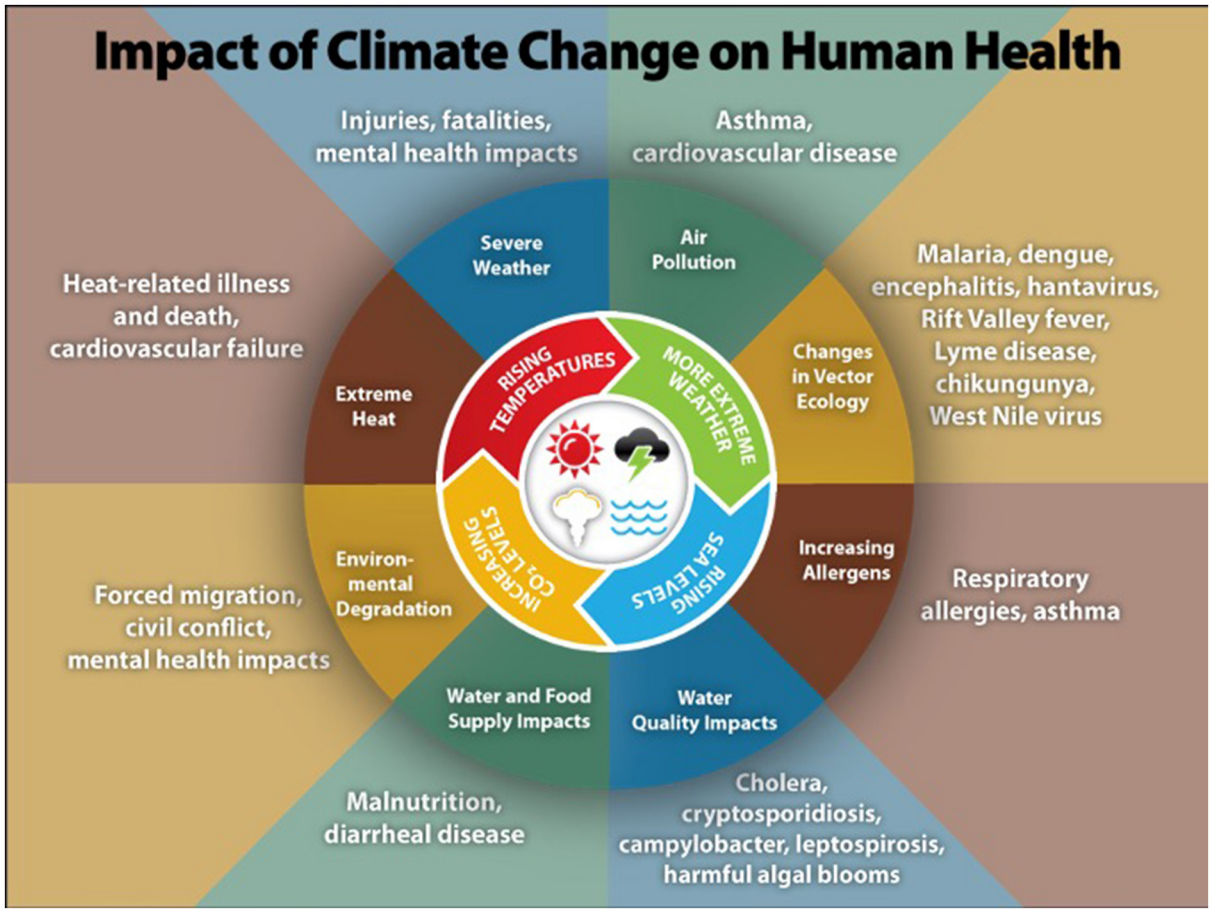

FIGURE 1
Illustration of the most significant climate change impacts, their effect on exposures, and the subsequent health outcomes that can result from these changes in exposures [from the Center for Disease Control (4)].

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TABLE 1 Summary of example climate solutions and adaptation measures with related climate and health benefits.

Solution type	Example solutions	Benefits for climate and health
Type 1	• Transitioning to renewable energy • Electric heat pumps and induction stoves • Electrifying transportation • Expanding public transportation • Infrastructure for pedestrian- and cyclist-friendly communities • Plant based diets • Increasing access to family planning	• Reduce heat-trapping emissions from household fossil fuel use, vehicle transport, energy-intensive livestock farming and consumption of energy resources • Clean air and water • Reduce air pollution • Increase physical activity • Decrease stress and improve mental health • Access to reproductive health care • Promote gender equality
Type 2	• Forest restoration • Improved soil management • Greening urban and suburban spaces	• Reduce atmospheric heat-trapping pollution *via* sequestration in plant tissues and soils • Reduce flooding and resulting mold • Reduce urban heat islands • Reduce pesticide exposure • Improve mental health • Increase food security
Type 3	• Community cooling centers • Improved control measures for vector-borne diseases • Access to mental health resources and therapists	• Increase community preparedness for climate impacts • Limit exposure to extreme heat • Limit spread of disease • Improve mental health

are increasing in the United States and worldwide (3, 5, 6). The impacts of summer heat waves are one indicator of this increase. From 2000 to 2021, people were exposed to an average summer temperature of half a degree Celsius higher than the average from 1986 to 2005; such exposure can lead to illness or death and restricts people's ability to work or exercise (6). Furthermore, heat-related deaths among those 65 years and older increased by 68% from 2000–2004 to 2017–2021 (6). By 2100, the percentage of the global population exposed to deadly heat stress is projected to increase from 30 to 48–74%, depending on emission scenarios and population distribution (7). Furthermore, according to the IPCC AR6 risk report, other health risks—such as water- and vector-borne diseases—will become more severe at both global and regional levels with increased warming and vulnerability (3).

Poor air quality is one of the most harmful health impacts of climate change. One indicator of this is wildfire exposure, as climate change can lead to poor air quality through increases in wildfire smoke. From 2001–2004 to 2018–2021, the number of days of human exposure to very- or extremely high fire danger increased in 61% of countries, meaning more people were exposed to poor air quality from wildfire smoke, suffered the loss of infrastructure, and may have experienced lasting mental health impacts (6).

Furthermore, uncontrolled fossil fuel use produces air pollution which in turn drives climate change. Together, air pollution and climate change are one of the leading causes of morbidity and mortality worldwide. From 2012 to 2018, air pollution from fossil fuels was estimated to be responsible for 8.7 million premature deaths per year globally (8). In the United States, over 40% of the population (more than 137 million people) live in areas with unhealthy levels of particulate pollution or ozone (9). Children are especially vulnerable to the health harms of air pollution. Prenatal and early childhood exposure to air pollution caused by the burning of fossil fuels has been linked to impacts on children's brain development, including delayed development, reduced IQ, symptoms of anxiety and depression, inattention, increased risk of autism, and premature and low-weight births that may increase the risk of neurological disorders (10). This dire public health problem can be addressed by phasing out fossil fuel use, which would reduce outdoor air pollution and prevent the loss of up to 3.61 million lives per year (11).

While the greatest cost posed by fossil fuel use is on people's health and wellbeing, there are also significant economic costs associated with the health impacts of both climate change and air pollution caused by the burning of fossil fuels. Already, the combined health costs attributed to climate change and air pollution amount to over $800 billion per year just in the United States (12). Globally, health damages as a result of exposure to air pollution alone amount to $8.1 trillion (13).

The wide-ranging health impacts of fossil fuel use—and the resulting air pollution and climate change—on human health demonstrate that this is a complex public health issue that will continue to worsen if countries do not phase out the use of fossil fuels. Addressing this issue will require viable, accessible, and cost-effective climate solutions that mitigate the drivers of these harms while also improving human health and advancing equity.

3. Climate solutions are health solutions

Most climate solutions and adaptation measures that have links to health can be categorized into three broad types: (1) solutions that reduce the emission of heat-trapping pollution and transition to clean energy, (2) solutions that reduce the

amount of carbon pollution in the atmosphere, and (3) solutions and adaptations that enhance community preparedness (14). Many of the actions in each of these categories also produce health benefits and, if done right, equity benefits (15). Therefore, climate solutions have "co-benefits" that can quickly improve public health and wellbeing while also helping to stabilize the climate (16–19). Table 1 provides examples of the types of climate solutions and adaptation measures and their associated climate and health benefits.

Type 1 solutions that reduce emissions of heat-trapping pollution—and thereby reduce air and water pollution and improve human health—include rapidly transitioning away from fossil fuels to clean, reliable, and renewable energy sources [e.g., solar, wind, and geothermal; (6, 15)]; heating and cooling buildings and water with electricity-powered heat pumps and geothermal HVACs (20, 21); cooking with electricity-powered induction stoves (22); and electrifying all possible modes of transportation [cars, trucks, and buses; (15, 23)]. Developing pedestrian- and cyclist-friendly communities and effective, affordable public transit options are additional solutions to reduce air pollution, limit climate change, increase physical activity, reduce obesity, and improve mental health (15, 24, 25). Other measures can result in emission reductions while simultaneously addressing broader societal and health needs (21). For example, promoting plant-based diets and reducing food waste can also reduce emissions and enhance human health (26). Similarly, increasing access to family planning resources and educating girls can help slow future population growth and emission rates while also improving gender equality, access to education, and reproductive healthcare (19, 21).

At present, the primary Type 2 solutions to reduce carbon pollution in the atmosphere are nature-based, although technology-based carbon removal is an area of active research and development. Nature-based solutions include forest restoration, improved soil management practices for agriculture, greening urban and suburban spaces, and composting food waste (21). These actions also benefit human health by reducing urban heat islands, reducing flooding and associated health risks (e.g., mold), reducing exposure to pesticides and other agricultural chemicals, and improving mental health (15).

Finally, Type 3 solutions encompass adaptations that can enhance community resilience to the harmful impacts of climate change, often reinforcing Type 1 and Type 2 solutions. Examples of public health resilience measures include establishing community cooling and clean air centers to limit exposure to dangerous heat and air pollution (27, 28); improving control measures for vector-borne diseases (6, 29); and providing counseling to help people cope with mental health impacts of climate change, including climate anxiety and depression and post-traumatic stress disorder resulting from exposure to extreme weather events (30).

Put simply, *climate solutions are health solutions*, and they present local, national, and global opportunities to foster cleaner, healthier, and safer communities, reduce morbidity and premature mortality, and lower health costs (11). When designed and implemented wisely, climate solutions can also help redress systemic and social inequalities and ensure fair and equitable access to the social and environmental determinants of health, which include clean energy, air, and water; affordable, safe, and nutritious food; a safe and secure neighborhood with access to green spaces; and economic security.

Building enduring public and political will for climate and health solutions may therefore be the most important—and promising—public health objective for the next several decades. Health professionals have long intuited that acknowledging and promoting the human health benefits of climate solutions as "co-benefits" of climate action would help advance this objective (16–19). Social science research conducted over the past decade has confirmed this intuition and refined it.

4. Social science research on messages that build public and political will for climate and health solutions

Public understanding of the health relevance of climate change seems limited, although it appears to be growing. As recently as 2014, about six in 10 (61%) Americans had given "little or no thought" to how global warming might impact human health, and relatively few could name a single way in which climate change harms health or whose health is most likely to be harmed (31). A 2018 review of peer-reviewed studies on public awareness of the health relevance of climate change worldwide yielded similar findings (32). Between 2014 and 2020, however, Americans' understanding of the health consequences of climate change grew substantially (33, 34).

Social science research has shown that communicating the health relevance of climate change can increase public engagement with the issue (35, 36). Most fundamentally, presenting information about how climate change harms health and whose health is most likely to be harmed can increase people's concern about and engagement with the issue (37, 38). Moreover, providing information about the health benefits of climate solutions can enhance people's intentions to advocate for such solutions (39). Certain health benefits of climate solutions are more compelling than others, with messages about the health benefits of clean energy and improved community design being the most compelling (39). Including a call to action for climate solutions advocacy that demonstrates how many others are engaging in advocacy (i.e., a social norm) can further enhance the effectiveness of advocacy appeals (39). Among certain vulnerable populations (e.g., low income, less educated, and those with preexisting health conditions), communication that makes the connection between climate and health has also been shown to increase the understanding of the issue and intention to take action (38). Finally, including information about the bad-faith actors in the climate discussion—like the

CEOs of fossil fuel companies and politicians working against climate solutions—can also increase the effectiveness of climate and health messages by enhancing emotional engagement with the issue, policy support, and advocacy intentions (40).

A multinational study showed that providing health-framed information about climate change can significantly increase public support for climate mitigation policies, including among people who are not concerned about climate change *per se* (41). This finding—that health-framed climate messaging is effective with people who are not necessarily concerned about climate change—has been demonstrated in other studies as well (35–37, 39), suggesting that climate/health communication may be an important strategy for reducing political polarization about the value of climate solutions.

Similarly, messages that focus on the health harms of fossil fuels and air pollution have also been shown to increase public understanding of these issues, support for clean energy, and intentions to advocate for solutions (39, 42–44). In communication research focused specifically on climate change, messages about poor air quality are the most compelling form of climate change-related health harm (37, 39). Furthermore, one study suggested that air pollution messages may be more effective than climate change messages in building support for clean energy policies (44). Moreover, messages about the neurological harms of air pollution on babies (including before birth) and children are of particular concern to people (42). Other research shows that presenting information about policies aimed at reducing air pollution, as opposed to those aimed at addressing climate change outright, may increase Republican support for such policies (45). Health-oriented messages may be a more compelling reason to reduce fossil fuel use among conservatives compared to climate-oriented messages, which are more compelling among liberals (46).

Among Americans, people's understanding of climate change as a health issue is associated with their broader climate attitudes and beliefs (34). Prior research with Americans identified a spectrum of six distinct audiences, also known as Global Warming's Six Americas,[1] ranging from the Alarmed (i.e., those who are very worried and engaged with climate change) to the Dismissive (i.e., those who do not believe in the reality of climate change and rather likely consider it a hoax). When looking at how Americans' understanding of climate and health changed over the period from 2014 to 2020, the understanding increased among four of the six segments—the Alarmed, Concerned, Cautious, and Disengaged—while little or no change occurred among the two most climate-skeptical groups, the Doubtful and Dismissive (34).

1 For more information on Global Warming's Six Americas, see: https://climatecommunication.yale.edu/about/projects/global-warmings-six-americas/.

5. Social science research on climate and health messengers

Well-crafted messages can only be successful if delivered by trusted sources who are effective communicators. In April 2022, nearly seven in 10 (69%) U.S. voters said they trust their primary care doctor as a source of information about global warming; relative to most other sources, Republicans were especially likely to trust their primary care doctor as a source of global warming information (47). This role as a trusted communicator may allow health professionals to communicate effectively about topics that otherwise may be perceived as controversial. For instance, one study demonstrated that calling-out opponents of climate change did not diminish health professionals' credibility as a source of information about climate change; in fact, it led to greater trust in health professionals (40).

In addition to being trusted, health professionals also have many relevant skills and knowledge as well as many opportunities to be effective communicators on climate and health (31). Because of this, health professionals and health organizations are increasingly being called upon to educate and engage the public and push for climate-friendly policies and actions (48, 49).

Internationally, many health professionals are concerned about climate and health and would like to see strong climate policies enacted. Many, however, feel they lack the knowledge, time, or peer support to effectively educate the public and policymakers about the issues (50–54). These research insights help design strategies to educate and activate health professionals as climate advocates.

In a 2020 multinational survey of health professionals, most participants expressed the view that health professionals have a responsibility to bring the health impacts of climate change to the attention of the public (86%) and policymakers (90%), and about one-fourth (26%) were willing to participate in a global advocacy campaign to encourage world leaders to implement climate and health solutions (50). Interviews with hospital employees also demonstrated that health professionals are receptive to climate and health information and may be willing to advocate for solutions in their hospitals (55). Other studies asked members of specific medical societies—including the American Thoracic Society, the National Medical Association, and the American Academy of Allergy Asthma and Immunology—similar questions and found similar results, with majorities of members indicating that health professionals should be playing a role in responding to climate change and educating the public (52–54). Feeling a sense of professional responsibility is related to health professionals' willingness to advocate for climate and health solutions (56).

While research shows that many health professionals are ready and willing to act as climate and health communicators and advocates, the barriers they face must be addressed to

translate this willingness into action. Luong et al. (51) separated these barriers into three categories: (1) skills and abilities (i.e., knowledge, communication ability, and resource access); (2) environmental constraints (i.e., time constraints and leadership support); and (3) intentions (i.e., perceptions of advocacy's risks/benefits, effectiveness, and social acceptability). Some ways to address these barriers include continuing professional education and communication training; providing resources such as patient education materials and policy statements; demonstrating how to make healthcare workplaces climate-friendly; promoting workplace policies and professional cultures that are supportive of advocacy; and highlighting successful advocacy efforts and outcomes (50, 51).

6. Limitations and future research

There are several limitations of our review and areas for future research. First, there is currently not enough research to conduct a quantitative meta-analysis of this literature. Second, our overviews of the health harms of climate change and climate and health solutions are not comprehensive, as their purpose was to set the stage for the larger discussion of social science research on climate and health communication. Other resources can provide much more detail on these points [see IPCC (3), USGCRP (5), Romanello et al. (6)]. Third, much of the research to date has been conducted in the United States, and therefore, our review is U.S.-centric. Future research should seek to explore public perceptions of climate change as a human health issue and test the effectiveness of different climate and health messaging strategies in other countries. Fourth, there is minimal research focused on effective communication with the populations most vulnerable to the health impacts of climate change; this gap should be remedied to better understand how to support these communities. Finally, much of the research on health professionals as climate and health communicators is based solely on cross-sectional survey data. Future research should investigate messaging and behavior change strategies that can effectively engage health professionals in public communication and advocacy for climate and health solutions.

7. Conclusion

Because fossil fuel use, air pollution, and climate change are causing profound public health harm and changes in public policy are needed to prevent these harms from escalating, building public and political will for equitable climate and health solutions is a public health imperative. Current research demonstrates avenues for effective communication strategies to engage the public with climate and health topics, though it is important to note that simply providing the public with information does not directly bring about social and societal changes. Public will can help drive political will by making support for pro-climate policies and actions visible to those in positions to effect change. But, for substantive actions to be born out of this public will, trusted stakeholders (including health professionals, scientists, and others) must engage in productive collaborations with those in positions of power—including policymakers and other government officials, industries, corporations, and the news media—to translate public support into effective policies and actions.

While the communication strategies and messages outlined in this review are a starting point, future research should continue to explore (1) how to activate and support health professionals in their climate communication and advocacy efforts, including refining message strategies that have the most potential to create enduring public and political will for policies that protect human health and our climate and (2) how to facilitate the collaborations necessary for large-scale action. Social science research will continue to play an important role in addressing this imperative, and we encourage social science students and social scientists to join this effort. We also encourage health students, health professionals, and others working to protect human health to use their trusted voices to educate the public and policymakers about the health relevance of climate change and the health opportunities inherent in climate solutions. Now is the time to act together in defense of human health and the climate on which we all depend.

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EC: project administration, writing—original draft preparation, and writing—reviewing and editing. SU, JK, and EM: writing—reviewing and editing. All authors contributed to the article and approved the submitted version.

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A blueprint for strengthening climate and health literacy through professional adaptability

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Responding effectively to intensifying climate change hazards to protect human health in personal and professional settings is an urgent and pressing challenge. This will require collaboration and subject matter expertise of people across the life course and occupations. In this perspective piece, we build on a previously published compilation of climate and health literacy elements to explore tangible opportunities to strengthen climate and health understanding among individuals spanning educational levels, professional settings, and societal needs. Educational materials addressing climate change and health linkages have historically focused on K-12, college, post-graduate education, and continuing medical education, with less attention devoted to reaching students in trade schools and other professional settings. Here, we outline a flexible blueprint for strengthening climate and health literacy among all people by targeting education in a way that is relevant for each age group or profession. In particular, we discuss the idea of professional adaptability as a way to design practical climate and health training for people currently in the workforce.

KEYWORDS

climate change, health education, training, literacy, professional adaptability

1. Introduction

Climate change is a human health emergency (1). Numerous climate-sensitive health risks are well-established, including mortality from heatwaves, respiratory ailments from smog ozone and allergenic pollen, mental and physical effects due to wildfires and migration, increased transmission of vector-borne diseases, injuries from flooding, and undernutrition stemming from reduced crop yields (2–4). The urgency to act to reduce greenhouse gas emissions emitted when burning fossil fuels and from large scale deforestation is paramount. The world has warmed ~2°F compared to pre-industrial times, and 18 of the 19 hottest years ever recorded have occurred since 2000 (3).

Despite scientific evidence demonstrating the link between climate change and human health, this relationship is not well-understood by the general public and many professionals. In the U.S., for example, only about half of Americans believe climate change poses a risk to their personal wellbeing (5). While public understanding of the scientific fundamentals of climate change in the US (e.g., that there is scientific consensus that global warming is occurring and is driven by human activities) has improved slightly since 2010, it remains low overall (6). Perceptions of climate change risk among Americans, on the other hand, have increased consistently since 2008, but reflect a view that risk is greater for people and animals living "far away" from them (in space or time) compared to localized, individual, or community risk (5–7).

This lack of understanding of how the climate influences individuals and society and how individuals influence the climate is considered poor *climate change literacy* (also called climate literacy) (8). Climate literacy, as an educational framework, describes essential principles of climate science and overlays them with basic science literacy benchmarks. Climate literacy also defines one's ability to assess credible scientific information, communicate clearly, and make informed decisions related to behaviors that impact the climate. In its sixth assessment report, the Intergovernmental Panel on Climate Change (IPCC) recently emphasized that "Enhancing climate change literacy on impacts and possible solutions is necessary to ensure widespread, sustained implementation of adaptation by state and non-state actors… Ways to enhance climate literacy and foster behavioral change include access to education and information…" (9). Report co-chair Hans-Otto Porner also argued, "We have an education gap and an implementation gap" (10).

In the US, current national science curriculum standards do not broadly emphasize climate change content (11), nor the profound health implications of climate change. Current pressures to attain educational standards amidst challenging staff turnover in the wake of COVID-19 present an additional challenge to adequately prepare students for a world increasingly disrupted by a changing climate (12, 13). In a prior analysis of the existing training landscape (14), we identified major health content gaps in climate literacy elements, which are the only federally-endorsed criteria for climate change training in the US. To address this shortcoming, we have previously developed a set of seven *climate and health literacy* (CHL) elements that can help to standardize and strengthen climate change curriculum development by linking climate content to relatable human health concerns (7, 14, 15). These elements are shown in Figure 1 and are categorized into three literacy levels, functional, intermediate, or advanced.

Central to our concept of CHL is the degree to which one understands *complexity* in the relationship between climate change and health *via* both direct and indirect linkages, as well as the ability to make informed decisions based on such knowledge. CHL builds on an incomplete characterization of the health impacts of climate change as included in climate change literacy (8); specifically, it includes understanding of how mitigation and adaptation can reduce harms to physical and mental health (16), the overlap between fossil fuel dependency and worsening health (1), as well as the economic costs associated with climate-sensitive health impacts (14, 17, 18). Not all students or people need to engage in training to advance from functional, to intermediate, to advanced levels of CHL. Younger learners, for example, might begin with functional CHL, learning the root causes of mechanisms of climate change and overlaps with health. Professionals and educators, on the other hand, need intermediate and advanced literacy levels in order to better affect change in their respective fields. The real-world application of CHL requires an educational framework for various ages and learning groups such to help them master content relevant to their daily lives and professions. This strategy should be tailored to the needs of the target population. A one-size fits all approach would be inappropriate.

Responding effectively to intensifying climate change hazards to protect human health through education is an urgent and pressing need (19). Building CHL is essential across the population. The current and future challenges posed by climate change require collective action; individual action is necessary but insufficient (20–22). We believe an effective response will require collaboration, education, and subject matter expertise of people across industries and throughout society. To accomplish this goal, we must establish and advance a foundational understanding of the relationship between climate change and human health across society for all types of learners.

To date, climate change and health education has been focused predominantly within fields of medicine and public health (14). However, a rapidly changing climate necessitates resilience and adaptation among people of all professionals and life stages. To this end, we offer a blueprint for increasing climate and health literacy *via* strategic education efforts targeting individuals from kindergarten to retirement specifically within the United States, with potential for expansion and translation worldwide. Our blueprint builds on previous work defining CHL (14) by offering a practical guide for achieving CHL objectives across specific audiences. While Limaye et al. (14) identified specific learning objectives, the blueprint presented here provides pedagogical and curricular approaches to meet these objectives. A critical piece of this blueprint is the role of *professional adaptability* in framing climate and health education for the working population (23). Climate and health education is essential for offering people in the workforce skills to anticipate and accommodate changes (e.g., technological, competitive) important to one's profession and to allow for the capacity to modify elements of professional practice accordingly due to changes in the climate.

2. Approach

2.1. Audience

Most efforts to develop and evaluate climate change educational materials have focused on K-12, college, and graduate education (24–26). Collectively, these audiences represent a critical demographic for early education about climate change and continues to play a major role in pushing for aggressive climate action (27). Less attention has been paid to reaching students in trade schools, despite their potential as a key conduit of information to the public. For example, housing contractors and HVAC professionals can convey information about building design to protect inhabitants from locally-relevant climate-sensitive exposures like extreme precipitation or wildfire smoke.

Recent strategies targeting clinical and public health practitioners provide examples for reaching practicing professionals who are already in the workforce and are required to complete professional continuing education to maintain their credentials (28). However, there are a number of other industries where continuing education is not necessarily "part of the job," requiring new and creative mechanisms for teaching climate and health. For example, public service professionals, policymakers, farmers, and ranchers may not be exposed to formal continuing education courses. And yet, for these individuals, *professional adaptability* is especially crucial in a changing climate and can be a useful foundation for climate and health education. We know that adaptability alone refers to our human capacity to respond to

	Category	Description of CHL Element
1.	**Root Cause**	The fossil fuels that shape our lives worsen the climate crisis and our health.
2.	**Mechanism**	Climate change affects human health by altering global temperatures, the hydrologic cycle, and driving sea level rise.
3.	**Determinants**	The environment and our health are intertwined. Quality of life, physical, and mental health are strongly tied to our environment.
4.	**Implications**	Climate change worsens existing health disparities.
5.	**Interventions**	The adverse health impacts of climate change can be reduced through mitigation and adaptation.
6.	**Evidence**	Our understanding of climate impacts on health relies on different types of data and models.
7.	**Complexity**	The human health effects linked to climate change are complex and vary over space and time.

FIGURE 1
Climate and health literacy (CHL) elements as adapted from Limaye et al. (14).

change, uncertainty, and variability (29). However, in the context of a changing climate and the workplace, we suggest professional adaptability training. As described above, we define professional adaptability as the capacity for climate-informed adaptations in professional practice. For example, first responders might receive training on climate hazard scenarios that they may have to respond to in their community. With intensifying and increasing climate hazards, the necessity for on-the-job decision-making is critically important. Moreover, professionals should receive preparation through profession-specific training modules that include the tenets of climate and health literacy.

Finally, comprehensive climate and health education for the whole population will require consideration of people outside the traditional student or working populations, including life-long learners (e.g., retirees) (30). With regard to climate and health literacy, one of the major distinguishing features of this population is the role of life experience in their understanding of climate change. In contrast to current students, most of today's adult learners likely have not been exposed to information about climate change in formal coursework when they were in school and likely can draw on personal and place-based observations when discussing climate change (31).

2.2. Teaching approach

A core strategy in building climate and health literacy is adopting a *meeting people where they are* teaching approach. This broad pedagogy has been applied widely to other disciplines and topics, including design (32), equity and justice (33), and in healthcare and public health (34). A person-, human-, or student-centered approach is intended to improve knowledge attainment and sometimes shift behavior, giving emphasis to the personal characteristics and experiences of students, as opposed to traditional "content-centered learning" (35). Student-centered learning emphasizes active, not passive, learning, as well as efforts to build deep understanding, increased responsibility and accountability for the student, autonomy, and mutual respect between teacher and learner (36). Efforts to meet people and students where they are can be physical, in that they require going to where target audiences are located or reside, but they can also be ideological, contextual, and personal. Importantly, we see this approach as a means to explain concepts and ideas such that they are absorbed by representing them in an intriguing manner that resonates with students' lived experience. Previous research has identified focusing on personally relevant and meaningful information and using active and engaging teaching methods as potentially useful teaching strategies for effective environmental education (37). Moreover, other scholars have argued that the gap between educational vision and teaching practice can be overcome by adopting pedagogical approaches that contribute to the "development of a person as a whole" (38).

Given the urgency of the climate crisis, building a cohort of individuals across the population with at least functional climate and health literacy is essential to building resilience. Deep expertise of climate and health (reaching advanced literacy) is not necessary for the average person, nor is it realistic. We propose, rather, that educational efforts aim to help most people reach functional climate and health literacy at a minimum (Figure 1). Students who complete high school (grade 12), for example, should graduate with functional climate and health literacy or higher. If individuals enter the workforce with a foundation of climate and health literacy, we posit that they will be better positioned to embrace and grasp the premise of professional adaptability. Just as a better-informed citizenry can help reduce vulnerabilities and enhance resiliency of ecosystems impacted by climate change *via* better policy and decision making (8), improved climate and health knowledge can improve adaptation and decision-making to protect health. To achieve this goal, efforts to improve climate and health literacy cannot be limited to formal education settings. Below we outline a guide for integrating this education in various settings throughout the life course.

2.3. Blueprint for incorporating climate and health literacy across audiences

To elucidate tangible opportunities that strengthen understanding of climate and health among individuals spanning educational levels, professional settings, and societal positions, we offer a blueprint for building both climate and health literacy and professional adaptability by audience (Table 1). This blueprint for climate and health literacy rests on three guiding principles described above: (1) professional adaptability is a crucial skill in today's workforce and has practical appeal to working professionals, (2) climate and health education efforts will be most effective if they utilize student-centered learning approaches, and (3) developing functional climate and health literacy across the population is more important than deep expertise among a few professionals. With these values in mind, this blueprint offers the building blocks for adapting climate and health education to any audience and level of interest in the topic. In lieu of endorsing specific curricula for climate and health education, we provide example activities that can be adapted to the appropriate educational context.

We focus on three overarching categories of learners: (1) students (spanning K-12, undergraduate and community colleges, trade schools, and graduate programs including health and non-health related fields), (2) practicing professionals in the current formal workforce, and (3) other interested individuals, especially those out of the formal workforce (e.g., retirees). For each audience, we propose four tiers of engagement to build climate and health literacy, categorized in terms of the degree of time, effort, and planning involved in each level. The following sections summarize proposed activities within each tier, including examples of current resources that suit each tier.

We term Tier 1 "Fast Pass Exposure" intended to provide audiences with an introduction to climate and health literacy concepts [discussed more fully in (14)] on a broad level, especially the focus of the first climate and health literacy element on the basic mechanism by which fossil fuel reliance affects climate change and human health. Tier 1 activities for K-12, undergraduate, and trade school students can include short instructional videos and teacher-led discussions on the links between climate change and health. Offerings here could also include broader environmental education field activities to familiarize learners, especially the youngest ones, with the interconnectedness of human and natural systems. Materials to support Tier 1 activities could be developed by emphasizing the health-relevant content of existing videos and training modules centered on building general climate literacy, including those developed by the US National Oceanic and Atmospheric Administration (39), public broadcasters (40), academics (41), and non-governmental organizations (42, 43).

Tier 2 is referred to as "Breaking the Ice," with activities intended to strengthen professional development training and knowledge enrichment, with an emphasis on the health dimensions of the climate change problem. These activities build out functional climate and health literacy (14) to include information on the direct mechanisms by which climate change affects human health (e.g., altering global temperatures, the global hydrologic cycle, and sea level rise). These activities might include short electives or summer courses, building on existing training opportunities such as climate and health "bootcamps" that feature presentations from health experts that can familiarize participants with climate change content and its relevance to public health (44). While Tier 2 activities would be structured around professional development and knowledge enrichment rather than academic credit, upon completion participants could earn informal designations as trainees and ambassadors, potentially as a "train the trainer" model to expand the reach of Tier 2 content.

Tier 3 and 4 activities are more formal, structured instructional programs that provide students with expanded academic training in climate and health literacy content. Tier 3, or "A la carte learning," spans intermediate climate and health literacy elements (health determinants, the implications of climate change to worsen existing health disparities, and opportunities to intervene to address health consequences of climate change *via* mitigation and adaptation) (14). This set of activities involves a smaller range of academic credit options, including high school elective classes, University level certificate/minor programs or semester-long internships (offered during the academic year or summer) (45), continuing education classes for a more focused, customizable learning experience. Health professional students across subject matter areas could access Tier 3 content *via* formal professional development, such as the University of Colorado's innovative Diploma in Climate Medicine, which trains students to develop leadership skills on climate and health science policy, workforce training, research, and linkages to environmental justice (46).

Tier 4, is the most advanced and called "Apprenticeship" level training. It includes the most immersive climate and health literacy curriculum intended to enable advanced mastery of climate and health literacy elements, including an appreciation for the far-reaching evidence upon which climate-health understanding is based and continues to expand, and the complex mechanisms by which climate change effects on human health varies over space and time (14). Tier 4 activities could include entire University-level degree climate and health literacy programs and climate concentrations within Masters of Public Health degrees (47), capstone experiences, or recurring research seminars with required writing components. These formal academic training activities could include development of a climate and health certificate or full degree program, respectively. For example, Vanderbilt University recently introduced their new Climate Studies major that could easily provide a foundation for exploring careers in climate and health. This initiative is innovative because rather than isolating the major in the environmental studies department, it is trans-institutional with required courses in natural sciences, social sciences, and the humanities (48). Completing Tier 4 also lends itself to formal accreditation programs, such as the hypothetical Fellow of the Climate and Health Literacy Society or an accredited Climate and Health Professional program. Lastly, we view individuals in Tier 4 who may be outside of academia but have emerged as CHL subject matter experts to be essential in educating those in lower Tiers.

3. Discussion

Achieving the coordinated and substantial societal shift required to curb climate change requires motivating behavior change of a large segment of the global population. We argue

TABLE 1 Blueprint for building climate and health literacy (CHL) and professional adaptability by audience.

CHL elements	Levels 1–2 (functional)		Levels 3–5 (intermediate)	Levels 6–7 (advanced)
Audience	Tier 1: Fast pass exposure	TIER 2: Breaking the ice (professional development training and enrichment)	Tier 3: A la carte learning (for credit options)	Tier 4: Apprenticeship (immersive curriculum)
Students				
K-12	• 4 × 15-min videos, with teacher led discussion and activities. Separate video set targeting elementary, middle, and high school students.	• Extracurricular enrichment opportunities: summer camps, field trips, club activities(making climate and health relevant through local examples, hands-on, engaging activities, and practical skills training) • Certification *via* Cooperative Extension 4-H Program	• Not applicable for K-8 • High school elective class	• See available higher education options in local area
Undergraduate and community college programs	• University common book program • Freshman year orientation to climate and health opportunities on campus or in community • Campus events (speakers, film screenings)	• Elective courses and Summer experiential classes • Critical Analysis of news articles	• Certificate/minor linked with degree • Internships (for credit)	• Degree program in climate change health • Undergraduate multi-semester research and honors experiences
Trade School (e.g., plumbing, HVAC, carpentry, electrician)	• 4 × 15 min interactive videos • Profession-specific Fact Sheets • Yearly CHL Refresher Breakfast	• Workplace training/Online trade-specific training • Self-directed learning options • Certification *via* Cooperative Extension Program	• Climate and health certification • Work with consultants to help a business specialize in CHL • Continuing education course or retreat (3–5 days)	• See available higher education options in local area
Graduate and professional programs (non-health)	• Videos, seminars, brief readings/fact sheets	• Conferences or a 1–2 Day workshop • Critical analysis of news articles	• Certificate/Minor linked with degree • 1 credit seminars • Internships (for credit)	• Build into thesis work/professional capstone/Internships • Collaboration with health faculty • Case example: CHANGE at UW-Madison
Clinical and public health graduate and professional programs	• Video as part of orientation process/week + campus events • Included as part of core professional development curriculum	• Conferences or 1–2 Day workshop • Critical analysis of news articles	• Certificate/minor linked with degree • Internships (for credit) • MPH online major in climate and health	• Critical analysis of science studies • Recurring Research seminars with writing requirements • Professional conferences • Case example: Capstone experience
Practicing professionals and current workforce				
Current teachers and faculty	• Handouts, journal articles, or videos • 30-60 min interactive videos • Orientation training • Discipline Specific Fact sheets	• Webinar/1-2 day workshop • Team training	• Faculty learning community that meets regularly • See this: https://facultyforafuture.org/	• Recurring Research Seminars with writing requirements • Professional Conferences • Designated ways to help teachers evaluate CHL of their students
Non-health professionals (lawyers, architects, engineers, journalists)	• 4 × 15 min interactive video • Profession-specific fact sheets • Orientation training	• Continuing education 1-day workshop	• Semester-long continuing education • Continuing Education Retreats (2-5 days)	• Train-the-Trainer Model: Achieving designated CHL subject matter expert status for educating Tier 1/Tier 2 level

(Continued)

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TABLE 1 (Continued)

CHL elements	Levels 1–2 (functional)		Levels 3–5 (intermediate)	Levels 6–7 (advanced)
Audience	Tier 1: Fast pass exposure	TIER 2: Breaking the ice (professional development training and enrichment)	Tier 3: A la carte learning (for credit options)	Tier 4: Apprenticeship (immersive curriculum)
Clinical and public health practitioners	• Handouts, journal articles, or videos	• Conference session • Webinar for continuing medical education	• Semester-long continuing medical education • Continuing Education Retreats (2-5 days)	• Recurring Research Seminars with writing requirements • Professional Conferences (or sections at conferences)
Public service professionals (e.g., fire fighters, police officers, EMT, military, crossing-guards)	• Job onboarding/training (e.g., how climate hazards will affect their work) • Trade Specific Fact sheets • 4 × 15 min interactive video module • Yearly CHL Refresher Breakfast	• Continuing education (1-day workshop) • Scenario planning and job-specific climate hazard case studies workshop • Certificate *via* Cooperative Extension Program	• Continuing Education Retreats (2-5 days)	• Train-the-Trainer Model: Achieving designated CHL subject matter expert status for educating Tier 1/Tier 2 level
Policymakers (municipal, local, statewide, regional, national)	• 4 x 15 min interactive video modules • Short white papers with corresponding short presentations • Locale Specific Fact sheets Example: https://iclei.org/en/webinars/TR~	• Workshops at policy conferences: https://climateadaptationforum.org/	• Continuing education retreats (2-5 days)	• Train-the-Trainer Model: Achieving designated CHL subject matter expert status for educating Tier 1/Tier 2 level
Farmers, ranchers, and other agricultural managers	• Extension outreach • Continuing education • Conferences for targeted audiences put on by local Universities • 4 × 15 min video modules • Learning Hubs • Yearly CHL refresher breakfast	• Certification *via* local Cooperative Extension program • Training or education on Incentives for taking action on climate change + health and Scenario planning and job-specific climate hazard case studies workshop	• Continuing education retreats (1-3 days)	• Train-the-Trainer Model: Achieving designated CHL subject matter expert status for educating Tier 1/Tier 2 level
Other interested individuals				
Retirees, church groups, community organizations, non-profit organizations	• Videos (PBS NOVA type documentary) • Discuss/distribute articles in popular media	• 1 or 2 day workshop hosted by local organization • Certification *via* Cooperative Extension program	• Local academic lectures or view online lectures • Translation of big analyses (e.g., IPCC, National climate assessment, lancet countdown) • Continuing education retreats (3-5 days)	• Train-the-Trainer Model: Achieving designated CHL subject matter expert status for educating Tier 1/Tier 2 level

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that increased education and training to build climate and health literacy (essentially a foundational understanding of climate change and how it affects human health), may be an effective way to accomplish this goal. Further, we offer a blueprint for building this instruction into the lifecourse through already existing educational routes. A key tenant of this blueprint is a student-centered approach that focuses on the learners' context. For example, we provide examples for tailoring this education to the participants' age, previous exposure to climate change education, interest level, and/or profession.

Momentum is already building to formalize climate training for students globally. For example, in response to mounting climate change concerns from university students, leaders at the University of Barcelona have planned a mandatory course on climate change for all students beginning in 2024 (49). As such instruction becomes more prevalent in the years to come, it is important that this training focus on equipping students with concrete knowledge about the threats posed by climate change to their health and wellbeing, and promote development of skills and techniques to build resilience amongst learners. And, since these student skills are inherently interdisciplinary, climate and health-literate learners are both marketable and transferable, assets that could lead to more career options in the future.

One of the major strengths of this approach is that it can be implemented at many levels today, without starting from scratch or reinventing the curricular wheel. Some universities already have climate change preparedness and climate change adaptation for emergency management classes in existence [e.g., (50)]. These classes could potentially be added to and modified for existing undergraduate and graduate training, or even amended for associate's degree programs/trade school programs. By integrating health content into existing formal and informal educational training platforms on climate change, implementation of this approach may be less financially costly and time-intensive than establishment of entirely new teaching programs. Additionally, the majority of US states have already have cooperative extension programs in place with missions to assist in preparing for and responding to emergencies, protecting the environment, and empowering people to adapt to changing technologies. Thus, enhancing cooperative extension programming to promote professional climate adaptability may be an effective way to reach people outside of the traditional student population.

A potential limitation of this approach is that for professionals interested in advanced tiers of education, the development of curricula, content delivery, and the coordination of formal continuing education credit must be governed by an official professional body. One example of a potential governing body would be *The American Society of Adaptation Professionals (ASAP)*, which is a professional home for people who are preparing from climate impacts in their jobs, in their communities, and in their fields of practice. The ASAP hosts education and training for climate adaptation and resilience professionals. While this governing body is currently for climate adaptation professionals, perhaps its model could be expanded to fields that are not explicitly focused on climate adaptation, yet are significantly affected by climate change.

Despite scientific consensus that climate change is real, there will continue to be climate change deniers in every occupation at every age group. The purpose of climate and health literacy is not necessarily to convince people that climate change is real. However, one overarching message of this CHL education initiative is to (1) ***convey*** the elevated risk to human health resulting from increasing exposure to climate hazards and (2) ***determine*** what is and ***execute*** the best course of action for resilience and adaptability in reference to specific professions. Moreover, by utilizing the "meeting people where they are" approach, this increases likelihood of assimilation among learners, no matter where they stand in accepting the science behind climate change.

As the changing climate continues to dramatically alter society and endanger public health (1), it is essential that a broad segment of the population is knowledgeable about the causes and impacts of climate change. To catalyze and sustain climate change action and adaptation, we believe targeted education highlighting climate and health literacy should be established across the life course. This blueprint is a foundation for a practical, transformational educational initiative across the US, with great potential to translate and expand worldwide.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MG is a post-doctoral fellow in the Department of Family Medicine and Community Health in the UW Madison School of Medicine and Public Health, and also co-led this effort with VS, MH, and VL. VS is a Research Scientist at the University of Wisconsin – Madison, Center for Sustainability and the Global Environment. MH is an Associate Professor of Environmental Health at the Institute for Circumpolar Health Studies at the University of Alaska-Anchorage. VL is a Scientist at the Natural Resources Defense Council. All authors participated in the conception of the perspective piece, reviewed relevant research, designed the blueprint, and conducted much of the writing of this manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Assessing climate and health curriculum in graduate public health education in the United States

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Climate change has been identified as both a challenge and an opportunity for public health. The onus to prepare the next generation of public health practitioners lies heavily on schools and programs of public health. This article (i) assesses the status of climate change and health curricula in accredited schools of public health in the United States and (ii) proposes strategies to better train professionals so they are more informed and prepared to mitigate, manage, and respond to the health impacts of climate change. Course offerings and syllabi listed in online course catalogs from 90 nationally accredited schools of public health were evaluated with the purpose of identifying the extent of climate change education in graduate programs. Only 44 public health institutions were found to offer a climate change related course at the graduate level of education. Of the 103 courses identified, approximately 50% (n=46) are focused on this climate change and health. These courses cover a wide array of topics with an emphasis on conveying fundamental concepts. In-depth assessment revealed a need for integrating learning opportunities that build practical skills useful in a hands-on public health practice environment. This assessment indicates the limited availability of climate-health course offerings available to graduate students in accredited schools. The findings are used to propose an educational framework to integrate climate change into public health curricula. The proposed framework, while rooted in existing directives, adopts a tiered approach that can be readily applied by institutions training the next generation of public health leaders.

KEYWORDS

climate change, curriculum and instruction, training, climate and health education, climate and health

1. Introduction

Climate change is a complex and present challenge facing current and future generations. Climate change is increasing the frequency, duration, and intensity of climate-driven events (1) posing significant threats to human health and wellbeing. Health impacts include higher incidence of asthma and respiratory disease related to air pollution and allergens; increased deaths due to extreme heat; and, increased risk of waterborne, foodborne, and vector borne disease as a result of higher temperatures (1, 2). The far-reaching and diverse impacts on both environmental and human systems introduce challenges associated with identifying, mitigating,

and managing the myriad direct and indirect consequences to health and wellbeing. The opportunity, however, lies in the ability to frame climate change as a public health issue, bringing together sectors and disciplines to adopt a human health-centric, holistic approach to enhancing resilience to climate change.

Governmental and non-governmental organizations including public health agencies at local/municipal, tribal, state, province/district and national levels play a critical role in managing and responding to the health effects of climate change. Although this paper focuses on building public health capacity in the United States, the principles and recommendations described in this paper also apply at an international level. All public health professionals need at least a basic understanding of climate change impacts on human health and wellbeing and how to mitigate, manage and respond to them.

Several national and regional assessments and surveys highlight workforce training needs to prepare public health professionals for understanding and managing the health implications of climate change (3–6). These assessments and surveys describe a pressing need for education and training that builds knowledge of climate science as well as climate-health relationships and illustrates relevance of public health essential functions and principles with climate change impacts (5, 7). In response, professional, non-profit and governmental organizations have initiated webinars, focused trainings, and have integrated climate-health relevant topics in conference agendas and themes. The plethora of resources available on national public health websites as well as the inclusion of climate and health topics on conference agendas (e.g., the 2017 National APHA Conference theme was Climate and Health) indicate climate change is being elevated as a priority in mainstream public health.

Institutions of higher education play a vital role in building future public health professionals' capacity to understand, manage, and address the health impacts of climate change (8). Higher education institutions can engage students from varied disciplines and programs (both public health and non-public health) fostering values in collaboration and systems thinking that cannot be easily replicated in a workforce environment. As of December 2022, there is currently no direct reference to climate change in the Council on Education for Public Health (CEPH) accreditation criteria; however, there is clear alignment with multiple core competencies at the undergraduate and graduate levels (9, 10). CEPH is the national organization responsible for accreditation of both schools of public health and public health programs while the Association of Schools & Programs of Public Health (ASPPH) is a national organization that advocates for high-quality education standards and comprises of both CEPH-accredited schools and programs of public health as well as those in applicant status for CEPH-accreditation. ASPPH has also released a toolkit in collaboration with the Global Consortium on Climate and Health Education (GCCHE) that "provides practical approaches and tools for integrating climate change and health education into a public health curriculum" (11). Housed in Columbia University, the GCCHE advocates for climate-health education among all health professionals. Public health professional organizations and academic institutions have also begun to emphasize the need and opportunity to enhance the future public health workforce's understanding and capacity to respond to climate change. Recent initiatives including the release of this toolkit by the ASPPH, in collaboration with the GCCHE, have elevated the need for active involvement and intensive action to prepare the future public health workforce in meeting the climate change challenge. The toolkit is built on the GCCHE core competencies, which are geared toward educating all health professions about climate and health relationships (8).

While several studies highlight the need for climate and health education for the health professions, including public health (8, 12, 13), little is known about the current extent of climate change education in graduate programs of public health in the United States. This study builds on Becker et al. (14) and assesses the extent of climate change and health courses offered at ASPPH institutions of public health in the United States at the graduate level (Master's and Doctoral degrees) through a broad scoping analysis and reviews of available course syllabi.

2. Methods

This study assessed the extent to which ASPPH-accredited colleges of public health integrate climate change into existing graduate curricula by identifying courses listed in online program websites and catalogs. A list of accredited institutions awarding any form of graduate degree in public health (e.g., MPH, MHA, MS, MHS, PhD, ScD, and DrPH) were obtained from the ASPPH website. Each institution's website, course catalog, and schedule of classes was assessed to identify any course offerings that used a range of terms including "climate," "climate change," "global warming," "environment," or "environmental change" in the course title and/or description. Results referring to climate in the non-environmental context (e.g., economic, work or cultural climate) were excluded from analysis.

2.1. Data collection and analysis

All data were collected between May and July 2018 and maintained in an Excel spreadsheet. Primary syllabus analyses were conducted using NVivo Pro to categorize learning objectives and course deliverables along Bloom's taxonomy. Course information including title, description, objectives, and delivery (online, hybrid, or face to face), was obtained for each course that was identified. Two levels of analysis were conducted to characterize the integration of climate change into the curricula. Level 1 analysis focused on the extent climate and health topics were addressed in coursework. Level 2 analysis assessed the approach (i.e., learning objectives, content areas) adopted in courses identified in Level 1.

Each course was assigned into one of two categories: Focused, if climate change was deemed to be the focus of the course or Integrated, if climate change was included as one of the topics in the course. Designation into the above categories was determined by a review of the course title and description. If the terms "climate," "climate change," "environmental change" or "global warming" were listed in both the title and description then the course was listed under the "Focused" category. If these terms were listed under the course description but not course title and a scan of the course content revealed only a specific lecture on this topic, then the course was designated as "Integrated" referring to the integration of the topic into the course. We distinguished between focused courses and those that integrate climate and health across multiple courses. This provides a more in-depth understanding of the extent to which climate and health is being taught at schools of public health.

2.2. Assessment frameworks

Course syllabi were downloaded for any courses that were openly available on the school or program's website. Contacting authors in a thorough comprehensive and consistent way was not feasible at the time of the study, leading to a focus only on those courses and syllabi easily accessible online. Primary search efforts were focused on current course catalogs and listings; however, any available past course listings were also assessed for this study. Course syllabi and objectives were evaluated using Bloom's revised taxonomy (15) as an indicator for the degrees of complexity and cognition required in the course. Bloom's revised taxonomy provides a structure through which instructors can engage students in differing levels of learning. Learning objectives, if provided in the syllabi, were aligned to one of the six taxonomy categories to assess the level at which the climate-health relationship was covered. The verbs used to structure a learning objective were classified into each category to determine the level of learning expected in these courses collectively. Verbs falling under the remember, understand and apply categories were indicative of less complex learning expectations such as defining, classifying, and developing. Verbs associated with analyzing, evaluating, and creating categories were classified as more complex, higher order learning.

3. Results

Our course search provided insight into the availability of climate and health courses at schools and programs in public health. Of the public health institutions evaluated in this study, 51% (46 of 90) did not offer any climate change-related course. The remaining 44 institutions were found to offer 103 climate change-related courses of which there were 44.6% (or 46) courses that were *focused* on climate and health while the remaining 57 courses *integrated* this topic into a broader course topic area.

The courses identified were all offered by the public health school or program either currently or within the previous 4 years; they included graduate only and joint undergraduate/graduate courses, and both online and in-person forms of delivery. In addition, 23% of ASPPH schools were found to offer more than 1 course that either focused on or integrated climate change and health.

As each course was identified, further research was conducted to locate and download the course syllabus for further analysis. Syllabi of 46 courses (22 focused, 24 integrated) were readily available for download and review. All graduate course syllabi were reviewed for further analysis, resulting in the exclusion of eight courses that were undergraduate courses, non-public health courses, or climate change associated courses that had incomplete open-access syllabi (6 focused, 2 integrated). Table 1 illustrates the breakdown of courses identified in this study.

Integrated courses: Courses were categorized as integrated if "climate change" environmental change," "global warming," "environment" or "environmental change" was identified as a course sub-topic or described in a learning objective. The 22 integrated syllabi were reviewed to determine the extent to which climate change, global warming, and/or environmental change were covered in the syllabi.

Although all courses integrated a discussion of climate change as a public health issue, they differed in the scope and context within which the topic was discussed: Fifteen courses were found to describe or list climate change as one of many topics in relation to human health; two courses covered a specific aspect of climate change such as global climate change models and mechanisms of climate change and seven courses discussed the topic in the context of a broader topic (e.g., built environment, deforestation, advocacy and environmental justice, and frameworks to address global challenges).

TABLE 1 Climate-health course summary.

Number of institutions reviewed	90
Institutions with zero courses	46 (51.1%)
Institutions with at least 1 course	44 (48.8%)
Number of total courses identified	103
"Integrated" courses	57 (55.3%)
"Focused" courses	46 (44.7%)
Syllabi available for download and included for analysis	38
"Integrated" course syllabi	22 (57.9%)
"Focused" course syllabi	16 (42.1%)

Among all evaluated courses in this category, only 10 courses included a learning objective in relation to climate change and health.

Focused courses: Sixteen syllabi for courses specifically focused on "climate change" or "environmental change" and health were analyzed to contextualize how climate change was addressed in curricula. The analysis revealed that 87.5% (or 14) courses were housed in the environmental health science department of the public health program. As illustrated in Figure 1, these courses covered an array of topics.

Courses also discussed a wide range of relevant issues such as communication, food and water security, and energy and sustainability. A review of the readings list (when available) and course description also indicated the use of both international (i.e., International Panel on Climate Change Report on Global Warming) and national (i.e., United States Global Change Research Program National Climate Assessment) reports to inform students of the current state of knowledge. Figure 2 provides the breakdown of learning objectives across Bloom's taxonomy.

A review of course syllabi including course evaluation criteria and forms of student assessment indicated term papers, in-class (individual or group) presentations, and exams as preferred methods to evaluate student learning. The evaluated syllabi identified minimal use of case studies and performance on problem-solving, scenario-based activities as assessment formats in these courses. On the other hand, instructors seemed to encourage students to delve into more focused topics of interest through term papers or presentations.

3.1. Proposed framework

Drawing on the analysis and findings above, we propose the following 4-tier framework for accredited schools of public health to increase knowledge and awareness as well as skills in managing and addressing the health impacts of climate change. The framework recognizes the challenges (e.g., limited topical expertise, timeframe, staffing, budget, etc.) faced by institutions to create and launch fully functional courses on the topic. Therefore, the proposed framework adopts a tiered approach for easy, staged adoption through which to increase awareness of climate change into public health education. The framework proposes treating climate change as a public health stressor no different than other cross-cutting public health issues (e.g., socio-economic factors) in the curriculum.

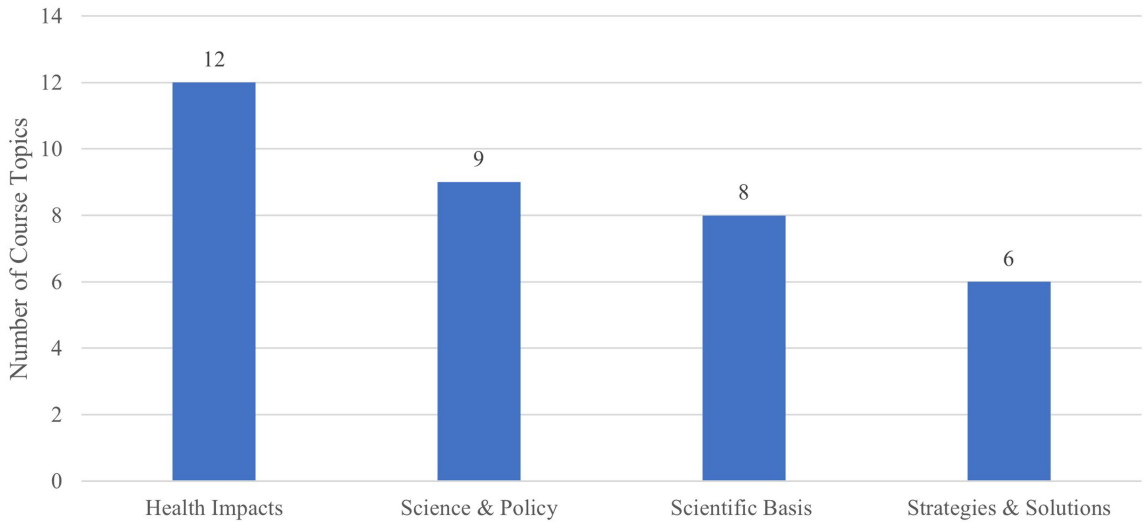

FIGURE 1
Most commonly taught topics in climate-health courses.

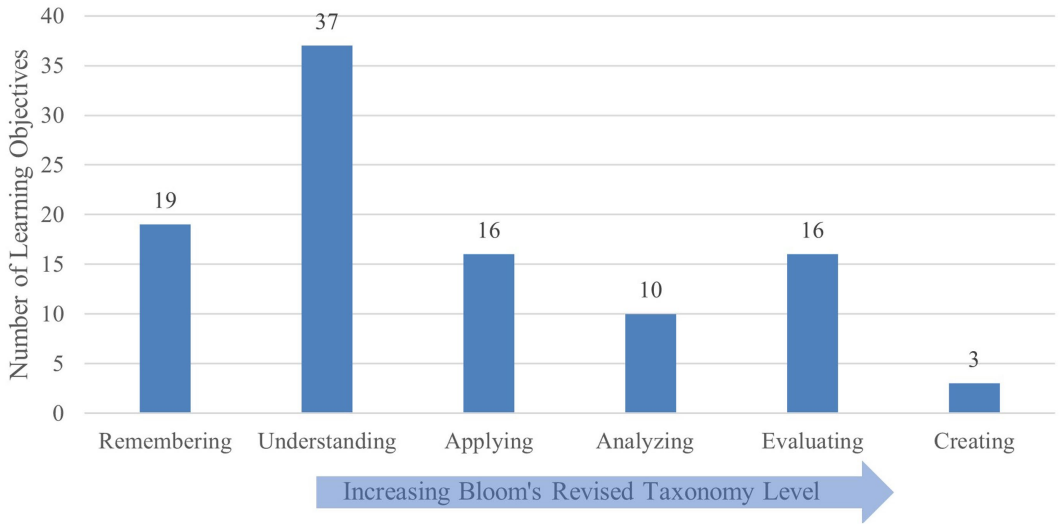

FIGURE 2
Analysis of focused course learning objectives using revised Bloom's taxonomy.

The framework proposes that climate and health curricula in public health should:

1- Be rooted in pedagogy that utilizes backwards design methodologies that emphasize skills, learner-centered course design, and integrate active learning approaches.
2- Acknowledge the complexities of graduate in-person (i.e., face to face) and online teaching, including the diverse preparation of students in climate change topics.
3- Provide opportunities for peer-to-peer as well as instructor-led learning.
4- Illustrate the importance of the interdisciplinary nature of the issue and the approaches required to both understand and address it.

We encourage higher education institutions and, in particular, schools and programs of public health to provide students with multiple, consistent opportunities through which to understand the challenges associated with climate change. In the absence of national curricula directives, individual institutions should collaborate with experts and existing communities of practice to develop and share curricula best practices for adoption in their respective public health programs.

At a minimum, we propose that institutions dedicate resources and efforts to integrate a climate change lens into the core public health courses and disciplines (Tier 2-Building knowledge) including biostatistics, environmental health sciences, epidemiology, health policy and management and social and behavioral sciences. This will ensure that students in all public health focus areas not only receive the

TABLE 2 Proposed climate and health educational framework.

Tier	Objective	Modality	Examples
Tier 1: Building awareness	Provide students with exposure to climate change and health relevant issues.	Single-point lectures and activities to introduce the topic area.	Forums, Brownbag series, Seminars, Colloquiums.
Tier 2: Building knowledge	Ensure that students understand the importance of climate change and its relevance to all public health topic areas.	Climate change lens and case studies integrated into public health core courses.	Module on evaluating existing healthcare policies on how climate and health co-benefits can be achieved.
Tier 3: Enhance knowledge, problem-solving, and critical thinking	Prepare students for assessing and addressing the health impacts of climate change.	Interdisciplinary education opportunities that provide fundamental knowledge and opportunities for application of material to address practical field challenges.	Dedicated course on public health aspects of climate change, Inter-professional education courses.
Tier 4: Tailored skill building	Provide students with the platform to delve into a focused area of study in relation to climate and health.	Specialized course and/or program with a topical focus.	Climate modeling methods course, Special topics course on climate change communication.

required fundamental concepts but understand the relevance of this issue to their specific discipline. We acknowledge the time and resource constraints required to undertake the implementation of this goal and accomplish Tier 1 (building awareness) activities through collaboration with academic and field experts to organize guest lectures and forums. In the long-term, public health institutions should strive to complement Tier 1 and 2 educational activities with the development of a course specific to public health and climate change (Tier 3- Enhance knowledge, problem-solving, and critical thinking). Existing toolkits and guidelines can be expanded to include modules and slide decks that cover climate and health basics to support institutions that have limited expertise in attaining at least Tier 1 implementation. Dedicated courses can be co-created with multiple academic (both health and non-health) units to provide a comprehensive, cross-sectoral, and multidisciplinary understanding of the health aspects of the climate change problem. Similarly, once a fundamental basic climate and health course has been established, it is recommended that public health schools and programs consider implementing any special topics courses (Tier 4- Tailored skill building) and/or climate and health concentration areas for developing a skillset in this area. The tiers comprising this framework are summarized in Table 2.

4. Discussion

Public health practitioners are at the forefront of responding to health outcomes that result from climate change. Whether willing or not, public health is being called upon to take action to prevent, manage, and address the health impacts of climate change (16).

Training the next generation of public health leaders is an initiative that can be addressed by schools and programs in public health. Approximately 50% of ASPPH institutions assessed in this study did not list a course that clearly included climate change content on their program website or course catalog, indicating a need for the development of further structured opportunities in climate and health in graduate public health education. These findings highlight a significant gap in the knowledge and skills provided to the entering public health workforce members, in particular, their awareness and ability to inform public health action and management of climate change impacts.

All focused courses were electives offered by departments and units responsible for the environmental health focus area of public health. We recognize that a certain level of expertise resides within this sub-discipline, but this is done at the cost of overlooking other aspects of the issue (e.g., policy management, health promotion) that may not be as well incorporated into the existing curricula. This assessment corroborates findings from public health professional interviewees that stressed the need to communicate and engage with counterparts in different branches of public health to incorporate the climate change dialogue and inform decisions that have climate and health co-benefits (17).

Current offerings of climate change courses focus on fundamental climate and health relationships and do not cover topics relevant to public health practitioners. Courses cover a wide array of sub-topics referenced in the GCCHE competencies (18), ranging from climate dynamics and environmental drivers of health to human health impacts and public health actions including adaptation, policies, and risk assessments.

The systematic review of the course syllabi implies a tendency to focus on transmitting knowledge of key issues that form the basis of our understanding of climate change and health (i.e., scientific basis, health impacts, and possible solutions) rather than expressing climate change in ways directly relevant to public health practitioners such as public health practice and policy aspects of the issue (e.g., health equity, systems thinking, program development, and planning) (16). While the course content focuses on knowledge, course assessments focus on critical thinking and understanding key concepts as evidenced by research papers and in-depth topic investigations. These findings indicate areas for improvement to optimize the learning opportunities that facilitate practical skill-building and translate knowledge to skills useful in an environment of public health practice.

Graduate public health education needs to prepare students for working effectively in the field. In dealing with the challenge of climate change, graduate public health education should be applied, build a strong foundation in the human-environment dimensions of health, promote interdisciplinary problem-solving and critical thinking, and provide graduates with a set of tools in their toolbox with which to approach problems in the field.

Graduate institutions must meet the needs of future employers. These are the individuals who will find themselves communicating the relevance of a changing climate to their communities, expanding their collaborative networks to include city and county divisions of transportation and urban planning to heighten awareness of the

health implications of local decisions; and conducting research to inform the development of tailored, community-based interventions. The proposed framework allows schools and programs to assess their expertise and adopt any combination of the tiers proposed. It is recommended that all institutions implement at least Tier 1 and Tier 2 over the next 5 years. For smaller programs with limited faculty expertise, curricula resources including videos and activities are available through the ASPPH and GCCHE toolkits.

Existing competency frameworks such as the GCCHE provide recommendations on how to achieve foundational knowledge on climate change and health in graduate public health education. Central to existing GCCHE competencies and ASPPH guidelines is the notion of collaborating, communication, and the underlying goal of preparing health workforce (including public health and other health professions) to address the health impacts of climate change. Given the highly integrative and transdisciplinary approach needed to adapt to the global climate crisis, we further recommend that all academic institutions and broad national professional organizations such as GCCHE deepen their collaborations across disciplines and sectors to develop more complex and realistic case studies to enhance training and preparation for the challenges associated with climate change.

4.1. Limitations

This study was limited due to inaccessibility of all syllabi and course information on institutional websites. Many institutions did not provide access to the course catalogs on their school or program webpage, potentially resulting in the exclusion of courses that may have been offered in prior years or are offered in a cyclical manner (i.e., every other year). Furthermore, when course listings were provided, course syllabi were often unavailable. Topical seminars offered by schools and programs but not listed with content-specific details were likely missed during the course search process.

Another limitation of this study is that courses outside of the schools of public health were not considered in the analysis unless they were explicitly identified as a required or elective course. Courses may be offered by other departments within the academic institution such as Geography, Environmental Sciences, Natural Resources, or Communications. However, they were not included in this study.

5. Conclusion

A review of existing syllabi indicates the need for courses that provide students with meaningful, relevant, and higher order learning on climate change and health. Existing guidelines developed by national organizations such as ASPPH and the GCCHE should inform curricular design. In the absence of climate change in national public health accreditation criteria, these guidelines and calls for action should inform the approach to exposing the public health student to the significance of climate change on public health. However, the inclusion of climate and health in graduate and undergraduate public health program accreditation criteria is long overdue and is needed to ensure a baseline level of competency among graduating, future public health professionals.

Our proposed framework proposes mechanisms to enable public health graduate programs to integrate climate and health education into the existing curricula. The proposed framework allows schools and programs to assess their expertise to adopt any combination of the tiers proposed to provide multiple opportunities for building knowledge and skills among their student body. It is recommended that all institutions, particularly smaller programs with limited expertise, strive to attain Tier 2 and 3 of this framework to foster awareness and knowledge regarding the health aspects of climate change. Larger programs and schools should have access to expertise and resources to adopt all tiers of the framework to provide students a range of opportunities to learn about climate and health.

While this framework focuses on graduate education, it can be adapted and tailored for integration of climate change into undergraduate education including standalone public health bachelor's programs. Small local health departments are less likely to employ public health professionals such as epidemiologists and statisticians that have graduate degrees (19). Therefore, building local public health capacity will require training students at both undergraduate and graduate levels on the complexities associated with climate change. Thus, we advocate for the adoption of this framework to train students regardless of degree (e.g., undergraduate or graduate) or health field focus (e.g., public health, medicine, nursing) as well as for continuing workforce education. Finally, we encourage the integration of climate change into existing accreditation criteria and credentialing mechanisms.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MA: analyzed the data. All authors conceived and designed the study, and contributed to the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ten characteristics of high-quality planetary health education—Results from a qualitative study with educators, students as educators and study deans at medical schools in Germany

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Aim: The climate and ecological crises are considered fundamental threats to human health. Healthcare workers in general and doctors in particular can contribute as change agents in mitigation and adaptation. Planetary health education (PHE) aims to harness this potential. This study explores perspectives among stakeholders involved in PHE at German medical schools on the characteristics of high-quality PHE and compares them to existing PHE frameworks.

Methods: In 2021, we conducted a qualitative interview study with stakeholders from German medical schools involved in PHE. Three different groups were eligible: faculty members, medical students actively involved in PHE, and study deans of medical schools. Recruitment was performed through national PHE networks and snowball sampling. Thematic qualitative text analysis according to Kuckartz was used for the analysis. Results were systematically compared to three existing PHE frameworks.

Results: A total of 20 participants (13 female) from 15 different medical schools were interviewed. Participants covered a wide range of professional backgrounds and experience in PHE education. The analysis revealed ten key themes: (1) Complexity and systems thinking, (2) inter- and transdisciplinarity, (3) ethical dimension, (4) responsibility of health professionals, (5) transformative competencies including practical skills, (6) space for reflection and resilience building, (7) special role of students, (8) need for curricular integration, (9) innovative and proven didactic methods, and (10) education as a driver of innovation. Six of our themes showed substantial overlap with existing PHE frameworks. Two of our themes were only mentioned in one of the frameworks, and two others were not explicitly mentioned. Few important elements of the frameworks did not emerge from our data.

Conclusions: In the light of increased attention regarding the connections of the climate and ecological crises and health, our results can be useful for anyone working toward the integration of planetary health into medical schools' and any health professions' curricula and should be considered when designing and implementing new educational activities.

KEYWORDS

climate change, climate resilience, planetary health, planetary health education, medical education, transformative education, education for sustainable healthcare, eco health

1. Introduction

The climate crisis has been called the most significant threat to human health in the twenty-first century (1). It is one important element of a planetary health (PH) perspective, others include biodiversity loss, global social injustice, limits to growth (2) and the risk of civilization collapse via nuclear conflict. Effects of the climate and other environmental crises on human health worldwide can already be observed (3). These health impacts vary by region. Prevalent risks in Western Europe, including Germany, include extreme weather events, such as heat waves and flooding. Moreover, a rise in disease burden through allergies and changes in occurrence of certain infectious diseases linked to the climate crisis are observed (4–6), as are negative mental health effects, especially for young people (7, 8). The interdependence of human health and wellbeing and planetary ecosystems is at the core of the emerging concept of PH, which has been defined as "the health of human civilization and the state of the natural systems on which it depends" (9). Achieving PH requires a profound transformation of all areas of human activities, for example the energy, mobility and agri-food systems. At the same time, adaptation to the already occurring (health) impacts of the changes in planetary ecosystems is required. Education can play an important role in this regard when it "includes knowledge transfer to raise awareness of certain realities, critical analysis to understand the complexities underlying these realities, and experiential exposure to connect to these realities" (10, 11).

The health (care) sector plays a specific and important role in the mitigation of and adaptation to the unfolding planetary crises: On the one hand, it contributes to the climate and ecological crises by generating 4.4% of the global greenhouse emissions and a high resource use (12). On the other hand, it has to respond to changing disease burdens caused by these crises (3). This implies that the education of health professionals needs to be adapted so that they become equipped with the knowledge and skills they need to address these health impacts. Additionally, it has been suggested that health professionals can play an important role as change agents in driving the transformative societal changes needed to mitigate the climate and ecological crises (13, 14). Health professionals belong to the most trusted of all professional groups in society (15) and the medical professional ethos demands care for individual and population health, including that of future generations (16). In Germany, the duty to maintain natural living conditions is explicitly mentioned in the medical professional code (17).

Planetary health education (PHE) aims to "equip people with the necessary knowledge, skills and values, as well as a sense of self-confidence and self-efficacy in the face of multiple environmental and social crises, in order to collectively achieve the necessary transformation of societal activities for planetary health" [own translation (18)]. Within medical education, it cannot be expected for all students to become experts for PH topics, but it is crucial to get a general understanding of the most important aspects as well as (further) develop values aligned with planetary health in their professional identity formation.

Several conceptual frameworks, detailed road maps, and principles for PHE have recently been developed. The Association of Medical Education in Europe (AMEE) has laid out in its "Consensus Statement: Planetary health and education for sustainable healthcare" (19) examples of learning activities, opportunities, and possible assessment modes as well as a road map and targets for implementing PHE. Further conceptual frameworks that define the scope and aims of PHE are the 12 "Cross-cutting principles for planetary health education" (20) and "A framework to guide planetary health education" (21).

Although the integration of PHE into the medical curriculum has been demanded repeatedly, including by medical students in Germany and globally, the integration of PHE into medical education and the monitoring of these processes remains insufficient (22–27). Like in other countries, such as the UK (28), previous studies show that that the majority of German students is not yet familiar with the PH concept, but would like to learn more about PH and consider it relevant to their studies (29). While a growing number of curricular and extracurricular educational activities is being implemented at several institutions, including nationwide lecture series (11), the experience of stakeholders involved or interested in PHE at German medical schools has, to our knowledge, not yet been explored. The opinion of the stakeholders of what characterizes high-quality PHE could inform the process of integrating PHE into medical education in Germany.

The aim of our study therefore is to explore the insights into the characteristics of high-quality PHE of a broad range of stakeholders - educators, students as educators and study deans - who are involved in PHE at German medical faculties. We also assess whether our findings are related to existing PHE frameworks.

2. Materials and methods

2.1. Study design

This qualitative interview study is a component (substudy C, see Supplementary material S1) of the mixed methods study: Planetary Health in Medical Education in Germany (PlanetMedEd). The aim of the PlanetMedEd study is to comprehensively investigate and explore the current state and diverse perspectives of the potential ways forward for PHE at German medical schools. Further components include a nationwide student survey and a systematic overview of PHE initiatives including a systematic web search. Results of these components will be published elsewhere.

2.2. Study population and recruitment

Three groups were eligible for participation in this study: Educators, students as educators (18 years and older), and study deans who were involved in PHE or were interested in establishing PHE at their institution. Participants were recruited *via* the contact list of the PHE working group (30) of the German Alliance on Climate Change and Health (KLUG e.V.) and through snowball sampling. Some individuals were recruited in alumni and student groups within the Master in Medical Education (MME-D) programme at Heidelberg University. In addition, results of the web search conducted as part of the PlanetMedEd study (Substudy A) were also used to identify eligible individuals.

2.3. Data collection and analysis

We conducted interviews between June and September 2021 *via* the Zoom® video-conferencing software or *via* telephone based on a semi-structured interview guide (see Supplementary material S2). Additionally, sociodemographic data (gender identification, age in categories, academic background, and profession) as well as further professional qualifications and activities or expertise considered relevant for PHE by the interviewees were collected to allow contextualization of the qualitative findings. The transcripts were completely anonymized and contained no personal or third-person information that would allow tracing any identities. Data on sociodemographic characteristics were only collected for contextualization and are presented in aggregated categories.

Data were collected jointly by JS (doctoral thesis student) and E-MS-S (MD, MScIH, experienced in PHE and implementation research). JS conducted 4 interviews alone. Both researchers were present in 13 interviews and took turns in conducting the interviews and note-taking. The interviews were audio-recorded and transcribed verbatim. The same two authors (E-MS-S, JS) were involved in the coding process. Thematic qualitative text analysis with a content-structuring approach according to Kuckartz was performed in MAX-QDA 2020 (31). For the current study, we deductively grouped data into main categories adapted from the main interview questions (see Figure 1), then we inductively developed sub-categories within the first main category on PHE characteristics.

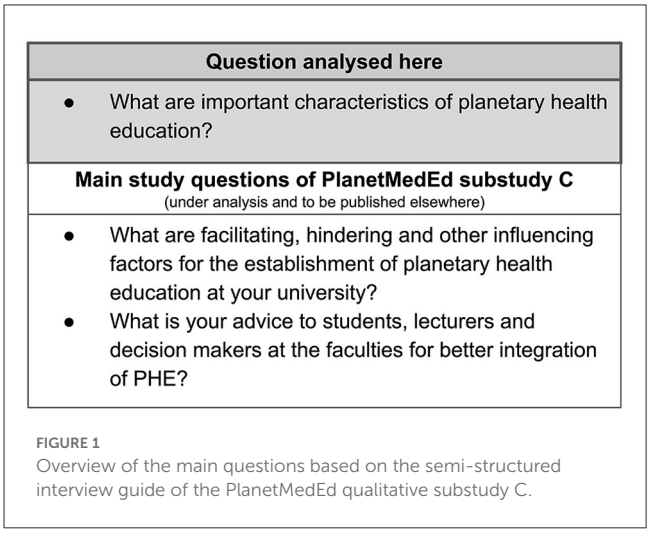

FIGURE 1
Overview of the main questions based on the semi-structured interview guide of the PlanetMedEd qualitative substudy C.

The process of inductively developing sub-categories included the following steps: After familiarizing ourselves with the data, we first created sub-categories independently for three randomly selected interviews. We then compared and discussed these sub-categories. As an intermediate analysis step, case summaries were created for each interview to create a better overview of the data. A detailed system of sub-categories was then created based on all interviews and was discussed several times in the research team for completeness and consistency before it was applied to the entire text material. We performed several iterations to adjust the sub-category system.

In a second analysis step, we compared the categories developed in this way with three existing frameworks for PHE: With the "Cross-cutting principles for PHE" by Stone et al. (20), with "A Framework to guide PHE" by Guzmán et al. (21), and with the "AMEE consensus statement: Planetary health and education for sustainable healthcare" by Shaw et al. (19). For this purpose, E-MS-S, JS, and KW (MD, experienced in PHE and qualitative research) independently assessed whether our categories corresponded to elements in the central figures of each framework. Any discrepancies were resolved through discussion. In this step, we did not aim to compare the three frameworks with each other or to explore in depth how our sub-categories corresponded to the content of the entire text body supporting each framework. We rather aimed to broadly compare them in order to assess whether our data could provide new aspects that were not yet covered in the existing frameworks, or if central themes were covered in the frameworks that were not mentioned by our study participants. As guidance for a comprehensible presentation of the study conduct, the checklist presented in the Consolidated criteria for reporting qualitative research (COREQ) guideline (32) was used (see Supplementary material S3).

2.4. Data management and protection

The audio files were transcribed anonymously directly from the recorder and then deleted. Data storage and analysis took place on password-protected computers, in anonymized form and in accordance with the privacy policy.

TABLE 1 Sociodemographic data of the participants.

Characteristics			Number of participants
Gender identification	Female		13
	Male		7
Age (years)	18–30		8
	31–40		5
	41–50		3
	51–60		4
Function	Students as educators	Study Progress: Clinical section/Masters degree up to internship year ("Praktisches Jahr")	7
	Faculty		11
		Professional experience (years)	
		<1	3
		1–10	3
		11–20	
		>20	5
		Teaching experience (years)	
		<1	3
		1–10	3
		11–20	3
		>20	2
	Study deans[a]	Professional and teaching experience: >20 years	2
Further personal information combined for all participants			
Academic background	Medicine with different sub-specialties, molecular biotechnology, biochemistry, public health, medical anthropology, history of medicine, nursing, physiotherapy, environmental health, tropical medicine, geography, medical education, medical informatics, research, and working experience outside of the home country		
Professional background, current occupation[b]	Preventive medicine, public health, medical education, environmental health, history of medicine, community medicine, biology, and toxicology, including various professorships in the listed areas; additionally, decision makers in non-governmental organizations		
Network activity considered relevant for PHE by interviewees[b]	German Alliance on Climate Change and Health (KLUG) and Health for Future (H4F), German branch of the International Federation of Medical student associations (bvmd), Globalization and Health Initiative (GandHI) of the bvmd, activity in various organizations working for environment, sustainability, climate mitigation, climate and health (education), or working groups in medical institutions		
Other experience and expertise considered relevant for PHE by interviewees[b]	Expertise in health education, higher education didactics, (medical) anthropology, human rights, science communication, long-term stays abroad, and long-term cooperation with partners abroad		

[a]Study deans were not actively involved in PHE, but supported PHE at their faculties.
[b]Data are presented in aggregated form for reasons of participant anonymity.

2.5. Ethical considerations

The ethics committee of the University Hospital of Würzburg approved the conduct of the study (file number 20210312-01). All participants were provided with study information sheets and provided written informed consent.

3. Results

A total of 30 potential participants were identified and contacted, of which 20 individuals agreed to participate and were interviewed in 17 interviews (3 interviews were conducted jointly with 2 participants from one university). The interviews lasted between 13 and 43 min, with an average duration of 31 min.

3.1. Sociodemographic data of participants

Participants reported a broad range of professional and academic backgrounds. Eleven participants were faculty members, seven were students actively involved in PHE, and two were study deans. Activity in several networks such as the German Alliance on Climate Change and Health or Health for Future and other experiences were reported as relevant to their PHE expertise or interest (Table 1).

TABLE 2 Ten main themes.

Ten main themes
1. Complexity and systems thinking
2. Inter- and transdisciplinarity
3. Ethical dimension
4. Responsibility of health professionals
5. Transformative competencies, including practical focus
6. Space for reflection and resilience building
7. Special role of students
8. Need for curricular integration
9. Innovative and proven didactic methods
10. Education as a driver of innovation

3.2. Characteristics of high-quality planetary health education

Ten main themes emerged (Table 2). The categories and examples of verbatim translations are listed in Table 3. The complete coding framework can be found at Supplementary material S4, verbatim supplement (VS) VS1-142 in Supplementary material S5, S6.

3.2.1. Complexity and systems thinking

Many participants stressed the importance of a solid foundation of factual knowledge that takes the complexity of the topic into account and at the same time introduces a perspective of systems thinking. The participants perceived fundamental challenges in developing a curriculum that covers the broad range of topics on PH and also discusses them in depth (VS1-3).

"Factual knowledge" (VS7) on climate and environmental changes, knowledge on environmental factors as health determinants, such as urban planning and the psychosocial environment and a historical context of the development of human societies to date were considered important (VS4). Students should be enabled to understand and classify the multiple complex interrelationships of the system and the interaction of these interrelationships with human health (VS17-19) as well as to consider patients in their entire environment (VS19). This eclipses the classical medical curriculum by far (VS15).

3.2.2. Inter- and transdisciplinarity

An integral part of PHE is to bring different disciplines together and to teach and learn together (VS21, VS24-26). This concerns different professional groups and disciplines in the health sector (VS27), but also "the inclusion of other groups and members of society that have not been classically considered by us so far" (VS29). For example, interdisciplinary lectures might include lectures by geographers and space researchers (VS30).

3.2.3. Ethical dimension

An ethical discussion of issues such as gender-based discrimination, racism, sexism, capitalism (VS35), and modern medical treatments and their impact on the environment (VS34) should be included. "Social justice" in terms of a "global justice perspective" (VS40, VS39) and the different regional impacts of environmental change also need to be discussed (VS38, VS41). Students should consider and reflect the principles they see as the basis of society (VS36). "Think globally and act locally" (VS46) represents an important principle here.

Other areas mentioned were individual consumption habits, including those of the students themselves, for example with regard to air travel and meat consumption, including weighing the impacts and learning how to make difficult consumption choices (VS43, VS44).

3.2.4. Responsibility of health professionals

A reflection of one's own position in society as well as options for action or even agency, including the role of a change agent as a healthcare professional, should be part of PHE (VS48-50, VS53). Health professionals should develop a "sense of duty and responsibility" (VS55), and be aware of their social role-model function (VS54). This does not only mean the education of patients about PH issues, but also considers the sustainability aspects of one's own medical practice, financial investments, and mobility (VS51). This requires addressing questions of the (professional) attitude of "medical students as critical citizens" (VS59, VS60).

3.2.5. Transformative competencies, including practical focus

By acquiring knowledge about possible actions and reflecting about their own options for action, students themselves can become change agents and can gain confidence in their own agency (VS61-63, VS65-67), motivating the implementation of own ideas (VS68). Excursions with practical experience can be helpful in this regard, for instance a visit of a sustainable farm (VS64).

Science competencies, including searching, finding, correctly classifying, and evaluating sources of scientific evidence is relevant in order to be able to communicate knowledge properly and also to apply it to one's own actions (VS69-71). Thereby, it can also be part of PHE to acquire and practice communicative skills (VS72) by talking to other groups of society, for example in schools and nursing homes to support transformation within communities (VS73).

3.2.6. Space for reflection and resilience building

Learners need enough space for guided and unguided reflection inside and outside the classroom, to reflect and discuss freely and to share frustrating experiences (VS74-76). This is important to question one's own behavior and values, to promote "systemic thinking, critical thinking" to "broaden the horizon" (VS80), and to reflect on the learning journey (VS78, VS79, VS81, VS82). International and intercultural "long-term social relationships" (VS83) can also create changes in perspective and motivation. PHE

TABLE 3 Ten themes, description of the themes and example verbatims.

Theme	Description	Example verbatims
1. Complexity and systems thinking	The complexity of planetary health topics needs to be covered adequately. This poses a challenge, and PHE shall promote systems thinking	I think it's very important that you don't cut it down to environment and health, but that you include a lot of things, how everything is connected. (VS11, P5) [...] that you don't shorten it and that you somehow accept this whole, [...] huge system, which you can't understand at all because it is so big (VS 13, P5) I think that's the attraction, but also the difficulty, that it's so wide. (VS3, P10) If you want to understand [...] then you don't have to work through all the examples and then know all the examples, but it is enough to work through a few and then you simply have an understanding of how such structures work and how you can rethink such things. (VS14, P5)
2. Inter- and transdisciplinarity	Inter- and transdisciplinary collaboration is necessary for quality PHE	You can only try to take the various diverse facets into account, and that's why it's interdisciplinary, and you just have to work with colleagues who have other perspectives and ideas and with people who have other perspectives and ideas. (VS22, P3) I thought it was great to sit down with geographers, geologists, student teachers, psychologists, and talk about teaching didactics. And I found it very enriching. And then I already had this transdisciplinary idea, which plays an enormous role in planetary health. (VS 26, P8)
3. Ethical dimension	Learners should learn to reflect from a climate justice perspective as well as to think globally and act locally. They should also reflect consumption choices	Planetary health is also related to the social reality in the world, that one does not only see it from a scientific point of view, et cetera, and from the perspective of the Global North, but it is also related to the social issues, both social inequality here with us related to climate change and also [global] climate change consequences. (VS38, P3)
4. Responsibility of health professionals	Learners should recognize and learn to use their special role as agents in the health care system	It (PHE) must clarify in any case for the students the significance they can have as physicians later in their professional life for this issue, and students must be aware that it makes an immense difference whether they perceive this responsibility or not. (VS49, P7) [...] medical students as critical citizens and physicians as responsible critical citizens in a broader sense. (VS60, P10)
5. Transformative competencies including practical skills	Transformative competencies are an aim of PHE. This includes the acquisition of practical skills	Good teaching is more than simply learning facts by heart. Good teaching also includes, in particular, conveyance of the contexts and transformation of them into knowledge for action, so that students can actually apply this knowledge in their own actions, that they can also reflect on the knowledge, that they can deduce and discuss what consequences certain actions or non-actions have. (VS63, P9)
6. Space for reflection and resilience building	Learners need space for guided and unguided reflection inside and outside the classroom; PHE also needs to incorporate resilience building for learners as they are confronted with dire future scenarios	For me, good teaching means that the students are enthusiastic, that they come up with their own ideas, that they are allowed to discover and develop their own thoughts, that they are allowed to look for solutions themselves, that they are also encouraged in the process, and that they are not given a path to follow, but that they have room to develop things. (VS74, P2) [...] so that they are also accompanied in the findings that are gained on the way and that are sometimes very sobering, frustrating or also... yes, can also move you very much. (VS 75, P2)
7. Special role of students	PHE shall be student-oriented, and their role as possible experts needs to be appreciated. This will result in a flat (or no) hierarchy between teachers and learners	To connect with the students where they are at the moment. In other words, to link to topics that they might also throw into the classroom and then to make the connection to planetary health. (VS84,P8) [...] we could always use more space in which exchange takes place, because many (students) have prior knowledge in different areas and we can also learn from each other, so not only the lecturers can teach the students something, but also the other way around. (VS88, P7)
8. Need for curricular integration	PHE needs to be integrated throughout the entire curriculum, not only as stand-alone courses or only electives	[PHE] is not something that is only added to medical studies as something completely new that would otherwise be separate from medical studies in itself and is only an add-on, an add-on, an add-on, but it is clearly something that touches the core of medical studies and maps many competencies that are important for medical training, and modern medical training extremely well and also corresponds to a great interest and a great need from the side of the students. (VS99, P3)
9. Innovative and proven didactic methods	Both innovative and evidence-based competency-oriented methods of teaching and assessment shall be used	Because PHE is now implemented de novo, I think it has to have even more sophisticated didactic concepts. I don't think a classical approach would do justice to the topic. Instead, it must be highly innovative, just like the topic itself. (VS114, P16)
10. Education as a driver of innovation	Integrating PHE in the health sciences can ideally promote sustainability in the practical work of the health care sector through a general transformation of mindsets	For me, in the end, good teaching would be a complete mindset change of the teaching staff. So, I would like to see a critical attitude of all university lecturers, be it cardiologists or dermatologists... or pneumologists, who are at the same time also [...] sensitive of the state of our planet and the cross connections to their particular field. And that they would then address this there. (VS137, P8)

TABLE 4 Comparison of our ten themes with three international frameworks for planetary health education.

Themes	Cross-cutting principles for planetary health education (20)	AMEE consensus statement Planetary health and education for sustainable health care (19)	A Framework to guide PHE (21)
1. Complexity and systems thinking	Systems thinking and transdisciplinary collaborations A planetary health lens, Historical and current global values, *Urgency and scale*	Interconnection of human and earth systems, Complexity and unintended consequences, Dealing with complexity and uncertainty, Systems thinking, *Urgency and scale*	Systems thinking and complexity, The anthropocene and health, *Movement building and systems change*
2. Inter-and transdisciplinarity	Systems thinking and transdisciplinary collaborations	Transdisciplinary collaboration	
3. Ethical dimension	Inequality and inequity, *Historical and current global values*	Respect for human rights and dignity, Equity & social justice, Responsibility for ethical resource use, Challenging inequity & the misuse of power, *Differential impacts of ecological change*	Equity and social justice
4. Responsibility of health professionals		Professional duty to protect health, Eco-ethical leadership, *Good governance, accountability*	*Movement building and systems change,* *The anthropocene and health*
5. Transformative competencies including practical skills	Organizing and movement building, Communication	Communicating knowledge, Health promotion, Advocacy, *Evidence-based practice,* *Collaborative planning & action to mitigate & adapt to the ecological crisis (SDG 13.3)*	
6. Space for reflection and resilience building		Dealing with (...) uncertainty, Reflective practice	
7. Special role of students			
8. Need for curricular integration			
9. Innovative and proven didactic methods		Integration of varied forms of knowledge	
10. Education as a driver of innovation	*Organizing and movement building*	Supporting pathways to net zero health care, *Informing policy*	Movement building and systems change
Aspects that have not emerged from our data			
		(Acting in) Harmony with nature, Indigenous place-based perspectives	Interconnection with nature

Aspects from the three frameworks displayed in italics correspond only partly with our themes

Dark shading: Overlap of our theme with aspects from 2-3 of the frameworks (themes 1.–5. and 10.)

Light shading: Overlap of our theme with aspects from 1 of the frameworks (themes 6. and 9.)

No shading: Theme not explicitly mentioned in the frameworks (themes 7. and 8.)

also needs to incorporate resilience building for learners as they are confronted with dire future scenarios (VS75).

3.2.7. Special role of students in PHE

In the best case, PHE ties in with the real life of students (VS85) and takes up topics that students themselves suggest or are currently concerned with (VS84, VS86). It is also necessary to "take the students seriously, with their questions and concerns, ideas, and suggestions" (VS76). In the development of educational activities, students play an important role because they add a different perspective and have often already dealt with many topics more intensively than (older) lecturers themselves. Students and lecturers can learn from each other (VS88-90). Students can also act as promoters for the implementation of PHE at their universities (VS91).

3.2.8. Need for curricular integration

Extracurricular implementation of PHE is currently clearly predominant (VS93). Many interviewees called for the integration of PHE as a transversal theme into the entire curriculum (VS95, VS101, VS103). Lecturers of different subjects should repeatedly refer to PH within the core medical curriculum by enriching classical medical knowledge with related PH topics (VS96, VS107). PH aspects should not be presented in a disjointed manner, but "build on each other" in a coherent framework throughout the course of medical studies (VS106). In this context, PHE should not be just "an add-on" in the curriculum, but "touches the core of medical studies," and it corresponds to a "great interest and a great need of the students" (VS99).

Most participants in extracurricular and elective classes or courses are often already sensitized to the topic. Curricular teaching, however, reaches all students, even those who have not yet dealt with topics of PH (VS107).

3.2.9. Innovative and proven didactic methods

Interview participants suggested a wide range of didactic methods in PHE, both innovative and proven. Many suggested combining classroom teaching and blended-learning concepts (VS113, VS114). More discussion and interaction and less "multiple choice" knowledge is required (VS72, VS115, VS117, VS118). Teaching should be interdisciplinary to address the diversity of PH (VS21). Lecture formats would be most appropriate for basic knowledge and best embedded in a broader curriculum with additional seminars in small groups (VS126). Training of communicative competencies, with simulation patients (VS124), problem-oriented learning cases (VS120, VS125, VS128), constructive solution finding with experts (VS129), and excursions with practical relevance (VS64, VS130, VS131), were also mentioned. Examination formats in PHE could include essays on a self-selected topic (VS133, VS136), interviews in group work with various stakeholders (VS123), and a subsequent report that analyzes and reflects on a patient's care environment in group work (VS135). The assessment methods and their evaluation require more time and effort, but promote gaining "a deeper understanding" (VS136, VS135).

3.2.10. Education as a driver of innovation

The overarching concept of PH and its mediation through PHE holds the possibility of driving innovative teaching and research in the field so that each faculty member engages with the connection between his or her own discipline and PH. Educators can develop an awareness of the concept of PH and its complex interrelationships beyond their discipline (VS17, VS142). The goal is "a complete mindset change of the teaching staff" so that PHE is addressed by them in various educational courses (VS137). In this way, the topic could be highlighted also among students, colleagues, and people beyond the medical professions (VS87, VS138-140).

3.3. Comparison with three existing frameworks for PHE

When comparing each of the three frameworks for PHE [(19–21), see Table 4] with our ten themes, we found that six of our themes (1.-5.,10.) overlap with two or all three frameworks. We found that two themes (6. and 9.) overlap only with the AMEE Consensus Statement. For two (7. and 8.) of our themes, we did not find a clearly mentioned equivalent in any of the three frameworks. Additionally, we found aspects in the three frameworks, such as "harmony or interconnection with nature" and "indigenous place-based perspectives," that did not emerge in the interviews.

4. Discussion

To the very best of our knowledge, this study conducted with a large variety of stakeholders at 15 medical schools across Germany is the first study in the German-speaking context that explores high-quality characteristics of PHE through qualitative interviews. Participants reported diverse professional and personal backgrounds, in line with the transdisciplinarity often highlighted in the context of PH (33). Of the ten characteristics we identified, six overlap with two to three existing international frameworks for PHE.

4.1. Themes mentioned in two or all three compared frameworks

Complexity and systems thinking refers to the climate and other environmental crises as examples of so-called (super-)wicked problems that pose particular difficulties to public policy, mainly owing to being the emergent outcome of multiple interactions between natural and social systems in what are called complex systems (34, 35). Methods for training students in systems thinking include complex systems mapping (36, 37). Important paradigms that should form part of systems thinking in the context of PHE include the social (and other) determinants of health (38). An approach to understand the complex interrelationships between human health, social and economic factors and the environment can be the doughnut model (39). In medical education it can also be beneficial to explore analogies between the human body as a system of complex systems and the natural complex systems to appreciate the importance of systems thinking for tackling problems and finding solutions.

Inter- and transdisciplinary approaches are highlighted as essential but often lack conceptual clarity at least in relation to the public health workforce (40). Achieving profound changes for PH, such as decarbonizing health care systems, requires collaboration of different professional groups and stakeholders (33).

The ethical dimension includes aspects of equity and social justice in a global perspective (41–43) and questions of climate justice (44). Equally important are questions of ethical resource use in the health sector, with many open questions of implementation that need to be addressed in practice and teaching. Learners can take on an important role of pushing for reflection of current practice in resource waste in their clinical placements.

Regarding the responsibility of health professionals, part of the PHE learning objectives should be the sensitization of medical students to the double-edged role that health (care) systems play for PH including the training of skills for sustainable healthcare (45).

Transformative competencies that would enable learners to effectuate change, were confirmed as a key tenet of high-quality PHE, and also form the basis of high-quality health professional education (46). These can include conventional skills such as communication skills, which can unfold transformative potential if integrated with factual knowledge relevant to PH, for instance regarding the co-benefits of active mobility (meaning health benefits through physical activity as well as less emissions of CO_2 and air pollutants), a doctor might effectively integrate into a medical consultation. To adopt the role of change agents, learners also need to develop a set of values and attitudes that is in line with the goals of PH. As changes in values are usually not achieved through classic lecture formats but rather through experiential learning and constructive dialogue (47), PHE needs to encompass formats and nudges to trigger this kind of transformative learning in students (48, 49). Developing confidence as well as a sense of self-efficacy are further important competencies that enable students to

be agents of change. Faculty can contribute to this by increasing the students' understanding of transformation and their sense that transformative change is possible; enhancing the students' sense of their own agency and ability to make a difference; helping students see and apply PH concepts during rounds or debriefing of clinical encounters; and give support to articulate a role for themselves in processes of transformative change, also by overcoming a perceived gap between the impacts of individual and collective change (50–53). Recognizing and reflecting on the importance of even small contributions to social change in accordance with e.g., the concept of social tipping dynamics (54) can be beneficial to increase learners' self-efficacy and their self-identification as change agents. However, learners should be supported in setting realistic expectations regarding their impact to prevent them from feeling frustrated, discouraged or paralyzed which could result in impaired mental wellbeing.

4.2. Themes mentioned in one of three compared frameworks

Our theme space for reflection and resilience building was—among the three frameworks—only reflected in the AMEE consensus statement (19) as learning to face existing and upcoming uncertainties and to implement "reflective practice" as a teaching method. Our category extends this notion by explicitly mentioning the importance for students to be given space to share their emotions and worries in relation to the climate and environmental crises that they might become fully aware of through participating in PHE. Educators have a special responsibility here to consider students' psychological wellbeing when they are confronted both with the scientific evidence on the climate and ecological crises and their health impacts as well as with the implications these might have for their work as medical doctors, but also for their future life (55). Learning critical reflexivity, for example regarding one's personal standpoint, practice, research, and action, including the negative impact of affluent lifestyles (56) can help students to develop and strengthen personal and professional attitudes, and it can strengthen their emotional resilience (57).

4.3. Themes not explicitly mentioned in three compared frameworks

The special role of students is not explicitly emphasized in any of the three frameworks. According to our results, high-quality PHE should be student-centered as they are often the first to advocate for changes in their education based on their already existing civic engagement with the climate and other environmental crises (58). Student-led seminar formats can allow students to deepen their knowledge on a specific topic and strengthen their communication skills, thus swapping the traditional roles of student and teacher. A range of student-driven PHE formats have already been successfully realized and can be used as blueprints for further PHE initiatives (59, 60). Students can also play a central role in implementing PHE in the curricula (61).

Conceptualizing PHE as a longitudinal part of the core curriculum is not specifically mentioned in the central graphs of the three frameworks. More recent literature exists on roadmaps for curricular integration, having the potential to reach those who have not previously dealt with planetary health (62). Examples for curricular integration range from simply changing application examples in standard medical lessons (e.g., explicitly describing the effects of heat waves on elderly people or infants) to full lectures on the health impacts of the climate and ecological crises and dedicated teaching for development of practical skills for transformative action on the individual, organizational, and professional-political level (63, 64).

4.4. Themes not emergent in our data

The central feature of the PHE framework by Guzmán et al. is "interconnection with nature". Shaw et al. also refer to interconnectedness with nature as an important element of PHE. Surprisingly, this was not explicitly mentioned by our interview participants when they were asked about quality characteristics of PHE. In our opinion, an understanding of human beings as embedded within natural systems and the unconditional dependency of health and wellbeing on intact and thriving natural systems is essential for promoting and achieving PH.

Shaw et al. also highlight the importance of Indigenous knowledge systems which they claim should be recognized and discussed as part of PHE. This aspect did not emerge from our data either. Here a reason might be that compared to other regions of the world (i.e., America, Australia, Asia, and Africa), Germany has no indigenous populations (in the classical sense of living descendants of pre-invasion inhabitants in a given area that is now dominated by other inhabitants) that would lead a lifestyle close to nature. It is important, however, to also convey this perspective to students in Germany as indigenous populations play an important role in guarding a large proportion of the planet's biodiversity (65, 66) and can bear examples of sustainable lifestyles (67). We believe that the potential of Indigenous knowledge systems for addressing the ecological crises as well as sensitization of learners to the shared drivers of these crises and the marginalization of Indigenous communities and others groups - which can be subsumed under the labels of settler-colonialism, Eurocentrism and extractive economic practices - should be part of PHE. Therefore, more work is needed to sensitize educators in Germany to these issues and to practice dialogue between scholars who were scientifically socialized within different ontological and epistemological cultures.

4.5. Strengths and limitations

At the time of publication, the data were almost 1.5 years old. Because PHE is a very dynamic area, some progress may have been made in the development of PHE since we collected the data that is not yet reflected in our paper. We used PHE networks for sampling, followed by snowball sampling, therefore we cannot rule out a selection bias. Moreover, most of the interviewers all had a strong interest in promoting PHE, thereby potentially leading to social desirability bias. We interviewed students as experts who are actively promoting PHE within their medical schools, through which the role of students may be slightly overestimated. On

the other hand the inclusion of diverse stakeholders, from 15 universities from all over Germany and specifically the inclusion of students with an active role in PHE—whose contribution is essential—allowed us to gain a holistic understanding of current priorities in this dynamic field.

5. Conclusions and further implications

The ten characteristics of PHE we developed from interviews with a diverse group of stakeholders at medical schools throughout Germany can be helpful to all who are currently in the process of implementing and enhancing PHE nationally and internationally. While most of our findings were in line with existing frameworks, we also identified new themes. Focus should be laid on the special role of students, space for reflection and resilience building and transformative competencies. Further studies should focus on other health professions to meet the aspiration of inter- and transdisciplinarity in the design and underlying principles of PHE.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of the University Hospital of Würzburg file number 20210312-01. The patients/participants provided their written informed consent to participate in this study.

Author contributions

E-MS-S conceptualized the study. E-MS-S and JS planned the study and performed the data collection and the thematic qualitative text analysis. E-MS-S, JS, and KW performed the comparison of the themes to existing frameworks. AS supervised the whole project (doctoral thesis of JS). All authors contributed to the manuscript development and approved the final version to be published.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1143751/full#supplementary-material

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The gap in capacity building on climate, health, and equity in built environment postsecondary education: a mixed-methods study

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Institutions of higher education are feeling increasing pressure from both students and the international climate community to offer more courses and joint degrees on the role of the built environment in advancing climate action, population health, and social equity. The built environment plays a leading role in this new, transdisciplinary approach. Thoughtfully designed buildings, neighborhoods, and communities can simultaneously lower *per capita* greenhouse gas emissions, reduce population exposure to dangerous climate-sensitive extreme weather events, reduce disparities in climate-related health outcomes, and advance social equity goals. This mixed-methods study explored the extent to which post-secondary courses and joint degree programs teach students the research methods and technical skills they will need to design and implement built environment interventions addressing the effects of climate change on population health and social equity. The study found that the number of universities offering courses addressing climate, health, and equity in the built environment grew from 2018 to 2022. The number of joint planning/public health degree programs rose from four in 2005 to 15 in 2022. No joint architecture/public health degree programs were identified. A detailed review of 99 course descriptions from three universities found that 17 courses (roughly 1/5 of the total) covered population health, built environment, and climate change; and, 2/3 of the set ($n = 60$) covered two out of the three topics. Schools of public health were more likely to offer courses covering all three topics, whereas schools of architecture were more likely to include the building scale in relevant courses. Exposure pathways and social equity/vulnerable populations were the most common methods included in relevant courses. Professors and administrators at institutions identified by the study as "transdisciplinary-ready" reported that accreditation requirements and university rules governing the allocation of student tuition had slowed efforts to offer cross-listed courses. However, faculty in these institutions regularly collaborate informally with their peers – both on transdisciplinary research and by offering guest lectures in each other's courses. The results of this study show that, while universities have made great strides over the past 18 years in beginning to support transdisciplinary research and pedagogy, institutional barriers and gaps in key content areas remain.

KEYWORDS

climate change, population health, social equity, built environment, transdisciplinary curriculum

1. Introduction

Institutions of higher education are feeling increasing pressure from both students and the international climate community to offer more courses and joint degrees on the role of the built environment in advancing climate action, population health, and social equity.

Young people today experience climate change in real time. No longer is it spoken of as a phenomenon that may happen in the distant future to animals in remote locations. Each year is punctuated by deadly heat waves, wildfires, floods, and storms that result in destroyed communities and loss of life. No one is immune from experiencing climate change anymore – regardless of geographic location or income level (1, 2). Growing evidence shows that high school and college students not only consider climate change an existential threat to the future of humanity but also view it as a complex challenge spanning numerous disciplines and affecting society as well as natural ecosystems. For example, Hickman et al. found that over half of children and young people aged 16–25 who participated in a global survey about climate anxiety reported feeling "very" or "extremely" worried about climate change. Over half also responded negatively when asked whether the government in their country "was taking [young people's] concerns seriously," was "doing enough to avoid a climate catastrophe," or "was acting in line with climate science" (3).

Many students bring that anxiety, commitment, and transdisciplinary lens with them when they enter university with the goal of dedicating their lives to advancing solutions to the climate crisis. Too often, what they encounter is an institution that is designed to facilitate the creation of deep levels of knowledge on narrow topics but limited infrastructure supporting research into complex systems that cross traditional disciplinary boundaries.

1.1. Transdisciplinary pedagogy: background and relevance to curricula addressing the intersection of climate, health, and equity in the built environment

The concept of "transdisciplinarity" is relatively new. It was first publicly debated in 1970 at a seminar in Nice, France hosted by the Organization of Economic Cooperation and Development (OECD) and the French Ministry of Education (4, 5). That same year, a PhD student in human behavior sciences, Jack Lee Mahan, Jr., published a dissertation on the topic (5, 6). In both cases, the term was proposed as an alternative to the status quo amid a backdrop of university students protesting traditional, discipline-specific pedagogy and the publication of environmental treatises like *The Limits to Growth* (1972) (7), which questioned whether using linear concepts like "progress" to motivate discipline-specific scientific questions would eventually lead to ecosystem collapse (5).

The term fell out of usage during the economic and social retrenchment in Western countries that followed the economic crisis in 1973 caused by the Organization of Arab Petroleum Exporting Countries (OAPEC) oil embargo (5). Its return to prominence in the 1990's coincided with the rise of three complex, global challenges: (1) the end of the Cold War (which prompted a reorganization of the world order), (2) increasing concern about the effects of globalization on national economies and labor conditions, and (3) new urgency around environmental sustainability and climate change sparked by the 1992 United Nations Earth Summit in Rio de Janeiro (5).

Tress et al. (8) and Morton et al. (9) distinguish transdisciplinary research from other types of research as follows. Disciplinary research remains within a single academic tradition in all respects, including the development of the research question, use of theoretical frameworks and methods, and communication of results. Multidisciplinary research involves more than one academic discipline in developing the research goal, but each discipline conducts its assigned piece independent of the others. Participatory research involves knowledge exchange between academic and non-academic stakeholders, but all research activities remain separated (either taking place on the academic side or on the non-academic side). Interdisciplinary research crosses disciplinary boundaries to create shared knowledge, but the process remains entirely within the academy. Transdisciplinary research brings real world questions into academic settings by involving both academic researchers and practitioners and/or community members. In this way, transdisciplinary research is best positioned both to address complex, global challenges like climate change and to center social equity in the formulation of the research question and (ultimately) the recommended intervention.

As key producers of knowledge, universities have naturally found themselves at the center of the debate around transdisciplinary research and pedagogy – starting with student frustration in the late 1960's and early 1970's around the way universities were organized and taught academic subjects (10). More recently, Scholz (10) proposed transdisciplinarity as an alternative to the "Triple Helix" and "Third Mission" approaches to university research, both of which he rejects as overly profit-driven. Triple Helix involves an alliance between university, industry, and government. Third Mission refers to entrepreneurial partnerships between universities and private practice. Scholz proposes transdisciplinarity as a pathway that would center advancement of the public good in all research by authentically collaborating with practitioners and other stakeholders who have real-world experience working on complex projects spanning multiple disciplines. Scholz calls this approach "science with society," which he distinguishes from the current system which he calls "science for society" (10).

Daneshpour and Kwegyir-Afful (11) found in a scoping review of transdisciplinary curricula drawn from over ten countries that sustainability courses dominated the list. They hypothesized that the multidisciplinary nature of the United Nations Sustainable Development Goals (12) and the emphasis that is often placed on real world scenarios in sustainability courses are two reasons sustainability curricula are disproportionately likely to follow transdisciplinary pedagogy. Seidl et al. (13) go so far as to claim that transdisciplinarity has become the "consensus" pedagogy among sustainability science programs. Examples of transdisciplinary sustainability courses and trainings include the AGE-WELL (Aging Gracefully across Environments using Technology to Support Wellness, Engagement and Long Life NCE Inc.) training in Canada (14), the "Sustainability Challenge" course in Vienna, Austria (15), and a transdisciplinary master of engineering program at Texas Tech University in the US (16). Velez, Hall, and Lewis's public policy course at Virginia Tech in the US further illustrates the strong affinity between sustainable design research and practice and transdisciplinarity – beginning with the course's name, "SuperStudio." The course follows a similar process

to architecture design studio courses, which use project-based learning to iterate between research and design to solve a specific challenge and often include feedback from community stakeholders who will be impacted by the project (17).

This study explores the extent to which transdisciplinary pedagogy in architecture, planning, and public health schools addresses the intersection of climate change, population health, and social equity in the built environment, because that nexus represents a powerful leverage point in the climate crisis that could be activated using a transdisciplinary approach.

1.2. Definition of terms

Transdisciplinary pedagogy: the exact definition of transdisciplinarity continues to evolve (5, 8, 9, 18). However, several common elements reflect its roots in social justice and focus on complex, global challenges. For the purposes of this study, transdisciplinary pedagogy is defined as an approach to teaching that integrates multiple disciplines into a single course or degree program and includes practice-based learning.

The following definitions are provided to set a common understanding for the remainder of the paper.

Architecture (19): the art and practice of designing structures, including their relationship with the surrounding built and natural environment. The practice of architecture includes coordinating allied disciplines (such as engineers, landscape architects, and contractors) to develop a set of project documents that will protect the health, safety, and welfare of future building occupants and society.

Built environment (20): "a general term covering residential, industrial, and public buildings, roads, and services, such as water supplies, electrical wiring, and sewerage in human settlements."

Climate change (21): "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Climate change mitigation (22): "a human intervention to reduce emissions or enhance the sinks of greenhouse gases."

Climate change adaptation (22): "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities."

Climate change resilience (22): "the capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure."

Population health (23): "the health outcomes of a group of individuals, including the distribution of such outcomes within the group."

Public health (20): "an organized activity of society to promote, protect, improve, and when necessary, restore the health of individuals, specified groups, or the entire population."

Social equity (24): "social equity implies fair access to livelihood, education, and resources; full participation in the political and cultural life of the community; and self-determination in meeting fundamental needs."

Urban planning (25): the process of planning, designing, and developing the physical, social, and economic aspects of urban space, primarily concerned with improving the quality of life for residents.

1.3. Built environment's central role in population health equity and the health effects of climate change

The built environment plays a leading role in setting the context for population health and the ways in which different segments of society experience climate change. Buildings are responsible for almost 40% of global greenhouse gas emissions. Adding the allied fields of transportation and land use raises the estimate to 60% worldwide (26). Buildings are also overwhelmingly the location where populations shelter during climate-sensitive extreme weather events. Also, many of the underlying social determinants of health (27, 28) that increase the risk of poor health outcomes after exposure to such events (29) are influenced by building design and land use (30). For example, an individual who lives in a neighborhood lacking sidewalks, parks, and a healthy grocery store is at higher risk of obesity, diabetes, and hypertension (31, 32). Lack of green space is also a risk factor for exposure to extreme heat and flooding (33, 34). Individuals diagnosed with obesity, diabetes, and hypertension are at higher risk of negative health outcomes when exposed to those two climate-sensitive extreme weather events (29, 35). If that individual's home is located in a flood plain or near a source of air pollution (such as a freeway), not well insulated, under-airconditioned/ventilated, and/or fitted out with building materials that off gas toxins, spending time in the home during a heat or flooding event could exacerbate symptoms arising from exposure to the event itself. Thoughtfully designed buildings, neighborhoods, and communities – on the other hand – can simultaneously lower *per capita* greenhouse gas emissions, reduce population exposure to dangerous climate-sensitive extreme weather events, and advance social equity goals such as reducing disparities in climate-related health outcomes (36, 37).

In spite of the built environment's central role in both the cause of climate change and its effects on human health, that link has been largely excluded from postsecondary education. This is particularly true at the building scale. Architecture, landscape architecture, and building engineering accreditation boards and professional core competencies continue to treat climate change mitigation as an abstract estimate of carbon equivalent emissions and resilience as a question of protecting infrastructure and property value (38–42). In both cases, the health needs of the population that the buildings were designed to serve are excluded from the conversation. Similarly, when courses tailored to the fields of public health and medicine teach students about the role of the built environment in climate, health, and equity, they either focus on healthcare facilities or zoom out to large scale community planning questions like greenways and urban sprawl, glossing over the crucial question of how a community plan translates into building design (43–45). While both of these approaches touch on important aspects of the topic, they do not prepare future leaders in real estate, design, and public health to effectively address the effects of climate change on population health and social equity – particularly at the local level where the majority of these activities take place. This paper argues that a transdisciplinary pedagogical approach is required to achieve that goal. It is necessary to teach students how to integrate tools and frameworks from multiple disciplines to address the complex adaptive challenges they will face in their post-graduate careers – whether in research or practice.

The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment reports (1, 2) reflect the shift in the scientific consensus

on how to study and act on climate change. Instead of dedicating the majority of the report to summary descriptions of individual phenomena, the report's authors highlight examples of how the scientific community and their partners in government and the private sector are moving towards transdisciplinary research and implementation science – with a particular emphasis on how human and natural systems intersect and influence each other. Figure 1, adapted from the IPCC report, illustrates how public health, architecture/real estate development, and planning interact with each other both in contributing to the current climate crisis and in working together to stop emissions and protect population and planetary health.

This mixed-methods study explores the extent to which academic institutions are responding to pressure from both students and the international climate community to build capacity in this area. It asks the following research question: how widespread are postsecondary courses and joint degree programs that teach students the research methods and technical skills they will need to design and implement built environment interventions addressing the effects of climate change on population health and social equity?

2. Materials and methods

2.1. Background: synthesizing existing model curricula and core competencies into key elements for transdisciplinary curricula addressing climate, health, and equity in the built environment

This study was motivated by a preliminary review of the literature conducted in fall 2022 on model curricula and key competencies at the intersection of climate change, public health, and the built environment (e.g., architecture and planning) – particularly in relation to advancing social equity. A query in Google Scholar for "curriculum + climate change + health + built environment" returned two relevant entries, the seminal 2009 paper "A Model Curriculum for a Course on the Built Environment and Public Health: training for an Interdisciplinary Workforce" by Botchwey et al. (47) and a qualitative study from 2020 assessing the pedagogical strengths and lessons learned from a pilot course based on Botchwey et al.'s model curriculum that was targeted to architecture and landscape architecture students at an historically black university (HBCU) in the US (48).

Botchwey et al. (47) builds off of the 2005 report *Promoting Interdisciplinary Curricula and Training in Transportation, Land Use, Physical Activity, and Health* by Sclar et al. (49). Both papers scanned existing curricula at US postsecondary institutions and contacted instructors for additional information about active courses. Sclar et al. developed an "ideal" curriculum derived from a scan of coursework in all 70 accredited urban and community planning schools on the Association of Collegiate Schools of Planning (ACSP) list at the time of the study. Botchwey et al. synthesized overarching themes and best practices from six courses in US postsecondary institutions that were offered in either planning schools, public health schools, or cross-listed in both. Table 1 summarizes both papers' recommendations.

While climate change is mentioned in passing in both model curricula, it is not integral to either. The third column in Table 1 fills that gap by summarizing the Global Consortium on Climate and Health Education (GCCHE) core competencies for postsecondary courses addressing the links between climate change and health at health profession schools (50).

I synthesized the concepts in Table 1 and added two missing topics: (1) a review of key elements in courses delivered by schools of architecture and (2) the links between climate change, the built environment, and population health (particularly health disparities). The result is a list of five key elements that appear to be fundamental to developing a successful transdisciplinary curriculum addressing climate, health, and equity in the built environment:

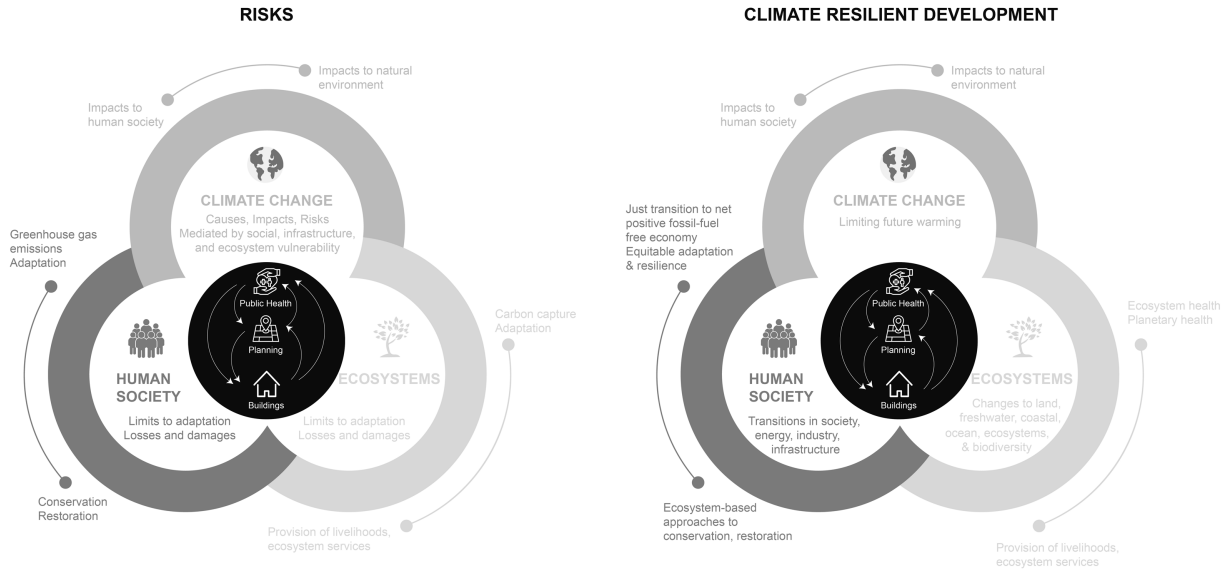

FIGURE 1
Interrelations between buildings, planning, and public health related to climate risks and resilient development. Adapted from Figure SPM.1, IPCC, 2022: summary for Policymakers (46).

TABLE 1 Key elements for transdisciplinary curricula addressing climate, health, and equity in the built environment.

Promoting interdisciplinary curricula and training in transportation, land use, physical activity, and health (2005) (49)	A model curriculum for a course on the built environment and public health: training for an interdisciplinary workforce (2009) (47)	Global Consortium on Climate and Health Education (GCCHE) Climate & Health Core Competencies for Health Professions Students (2020) (50)
1. **History**: Historical perspectives on urban planning and public health 2. **Theory**: Concepts and theories in transportation, land use, and population health 3. **Methods**: Research designs, methods, and approaches for studying the effects of the built environment on population health 4. **Tools**: Research and policy tools used to intervene on the built environment to improve public health	1. **Planning and public health foundations:** Planning history, Public health history, Interdisciplinary applications 2. **Natural and built environments:** Land use and transportation, Planning design approaches, Health impact assessments, Environmental-impact assessments, Indoor and outdoor air quality, Water quality, Food security 3. **Vulnerable populations and health disparities:** Groups who are at higher risk of disparities in health outcomes, Mental health, Social capital, Environmental justice 4. **Health policy and global impacts:** Health policy, Sustainable planning and global warming, Healthy housing 5. **Integration:** Final portfolio	**Domain: Knowledge and Analytical Skills** 1. Define climate drivers (both natural and human-caused), weather, climate change, and climate variability. 2. Identify the health impacts of climate change and effective responses on the part of specific health services. 3. Apply knowledge of levels of prevention, climate mitigation and adaptation, and explain health co-benefits of actions. 4. Describe public health and its determinants. 5. Apply knowledge of emergency planning skills. 6. Access and interpret relevant local, regional, national, and global information about climate change effects on health. 7. Apply knowledge of the ethical, professional, and legal obligations relevant to climate and health. 8. Demonstrate understanding of the scientific consensus on climate change and concept of evolving science. **Domain: Communication and Collaboration** 9. Demonstrate effective communication with stakeholders about climate and health topics. 10. Work collaboratively and across disciplines on climate and health issues. **Domain: Policy** 11. Explain the role of subnational, national and global policy frameworks and governance structures to address health risks associated with climate change. 12. Explain climate-health activism and policy engagement roles of health professionals. **Domain: Public Health Practice Competencies** 13. Apply climate and health knowledge to improve decisions about public health services, and adapt and improve population health. 14. Apply knowledge of the connection between habitat and biodiversity loss and infectious diseases. **Domain: Clinical Practice Competencies** 15. Describe ways that health care professionals and facilities can prepare for and respond to climate related health risks. 16. Apply knowledge of climate and health to clinical care of patients.

*The text in this table is a direct quotation from each of the cited documents.

Exposure pathways: it is important to map the way environmental exposures reach their target within a population or within an individual's body, so that interventions (such as building design and land use configuration) can be tailored to interrupt negative exposure pathways and promote behavior that leads to optimal physical and mental health and wellbeing. Climate change-related exposure through the built environment often occurs across multiple pathways simultaneously. For example, when Hurricane Harvey struck Houston, Texas, US, in 2017, it set in motion exposure pathways related to flood risk (and, later, exposure to mold), extreme heat, and waterborne disease/toxins. The storm shut off power both to local residents and to 11% of US oil refining capacity, which both left residents without access to air conditioning during the heat of the summer and resulted in higher gas prices regionally and nationally. 43 US EPA Superfund sites and local wastewater treatment plants were flooded during the event, releasing toxic chemicals and pathogens into flood waters that came in contact with residents and first responders (51). Understanding the potential exposure pathways associated with the range of climate change-related hazards that might be relevant to a building site or neighborhood is the first step in designing a project that makes the best use of its location to meet net zero goals and maximize its contribution to community resilience.

Social determinants of health (SDOH) (28) are defined as the underlying social, economic, environmental, and political systems that contribute to disparities in health outcomes among different segments of the population. Discriminatory land use decisions like redlining (e.g., the historic practice of denying bank loans to property owners in majority non-white neighborhoods) have left a legacy of economic and health disparities in the US. Studies have shown that people living today in neighborhoods that were redlined in the 1930's are more

likely to experience lower levels of vegetation (which protects from extreme heat events) (52), lower levels of home ownership (53), and lower access to healthy food options (54), among other disadvantages that can harm their health and wellbeing. Understanding the SDOH of the population that will be served by a building or neighborhood and how their circumstances increase or decrease their risk of negative health outcomes after exposure to a climate-sensitive extreme weather event should be a fundamental component of the site assessment/scoping exercise for any building or neighborhood project, so that the design can prioritize interventions that promote health and wellbeing – particularly for those most at risk of negative health outcomes.

Equity/vulnerable populations: some groups in society are at higher risk of negative health outcomes either because of physiological characteristics (such as very young children and elders) or as a result of the social determinants of health (55). Buildings, land use configuration, and transportation systems can be designed to both protect vulnerable groups from exposure to climate change-related hazards and encourage health-promoting behaviors. For example, the High Point residential development in Seattle, WA, US, actively involved existing residents in the design process. As a result, the final design combines green space, walking paths, and a community garden for adults at risk of cardiovascular disease (56) with so-called "Breathe-Easy" homes targeted to the high percentage of children living with asthma in the existing public housing development (57). The combination of environmental exposures and vulnerable populations changes from one neighborhood to the next. It is therefore important to include an assessment of the current and likely future interactions between environmental exposures and population health needs on and around a building site or community plan prior to setting design goals, so that the design can respond to its context. Many times, this sort of assessment will require expertise in qualitative methods such as participatory action research (58, 59), so that community needs and priorities are centered in the final design.

Epidemiology/biostatistical methods (60): these methods are fundamental to applying an evidence-based and data-driven approach to building design and community/urban planning. They make it possible to estimate the relevant strength of association between a set of environmental exposures, potential health outcomes, and the role of building or land use design as a mediating factor. Quantitative methods are often used to explain the links between exposure pathways and vulnerable populations, as well as how certain design strategies could protect vulnerable populations from exposure to climate change-related hazards – such as air pollution, flooding, extreme heat, etc.

Geospatial analysis/GIS methods (60): spatial analysis makes it possible to estimate which environmental health exposures are more relevant to one property, neighborhood, or community compared with a different location. This last skillset is particularly important for building and neighborhood design, because their interventions will bring the greatest benefit if they are targeted to the unique combination of needs on and immediately surrounding the project site.

Each element adds an important dimension to understanding how a discipline-specific task such as: designing a health clinic in a low-income urban neighborhood (discipline: architecture); drafting a climate action plan (discipline: planning); or updating a community health needs assessment (discipline: public health) could leverage synergistic action in other disciplines to maximize co-benefits and minimize co-harms to population and planetary health. Students who learn how to use all of these elements in concert with each other will be well positioned after graduation to diagnose and act on hitherto unrecognized leverage points in the climate crisis.

2.2. Built environment and public health clearinghouse

This study draws from two openly available clearinghouses, the Built Environment and Public Health Clearinghouse (BEPHC) and the Global Consortium on Climate and Health Education (GCCHE), to scan the landscape of university offerings at the intersection of climate, health, and equity in the built environment (47, 61, 62).

The BEPHC was initially compiled to support the development of the seminal 2009 Botchwey et al. paper described above. Dr. Botchwey confirmed via private correspondence that the original list was manually updated between 2019 and 2021. As part of the update, researchers verified the information in the original list and added universities, programs, courses, and staff names that were gathered through a manual Internet search.

The current website shares information about universities that offered interdisciplinary courses on the links between the built environment and public health at one time, available joint degrees and joint concentrations, as well as model curricula, such as "History and Theory of Architecture + Health (Health and the Built Environment)" taught by Dr. Stephen Verderber at the University of Toronto (63). It also links to relevant openly available datasets.

The degree programs portion of the clearinghouse divides academic offerings into four tiers of content. The higher the tier, the stronger the institutional support for training at the intersection of population health and the built environment (61):

Tier 1: some faculty members have a stated research interest or specialization in the links between human health and the built environment.

Tier 2: at least one course addressing the links between human health and the built environment is offered and may be cross-listed with another department.

Tier 3: at least one interdisciplinary concentration, specialization, certificate, or specialize degree is offered.

Tier 4: joint degree in Master of Public Health and Master of Community or Urban Planning is offered.

The clearinghouse mostly points users to university architecture and planning departments. It occasionally offers links to schools of public health if that is where the joint degree program is housed. But, the website is primarily designed to support students, professors, and university leaders in the design fields.

Information from the 2018 version of the clearinghouse was collected in mid- to late 2018. Information from the revised clearinghouse was collected in October 2022.

2.3. Global consortium on climate and health education list of member institutions

The Global Consortium on Climate and Health Education (GCCHE) was founded in 2017 in response to a 2015 pledge that was spearheaded by the US White House and the Columbia University

Mailman School of Public Health's Climate and Health Program and signed by 115 health professions schools from around the world in the lead up to the COP-21 meeting in Paris (64). Its mission is "[t]o unite health professional training institutions, health societies, and regional health organizations to create a global climate-ready health sector, prepared to mobilize and lead health promotion and response in the era of climate change, while restoring the health of the planet." To that end, the GCCHE recruits health professions schools to publicly endorse climate and health educational offerings in their school by joining the consortium.

Membership in the consortium is mostly limited to schools of medicine, nursing, and public health. The list included in this study focused on schools of public health, because those are the schools that have been more likely in the past to establish joint degree programs with urban and community planning schools.

Information from the 2018 version of the clearinghouse was collected in mid- to late 2018. The 2022 dataset includes the list of member institutions active in October 2022.

2.4. Mixed-methods study design

This study used a three-step, mixed-methods process to explore the extent to which all three topics (climate change, population health, and built environment) are integrated into course curricula and the pedagogical and institutional reasons underpinning the current system (Figure 2).

Mixed methods research draws on both quantitative and qualitative methods, combining an assessment of the magnitude or frequency of a phenomenon with an exploration of the meaning behind the quantitative results (65). According to the US National Institutes of Health (65), mixed methods are well adapted to multi-level research questions such as the one posed by this study, which crosses both geospatial levels (e.g., building scale up to global scale) and disciplinary boundaries.

Following a similar method to Sclar, et al. (49) and Botchwey et al. (47), information was collected about degree programs, courses, and commitments made by universities to teach a combination of climate change, population health, and/or the built environment. I followed the quantitative analysis with a set of qualitative, semi-structured interviews with university representatives to generate hypotheses explaining the pedagogical and institutional reasons behind the current system. Finally, I combined the quantitative and qualitative results into a set of synthesized hypotheses about the current extent of training available to students who will graduate into fields where they will be expected to consider the wider systemic implications of their work beyond their home discipline (Figure 2).

2.5. Quantitative analysis

I compiled a list of universities (including schools) offering courses and/or joint degree programs at the intersection of climate change, population health, and/or built environment at four points in time (Figure 3): 2005 (49), 2009 (47), 2018 (66), and 2022 (current study).

The 2018 and 2022 lists drew on the same two curriculum clearinghouses: the Built Environment and Public Health Clearinghouse (BEPHC) (61) and the list of Global Consortium on Climate and Health Education (GCCHE) (64) member institutions. Universities that were both members of GCCHE and listed as Tier 2, 3, or 4 in BEPHC were identified as having all the components in place to provide transdisciplinary curriculum addressing climate, health, and equity in the built environment. These universities are labeled "transdisciplinary-ready" through the remainder of the paper.

In 2022, I reviewed the entire course catalog for the schools of architecture, planning, and public health in three of the 15 transdisciplinary-ready universities: Columbia University, University of Colorado, and University of California at Los Angeles. I selected these universities for review based on the diversity of their geographic locations (East Coast, Mountain West, and West Coast, respectively) and ownership (one private institution and two public institutions, respectively).

For each course including climate change, population health, and/or built environment, I tabulated the geographic scales and number of key elements that were covered. In total, I reviewed 99 course titles and descriptions across the three universities. I also reviewed the course syllabus, if publicly available.

Finally, a research assistant and I performed descriptive statistics to explore the frequency and distribution of geospatial scales and key elements across disciplines. We used Microsoft Excel Version 2023 (Microsoft 365, Redmond, WA) and Stata BE Version 17.0 (StataCorp, College Station, TX) to develop bar charts, frequency tabulations, and chi-square tests.

2.6. Qualitative analysis

I used purposeful and snowball methods to recruit professors and administrators from "transdisciplinary-ready" universities to participate in semi-structured interviews in late May and early June 2023. All interviews were conducted over Zoom (San Jose, CA) and analyzed using the video recording and written transcript. The interview guide and consent script adhered to the Harvard T.H. Chan School of Public Health Institutional Review Board (IRB) protocols for non-human subject research. As a result, I only asked participants questions related to the facts about the program at their organization and its development, excluding any questions about personal thoughts and interpretations.

The interview guide was structured to support inductive thematic analysis based on grounded theory (67) – an approach that acknowledges the interviewer's active participation in the creation of knowledge. Given my active role in each interview, I included safeguards against confirmation bias (i.e., the tendency to focus on evidence supporting one's existing hypothesis and discount contrary evidence (60)), such as reminding participants not to share their personal opinions and consciously crafting neutral (i.e., non-leading) questions.

2.7. Synthesis

I used the results of the thematic analysis to interrogate and frame the results from the quantitative analysis. Of particular interest was the question of whether the clearinghouses' focus on formal institutional policies and programs might have hidden informal transdisciplinary activity that would benefit from formal institutional support.

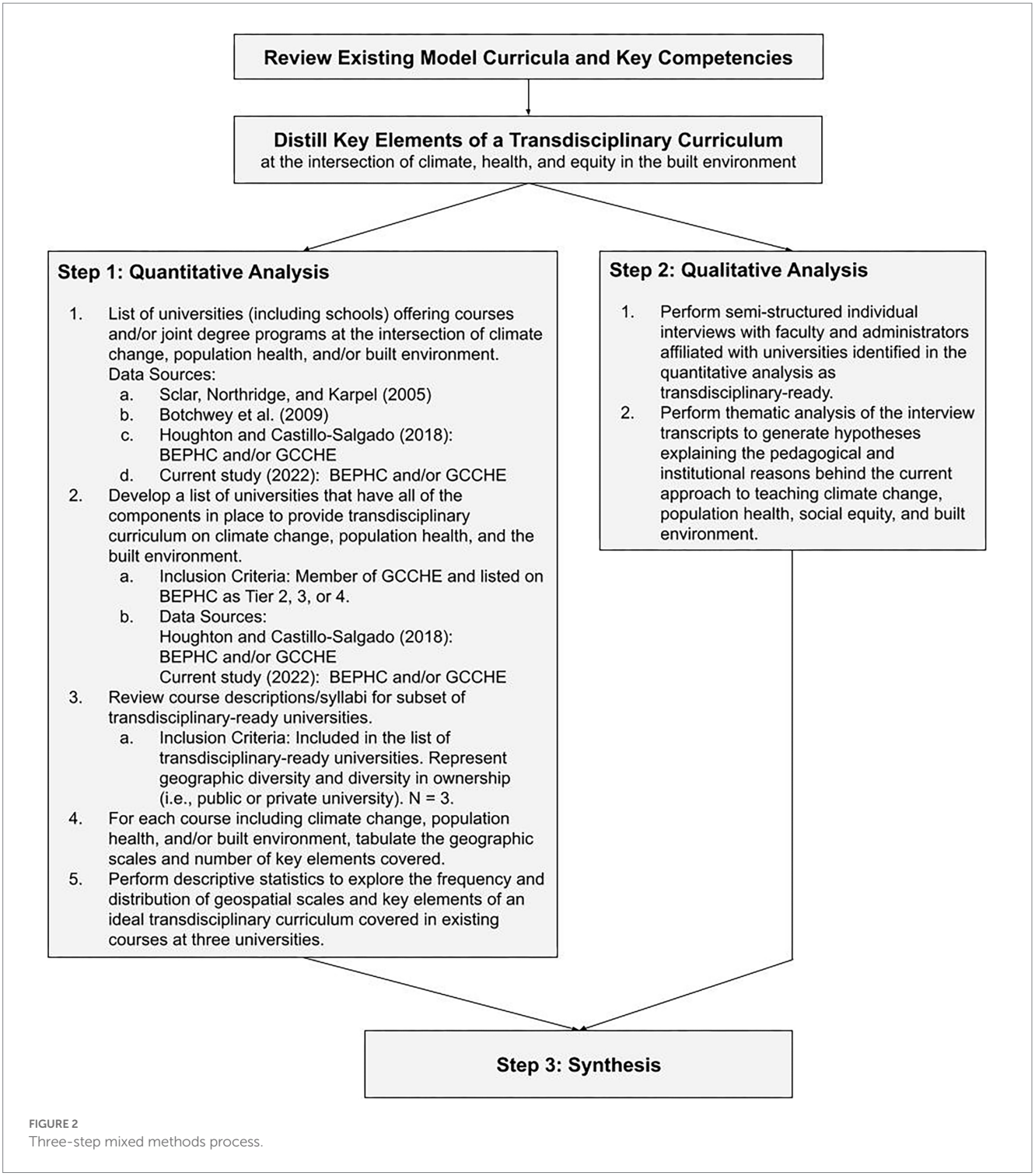

FIGURE 2
Three-step mixed methods process.

3. Results

3.1. Change in number of multidisciplinary and/or interdisciplinary courses linking climate, health, and equity in the built environment

The number of universities offering multidisciplinary (i.e., multiple disciplines involved, but discipline-specific methods) and/or interdisciplinary (i.e., methods cross disciplinary boundaries to create shared knowledge) curricula linking the built environment with population health has increased substantially since 2005–2009, as shown in Figure 3. Houghton and Castillo-Salgado (66) built on the 2005 and 2009 studies by adding a screen for the health effects of climate change in addition to considering the links between population health and the built environment. From 2018 to 2022, the number of universities in both clearinghouses grew modestly both in the US (increasing from 131 to 143) and in other countries (increasing from 36 to 62).

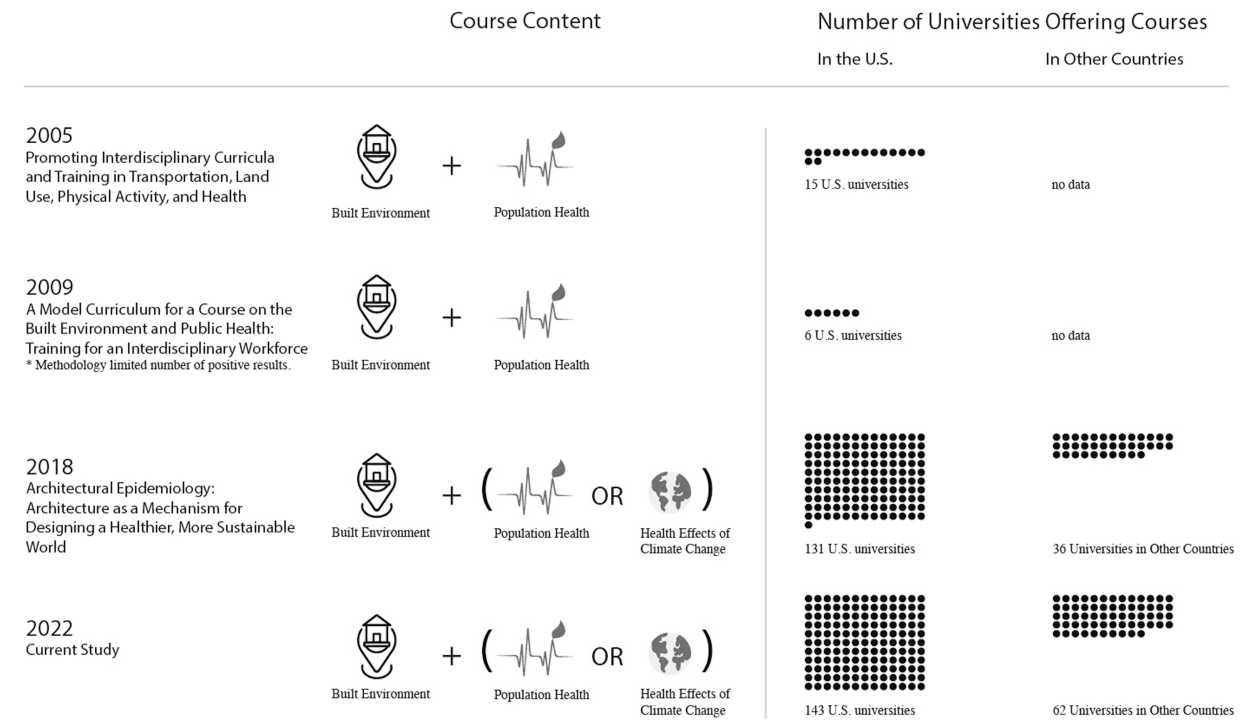

FIGURE 3
Change in the number of universities teaching courses addressing the relationship between the built environment and population health and/or climate change (2005–2022).

The reader is advised to consider three important caveats when considering the information in Figure 3. First, neither the BEPHC nor the GCCHE clearinghouse should be considered a comprehensive list. Instead, the righthand column should be read more as an indication that the number of universities offering courses at the intersection of the built environment and either population health or the health effects of climate change appears to be growing both in the US and worldwide. Furthermore, given the fact that only 13 non-US universities appear in the 2022 BEPHC clearinghouse, that set of results should be viewed with particular caution.

Second, many universities included in the BEPHC and GCCHE lists offer more than one relevant course. The total number of courses could therefore be expected to be larger than the number of dots in Figure 3 (which represent universities, not courses).

Third, most of the courses included in the review did not include all three topics (built environment, population health, and climate change). Instead, they addressed the link between the built environment and either population health or the health effects of climate change. This is a major gap that should be central to the conversation about how to develop a truly transdisciplinary course of study addressing climate, health, and equity in the built environment.

3.2. Overlap in universities included in both clearinghouses (2022)

Figure 4 illustrates the limited overlap between universities in the BEPHC clearinghouse compared with the GCCHE clearinghouse, in that only 27 of the 55 universities listed at Tier 2, 3, or 4 in the BEPHC clearinghouse (roughly 50%) were also listed as members of the GCCHE.

A note to the reader: it is important to consider that the databases pick up different schools (architecture and planning schools in the BEPHC clearinghouse and schools of public health and medicine in the GCCHE clearinghouse). So, the fact that the same university is included on both lists does not necessarily mean that the two schools or departments realize that they are both claiming leadership on related topics. Instead, they could be considered "transdisciplinary-ready," having all the key components in place should they wish to provide courses and joint degrees that draw on multiple disciplines and offer practice-based learning opportunities.

3.3. Overlap in course offerings linking built environment with population health and/or climate change: sample of course descriptions

Figure 5 indicates that, of the 99 relevant course titles and descriptions included in the Columbia University, University of Colorado, and University of California at Los Angeles course catalogs, 17 courses addressed all three topics: population health, climate change, and/or the built environment. And, 60 courses addressed two out of the three topics (Figure 5).

When organized by discipline, we see that the majority of courses covering all three topics ($n = 11$) were located in schools of public health, with architecture and planning schools each offering three courses covering all three topics. The chi-square test for the frequency

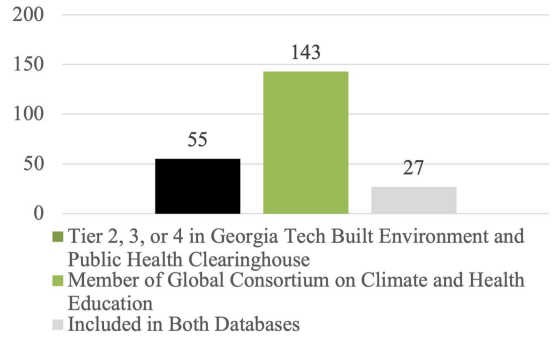

FIGURE 4
Number of universities listed at Tier 2, 3, or 4 in the built environment and public health clearinghouse, listed as a member of the global consortium on climate and health education, and listed on both databases (n = 225 total universities).

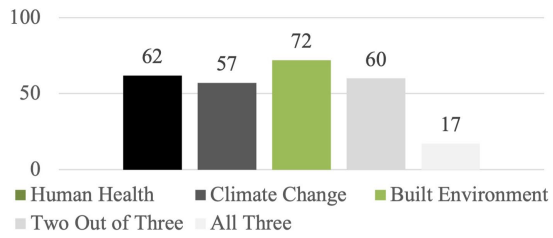

FIGURE 5
Number of courses in the 3 university sample that address one or more of the following topics: human health, climate change, built environment (n = 99 courses across the three universities).

estimate was statistically significant, $X^2(21, n=99)164.206$, $p<0.0001$ (Figure 6).

While the majority of courses in the three-university sample (68) covered the links between the built environment and population health/climate change at the community scale, most courses touched on multiple scales – including 37% ($n=37$) considering the building or organization scale at least to some extent (Figure 7).

Unsurprisingly, courses in architecture schools were much more likely than planning or public health schools to cover the building or organization scale. Figure 8 shows that 20 out of 22 courses in architecture schools met that criteria, compared with only two out of 32 courses in planning schools and four out of 45 courses in public health schools. The chi-square test for the frequency estimate was statistically significant, $X^2(6, n=99)161.727$, $p<0.0001$ (Figure 8). Given the fact that there were so many fewer architecture courses in the dataset compared with planning and public health, the fact that the building and organization scale are so often excluded from the curriculum in planning and public health schools further exacerbates the gap in opportunities for students to learn about the pivotal role that buildings play in a transdisciplinary approach to climate, health, and equity in the built environment.

Figure 9 compares the same sample set of 99 course descriptions to the five key elements described in the Introduction. The majority of courses ($n=57$) explicitly address the built environment as an exposure pathway for health outcomes – whether related to chronic disease, climate change, or another public health topic. Almost one third ($n=28$) center equity and/or vulnerable populations in the topics covered by the course. But, the remaining key course components (social determinants of health, epidemiology/biostatistics methods, and geospatial analysis) were not comprehensively addressed by most courses. Only one course, EHS C200B Foundations of Environmental Health Sciences for Public Health Professionals at UCLA, included all of the key course components for a transdisciplinary curriculum linking the built environment to population health and the health effects of climate change.

All of the architecture courses in the sample set of 99 course descriptions included only one key course element: either exposure pathways or equity/vulnerable populations. Planning schools followed close behind architecture schools, offering only three courses with two elements (exposure pathways and equity/vulnerable populations) and two courses with three key elements (exposure pathways, equity/vulnerable populations, and social determinants of health). Public health schools were by far the most likely to include two elements (mostly exposure pathways and equity/vulnerable populations) ($n=13$). Five public health courses included three elements. And, the course at UCLA covering all five elements (mentioned above) was housed in the school of public health. The chi-square test for the frequency estimate was statistically significant, $X^2(6, n=99)16.743$, $p=0.010$ (Figure 10).

3.4. Joint degree programs

The BEPHC clearinghouse identified 15 universities with joint degree programs in urban planning and public health in 2022 (Table 2). Four of the universities on the list were also identified as offering joint degrees in the Sclar and Northridge report from 2005: Columbia University, University of California Berkeley, University of Michigan, and University of North Carolina at Chapel Hill. Five joint degree programs (1/3 of the total) include the health effects of climate change as part of the required course of study. In all cases, this topic is covered in a course or courses taught in the school of public health.

Since the BEPHC clearinghouse is primarily focused on community and urban planning programs, it did not specify whether any joint degrees in public health were offered in collaboration with architecture programs. To fill this gap, I performed a Google search in September 2022 using the terms "master of public health," "public health," and "architecture" – returning no joint Master of Architecture/Master of Public Health (MArch/MPH) degree programs. I followed up the general search query by visiting the websites of 15 architecture schools included on the National Architectural Accrediting Board list of accredited schools (68). None of the schools offered a joint degree or concentration in architecture and public health.

From September to November 2022, I asked ten academicians in US universities whether their university had established or was considering establishing a joint MArch/MPH degree in collaboration with a school of public health or health science center. A professor at a public university responded that their school of architecture and health science center were in the early stages of conversations about establishing a joint degree. But, the remaining responses pointed either to a joint degree or concentration between the school of public health and the department of urban or community planning, an

Discipline	Topic: Health	Climate	Built Environment	Health + Climate	Climate + Built Environment	Health + Built Environment	Health + Climate + Built Environment	Total
Architecture	0	0	4	0	9	6	3	22
Planning	1	2	7	0	14	5	3	32
Public Health	10	0	0	15	0	9	11	45
Total	11	2	11	15	23	20	17	99

Pearson chi^2(21) = 164.2057; Pr = 0.000

FIGURE 6
Frequency and distribution of course topics by discipline (n = 99 courses across the three universities).

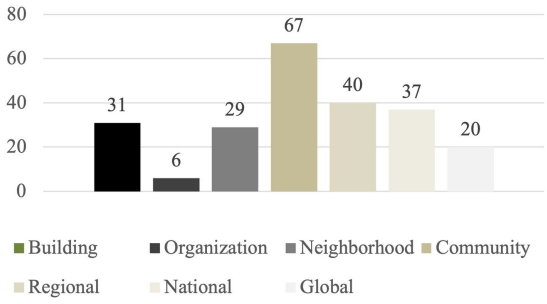

FIGURE 7
Geographic scale of courses (n = 99 courses across the three universities).

MArch degree with a concentration in the design of healthcare facilities (such as the Architecture + Health concentration at Clemson University (69)), or individual courses touching on the links between building design and population health outcomes or climate change.

In order to launch a comprehensive, transdisciplinary program on climate, health, and equity in the built environment, universities will need to offer courses, concentrations, and joint degree programs that are open to students from multiple departments (at a minimum: architecture, planning, and public health); explore the links between the built environment, population health, social equity, and climate change; and, incorporate project-based learning as part of the curriculum.

Table 3 lists the universities in the BEPHC and GCCHE clearinghouses that met all or all but one of these structural components. 18 universities met all of the components in both 2018 and 2022. 14 universities have all but one of the components in place to launch a truly transdisciplinary curriculum. In both sets of universities, an institution's level of transdisciplinary-readiness is tempered by its designated tier in the BEPHC clearinghouse. To clarify the stratification across institutions, the righthand column in Table 3 lists additional institutional supports that would strengthen a university's position as a transdisciplinary-ready institution: such as moving from Tier 3 in the BEPHC clearinghouse (interdisciplinary concentration, specialization, certificate, or specialized degree) to Tier 4 (joint degree program).

3.5. Qualitative analysis of pedagogy and institutional approaches to transdisciplinary courses and joint degrees on climate, health, equity and the built environment

I conducted ten key informant interviews with faculty and administrators at seven transdisciplinary-ready universities after completing the quantitative phase of the study. I used the opportunity to ask participants, many of whom are pioneers in the creation of university courses and joint degree programs at the intersection of the built environment and health, why these topics remain at the margins of all three disciplines: architecture, planning, and public health. The seven institutions in the dataset span four geographic regions in the US, vary in size, and include both public and private institutions. Using inductive thematic analysis, I elicited four major themes explaining current pedagogy and administrative priorities in US-based transdisciplinary-ready universities.

3.6. Accreditation

All of the interview participants stated that accreditation bodies play a pivotal role in moving areas of study from the margins to the center of academic curricula. A major barrier to institutionalizing transdisciplinary curricula addressing climate, health, and equity in the built environment is that one or more of those topics are not identified as core competencies in the named disciplines in the study (architecture, planning, and public health). For example, climate change is not listed as a core competency by the Public Health Accreditation Board (70) and the health effects of climate change are not listed as core competencies by either the National Architectural Accreditation Board (38) or the Planning Accreditation Board (71). Three participants described using their own research and/or status in their home institution to champion inclusion of climate change, population health, and/or social equity in the built environment in core courses – such as survey courses and core design studios. For example, one participant shared that they were able to integrate population health into a core course in a school of architecture as a result of "a series of alignments between an interim director, and … a few senior faculty [on the curriculum committee] who said, 'You've convinced us.'" The participant added, "It took me [a few] years of

	Discipline			
	Architecture	Planning	Public Health	Total
Building/Organization Scale Included in Course	20	2	4	26
Not Included	2	30	41	73
Total	22	32	45	99

Pearson chi^2(6) = 161.7268; Pr = 0.000

FIGURE 8
Geographic scale of courses (*n* = 99 courses across the three universities).

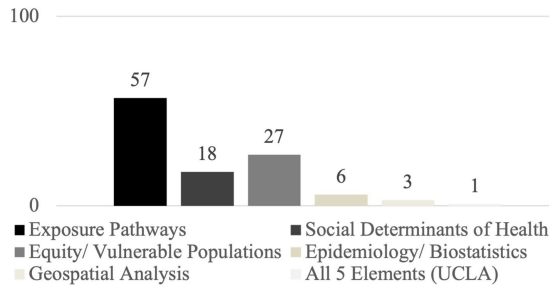

FIGURE 9
Key course elements across the sample dataset of course titles and descriptions (*n* = 99 courses across the three universities).

standing up in meetings and … [saying], 'We're doing something that other schools aren't doing. Please support it.'"

All participants pointed to the need to institutionalize the approach in order to ensure its longevity. Currently, even in universities with longstanding programs, interested faculty and administrators expressed a sense of fragility. They questioned whether even joint degree programs will survive after the current crop of faculty retires. One participant shared, "You know, I'm going to put health at the top of the list for an architecture course. But it's going to compete with every other topic that every other faculty member thinks is the most important thing anybody ought to be doing. … And so long as it's optional, you'll get a scattering of courses around the country. They are generally going to be based on the interest of the faculty willing to teach them. When that faculty retires, [the university is] not particular about a hire to replace [them], because [the topic] was never made central."

Another participant expressed frustration with the university and accreditation structures that stand in the way of change: "There's a lot of inertia. And I feel like I've been the lone or nearly the lone person trying to make these things happen for 10 years. And when a new administrator comes in and they do not seem to be at all interested in supporting [transdisciplinary or cross-listed courses]. … That's when I just get frustrated. And I'm like, okay. I'm this many years from retirement. I do not have a lot more to expend here." A third participant stated that a course remains on their university's website in spite of the fact that it has not been taught since the professor who created and delivered it retired.

3.7. Budgets and finances

Most participants stated that cross-listing courses – particularly across different schools at a university, but sometimes even across different departments within the same school – can be a challenge because school (and sometimes departmental) budgets are partially determined by student enrollment. In other words, if 10 students enroll in a cross-listed course using the school of architecture and planning code but only five students enroll using the school of public health code, the school of architecture and planning will receive two thirds of the enrollment funding even if classes are hosted in a classroom at the school of public health. This kind of incentive structure (coupled with bureaucratic hurdles, such as different grading systems in different schools) can create a real barrier to professors' collaborating to develop and deliver transdisciplinary courses or joint degree programs. It is easier to create a joint degree program that passes the student back and forth – so that she pays for courses in the planning department one year and courses in the school of public health the next year, for example. One participant shared a story about a graduate student who wanted to complete both a Master of Urban Planning (MUP) and a Master of Public Health (MPH). According to the interviewee: "It took three and a half years, because it was about money and revenue. She had to do the MUP and MPH separately. … It was because they wanted her to pay separately [for the two degrees]." Needless to say, those kinds of practical decisions do not necessarily optimize the student's learning opportunities.

Every participant agreed that an effective way to overcome the financial and bureaucratic barriers to transdisciplinary courses is for the university to establish a superstructure of sorts that offers funding, streamlined course approvals, and other support systems that lift transdisciplinary conversations out of the departmental level and up to a university level, where topics like climate change can be promoted by high ranking administration officials, such as the Provost or Chancellor. In 2022, Harvard University announced the creation of the Salata Institute for Climate and Sustainability, which is overseen by the Vice Provost for Climate and Sustainability. The Institute is designed as a university-wide initiative aimed at supporting "comprehensive University-wide education in climate and environmental fields" (72). Several interview participants expressed optimism that this experiment in university-wide efforts to tackle climate change might offer a possible solution to the budget and financing barriers to performing transdisciplinary work at Harvard.

Discipline	One Element	Two Elements	Three Elements	Four Elements	Five Elements	Total
Architecture	22	0	0	0	0	22
Planning	27	3	2	0	0	32
Public Health	26	13	5	0	1	45
Total	75	16	7	0	1	99

Pearson chi^2(6) = 16.7433; Pr = 0.010

FIGURE 10
Number of key elements per course, by discipline (n = 99 courses across the three universities).

TABLE 2 Joint master degrees in urban planning and public health: 2022 results.

University	Required Course Addressing Climate Change and Health?
Columbia University*	No
Florida State University	No
Harvard University	No
Portland State University	No
Queens University	No
University of California, Berkeley*	PH 271G Global Climate Change and Public Health
University of California, Los Angeles (UCLA)	EHS C200B Foundations of Environmental Health Sciences for Public Health Professionals
	EHS 208 Built Environment and Health
University of Colorado, Denver	No
University of Illinois at Urbana-Champaign	No
University of Maryland	No
University of Michigan*	No
University of Minnesota	PubH 6,250 Foundations of Public Health
University of North Carolina at Chapel Hill (UNC)*	ENVR 600 Environmental Health
University of Southern California	No
University of Washington	PHI 511 Foundations of Public Health
	ENVH 501 Foundations of Environmental and Occupational Health
	URBDP 538/ENVH 538 Public Health and the Built Environment

*Indicates this degree was also offered in 2005.

Other universities have attempted to circumvent school-specific budgetary siloes by creating small research grant programs and administrative support for developing transdisciplinary curricula. Unfortunately, these efforts often hit glass ceilings unless the university creates an infrastructure supporting their implementation. As one participant explained, "The college got a grant from the Chancellor's office to create [a cross-listed course]. … I spent [several] years doing a market study, working with the person who was in charge of the program in public health at that time. She was very committed to the collaborative effort. But, ultimately, she wasn't permanent. She was a contingent faculty member who had been put in charge because somebody retired or something. She also was the one who said, 'There's just no room in what we are doing [because of accreditation requirements].'"

Another participant described multidisciplinary grants issued by the university and requiring two or more schools to participate as an informal workaround that only involves students as research assistants. That interviewee observed that research assistants often do not make the connection about the links across disciplines by "coincidence" or "exposure." They continued: "I feel like education is a lot like the healthcare system. The burden of synthesis and coordination is on the student. … The curriculum is not working to help [the student] figure it out. … We started maybe a year back trying to develop a concentration [linking population health and the built environment], just identifying all of the courses across the university. … The burden of even putting together [an inventory of courses] was on the student. … [It's such a big lift that] there's an incentive to only showcase courses [in the concentration] that are in or adjacent to [the home discipline]."

3.8. Informal workarounds

Given the institutional and accreditation barriers to centering climate, health, and equity in the built environment in any given discipline, all of the interview participants described informal workarounds they use to introduce these topics into their research and interaction with students.

In many institutions, professors seek out like minded colleagues in different departments to jointly apply for research funding and deliver guest lectures in each other's courses. As one professor put it, "I cultivate relationships with faculty members [in other schools], partly because we work on the sustainable campus effort that brings the physical world front and center through the campus and structures. I serve on advisory committees and … doctoral committees. And, [professors from other schools and I] lecture in each

TABLE 3 Universities with all or almost all of the components in place to launch a comprehensive, transdisciplinary program on climate, health, and equity in the built environment (2018–2022).

Institutions listed in BEPHC and GCCHE clearinghouses in both 2018 and 2022	Relevant School/Department(s)	BEPHC Tier*	Adding the following elements would move the institution closer to a transdisciplinary curriculum
Columbia University	Graduate School of Architecture Planning and Preservation Mailman School of Public Health	Tier 4	
Harvard University	Graduate School of Design	Tier 4	
State University of New York at Buffalo	School of Architecture and Planning School of Public Health and Health Professions	Tier 2	Offer a concentration or joint degree.
Temple University	School of Environmental Design College of Public Health	Tier 3	Offer a joint degree.
Texas A&M University	College of Architecture School of Public Health	Tier 3	Offer a joint degree.
University of California at Berkeley (Berkeley)	College of Environmental Design School of Public Health	Tier 4	
University of California at Los Angeles (UCLA)	UCLA Fielding School of Public Health Luskin School of Public Affairs	Tier 4	
University of Colorado	College of Architecture and Planning Colorado School of Public Health	Tier 4	
University of Illinois at Chicago	School of Public Health Department of Urban and Regional Planning	Tier 2	Offer a concentration or joint degree.
University of Illinois at Urbana-Champaign	College of Urban Planning and Public Affairs Master of Public Health Program	Tier 4	
University of Michigan	Taubman College Architecture + Urban Planning School of Public Health	Tier 4	
University of Minnesota	Humphrey School of Public Affairs School of Public Health	Tier 4	
University of North Carolina at Chapel Hill (UNC)	Department of City and Regional Planning Gillings School of Global Public Health	Tier 4	
University of Oklahoma	College of Architecture Health Sciences Center – College of Public Health	Tier 2	Offer a concentration or joint degree.
University of Southern California	Sol Price School of Public Policy Master of Public Health Program	Tier 4	
University of Toronto**	Geography and Program in Planning Dalla Lana School of Public Health	Tier 3	Offer a joint degree.
University of Washington	Urban Design and Planning; Environmental & Occupational Health Sciences; Health Services School of Public Health	Tier 4	
University of Waterloo**	School of Planning School of Public Health and Health Systems	Tier 2	Offer a concentration or joint degree.
Institutions Meeting All But One Structural Criteria in 2022			
Boston University	Boston University Metropolitan College School of Public Health	Tier 2	Partner with the architecture department at a peer institution to offer courses linking architectural design to climate change, population health, and equity. Offer a concentration or joint degree with public health.

(Continued)

TABLE 3 (Continued)

Institutions listed in BEPHC and GCCHE clearinghouses in both 2018 and 2022	Relevant School/Department(s)	BEPHC Tier*	Adding the following elements would move the institution closer to a transdisciplinary curriculum
Florida State University	Department of Urban and Regional Planning College of Social Sciences and Public Policy, School of Public Health	Tier 4	Offer courses linking architectural design to climate change, population health, and equity. Join the Global Consortium on Climate and Health Education.
George Washington University	College of Professional Studies Milken Institute School of Public Health	Tier 2	Offer courses linking architectural design to climate change, population health, and equity. Offer a concentration or joint degree with public health.
Hunter College of the City University of New York	Hunter College Urban Affairs and Planning	Tier 2	Add the health effects of climate change to the curriculum linking architecture and planning to population health. Offer a concentration or joint degree with public health. Join the Global Consortium on Climate and Health Education.
Ohio State University	Knowlton School of Architecture School of Health and Rehabilitation Sciences College of Medicine		Removed from the BEPHC clearinghouse website between 2018 and 2022.
Ryerson University/Toronto Metropolitan University**	School of Urban and Regional Planning School of Occupational and Public Health		Removed from the BEPHC clearinghouse website between 2018 and 2022.
State University of New York at Albany	College of Arts and Sciences: Geography and Planning School of Public Health	Tier 3	Offer courses linking architectural design to climate change, population health, and equity. Offer a joint degree.
University of Arizona	College of Architecture + Planning + Landscape Architecture Mel and Enid Zuckerman College of Public Health		Removed from the BEPHC clearinghouse website between 2018 and 2022.
University of Iowa	School of Urban and Regional Planning College of Public Health	Tier 2	Offer courses linking architectural design to climate change, population health, and equity. Offer a concentration or joint degree with public health.
University of Massachusetts Amherst	Landscape Architecture and Regional Planning School of Public Health and Health Sciences		Removed from the BEPHC clearinghouse website between 2018 and 2022.
University of Memphis	College of Arts and Sciences School of Public Health		Removed from the BEPHC clearinghouse website between 2018 and 2022.
University of Nebraska	UN Medical Center College of Public Health – Omaha College of Architecture Creating Spaces – Lincoln		Removed from the BEPHC clearinghouse website between 2018 and 2022.
University of New Mexico	School of Architecture and Planning Health Sciences Center		Removed from the BEPHC clearinghouse website between 2018 and 2022.
University of Pennsylvania	School of Design Master of Public Health Program		Removed from the BEPHC clearinghouse website between 2018 and 2022.

Components: courses offered in architecture, planning, and public health schools; coursework linking climate change, population health, and social equity in the built environment and supported through a joint degree (Tier 4), concentration (Tier 3), or individual courses (Tier 2). The higher the Tier, the more structural components are in place at the intersection of population health and the built environment. *Curriculum Tier according to Georgia tech built environment and public health clearinghouse. **Located in Canada (All other universities on the list are located in United States).

other's courses. We always know that we are going to make something happen at the personal level [even if there is no formal partnership between the two schools]."

The goal of these informal partnerships is to expose students to courses and professors in other disciplines, so that it is easier for students interested in these topics to find like-minded professors. Participants showed less consensus around whether students were likely to connect the dots on their own without support from faculty members. One participant stated, "I actually feel pretty strongly that students can do that work to synthesize [the intersection between

health and the built environment] on their own. And, we do not have to design it for them every time." Another participant gave an example of the kinds of linkages students are expected to make without professorial support: "The students are getting more about climate change through, for example, their MEP courses and some of the other courses, and so it in some ways it is left up to them to make the bridge [between climate change and health]." A third participant shared, "I have observed that many students [particularly undergraduates] do not connect the dots on their own. It requires a professor to show them that the work they are doing links over to work happening in another department."

Professors use case studies and student projects to create opportunities for students to integrate disparate concepts learned earlier in the course into a synthesized response to a complex challenge. Practice-based learning projects add the component of learning from community stakeholders – a key component to centering social equity in transdisciplinary work. These courses and research opportunities face similar challenges to the elective courses described above. Unless they are institutionalized as part of the core curriculum, they are experienced as one-off projects, requiring additional work and returning questionable rewards to the professor or administrator who went to the effort to set them up. One participant shared, "The informal process [of connecting students with professors in different schools] serves my students well for the most part, because I know where to send them. … But [each connection] is a one-off, and it's not a very effective. … It's haphazard."

3.9. Role of the student, role of the university

Returning to Scholz's critique of the university (10), an area of disagreement among participants involved the role of the university in setting an agenda for the future of transdisciplinary research and pedagogy. Some participants reflected their institution's observation that students had been asking for transdisciplinary training for years – particularly around environmental sustainability, social equity, and health. One participant shared the observation: "It's not that there's not enough student interest. It's really that the professors aren't interested …. The students do amazing things. And most of them do pick up on [the links between design, population health, and social equity]. There's a core group of [undergraduates] that actually come back to our graduate program because they are really interested in it, and they know that we have this specialty."

Other institutions did not see the same level of interest from prospective students. One participant observed, "You're never going to have that many students who want to do a full transdisciplinary degree. We actually have a hard enough time getting enough students to fill a class. … But there is a demand for a mix and match way of having these two degrees [MUP/MPH]."

Still others described climate change as an existential threat. But, rather than emphasize climate change in the undergraduate core curriculum, the institution decided to introduce a transdisciplinary climate change and health program at the doctoral level. As a professor from that institution put it, "We do not see that many researchers being turned out who have the skill set that's going to be needed to address the most 'wicked' problems [like climate change]. But, we need people who have the skills to address them. We recognize that it's a gap in our curriculum. And, we have students who are coming out of the woodwork saying, 'We want to be part of this solution by doing research in this area.'" A participant from a different institution observed: "Part of [the purpose behind establishing transdisciplinary research and pedagogy] more formally is a signaling process to society. [We are using the university as a platform to communicate that] these are critical issues that need to be rethought."

In sum, given the difficulties in institutionalizing any kind of transdisciplinary research or pedagogy, the fact that the number of courses and joint MUP/MPH degrees addressing climate, health, and equity in the built environment appears to be growing may reflect a larger shift in societal priorities that will lead to institutional reforms at universities over time.

4. Discussion

4.1. Historical precedents, future needs

A review of the BEPHC and GCCHE clearinghouses, web search, and semi-structured interviews with US professors and administrators revealed a strong history of champions within universities who have established joint degrees and worked informally with colleagues in different departments and schools to advance the state of knowledge and provide students with training on the intersection of climate change, population health, and social equity in the built environment.

This study revealed that four universities have offered joint degrees in planning and public health since at least 2005 (Table 2): Columbia University, University of California Berkeley, University of Michigan, and UNC. Furthermore, five of the universities currently offering joint degrees include the health effects of climate change in at least one required course in the MPH curriculum (Table 2): University of California Berkeley, UCLA, University of Minnesota, UNC, and University of Washington. This is an encouraging sign of the longstanding influence that pioneering researchers on the links between the built environment and population health have had on the fields of public health and community and urban planning. Notably, the book *Making Healthy Places* (62) edited by Drs. Andrew Dannenberg, Howard Frumkin, and Richard Jackson and released in 2011 has served as a textbook for courses following the proposed curriculum in the Botchwey et al. paper from 2009, which included Dr. Dannenberg and Dr. Jackson as co-authors. Furthermore, all three editors are or have been affiliated with two of the universities that both offer dual degrees and are well-positioned to launch a transdisciplinary program on climate, health, and equity in the built environment: UCLA and University of Washington. A new edition of the book, headlined by Dr. Botchwey, was released in 2022 in an expression of optimism that demand for this type of training remains strong (37).

Also striking is the geographic diversity and strong representation of public universities in the cohort of 32 institutions that have all or all but one of the structural components in place to launch a truly transdisciplinary program on climate, health, and equity in the built environment. These universities are located in 19 states and the District of Columbia, including conservative-leaning states like Iowa, Nebraska, Oklahoma, and Texas. Three universities are located in Ontario, Canada: Toronto Metropolitan University, University of Toronto, and University of Waterloo. 27 of the 32 institutions in the cohort (84%) are public universities.

While these universities have taken steps to establish the structural components necessary to launch a transdisciplinary program on climate, health, and equity in the built environment, it is far from clear that students, professors, and research faculty engage in these topics in a transdisciplinary manner. More is required than simply removing structural barriers to transdisciplinary education and research. Other actions will be needed, such as overcoming the disciplinary boundaries that are so entrenched in many universities; cross-listing courses in more than one school; establishing joint compensation mechanisms for transdisciplinary professors and researchers; incentivizing the creation of transdisciplinary courses, student projects, and research grant applications; and, celebrating early adopters of this new approach to education and research.

Eighteen years after the Sclar, Northridge, and Karpel report surfaced many of the same barriers to transdisciplinary programs (49), it is far from clear that these actions have been taken at any institution – even the eleven universities offering joint degrees and identified as having all the necessary structural components in place: Columbia, Harvard, Berkeley, UCLA, University of Colorado, University of Illinois at Urbana-Champaign, University of Michigan, University of Minnesota, UNC, University of Southern California, University of Washington.

The qualitative interviews with ten professors and administrators at seven transdisciplinary-ready institutions revealed informal partnerships filling the gaps that have been created by institutional barriers and the absence of a mandate in the form of accreditation boards. Many of the original pioneers who pushed for integration of built environment considerations into public health curricula and the integration of population health considerations into architecture and planning curricula sit on the verge of retirement and worry that the courses and joint degrees they championed may retire alongside them unless they are folded into the core curriculum in their home disciplines.

4.2. Architecture: a key missing element

Both the quantitative and qualitative portions of this study concluded that schools of architecture remain largely excluded from transdisciplinary curricula addressing climate, health, and equity in the built environment. This is a troubling finding, because building design is the place where neighborhood and community plans are either implemented or not. By excluding architects, real estate developers, and other building professionals, joint degree programs and concentrations are missing the key piece that will allow future practitioners to bridge this "last mile" problem and ensure that holistic community plans are built out – and therefore able to achieve their goals related to climate mitigation, climate adaptation, population health outcomes, and social equity.

4.3. Limitations

This study faced several limitations. First, the BEPHC and GCCHE clearinghouses list university names and, to some extent, the names of schools and departments. However, they do not provide up to date information. And, they do not link directly to course catalogs. Many universities do not make their syllabi public. And, some do not make their course descriptions public for active courses. As a result, the process of linking the presence of a university on one of the clearinghouse lists to course content was laborious and riddled with missing data.

Neither clearinghouse claims their content to be comprehensive. The BEPHC list was compiled manually using an Internet search. In order for a university to appear on the GCCHE list, that institution must opt in to becoming a member of the consortium. As a result, none of the results in this study should be construed as representative of the current state of transdisciplinary curriculum on climate, health, and equity in the built environment. It simply provides an indication of the rapid growth in joint programs, concentrations, and courses at the intersection of these topics. It also presents a group of transdisciplinary-ready institutions with the opportunity of establishing a learning network that could accelerate the transition towards a more effective approach to education and research on complex, global topics like climate change.

5. Conclusion

This study brings the most comprehensive clearinghouses on built environment, population health, and climate change curricula together for the first time to assess the extent to which some postsecondary institutions have all of the pieces in place that would be needed to create the truly transdisciplinary curriculum that is needed to train the future leaders who will usher the world into a post-carbon future.

It found that the number and geographic distribution of courses addressing the built environment, population health, and/or climate change have dramatically increased between 2005–2009 and 2022. However, the overwhelming majority of courses present material only at a conceptual level. The review identified only a handful of joint degrees – all of which link the school of public health with a community/urban planning degree. No joint degree programs were identified linking a public health degree with an architectural degree.

The results of this study show that, while universities are starting to respond to pressure to provide transdisciplinary courses and joint degree programs at the intersection of the built environment, climate change, population health, and social equity, these offerings remain too limited in scope and too conceptual in content as yet to produce graduates who fully possess the necessary research methods and technical skills required to design and implement built environment interventions that will address the needs of society in a changing climate.

Author contributions

AH conceived the idea for the study and conducted all aspects of research, writing, and editing.

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Conflict of interest

AH is President of Biositu, LLC. She declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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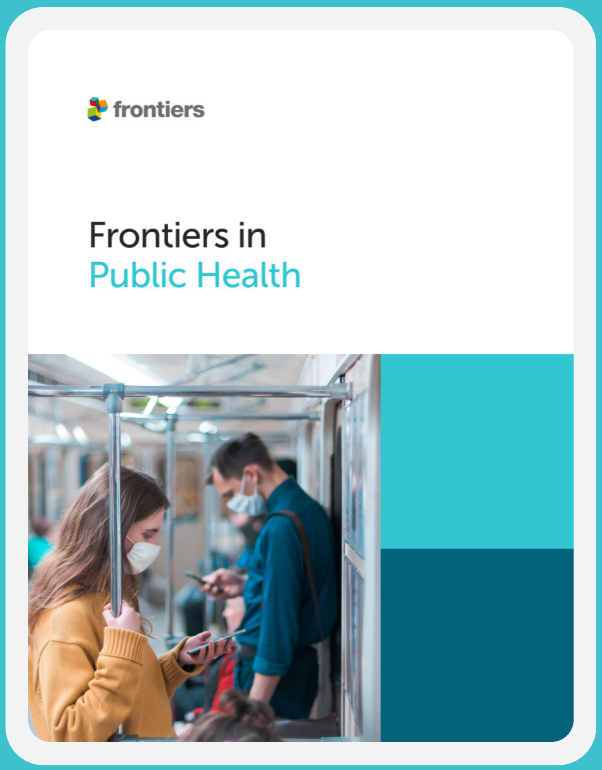

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