

**REVIEW ARTICLE**


# Child-focused climate change and health content in medical schools and pediatric residencies

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Anthropogenic climate change—driven primarily by the combustion of fossil fuels that form greenhouse gases—has numerous consequences that impact health, including extreme weather events of accelerating frequency and intensity (e.g., wildfires, thunderstorms, droughts, and heat waves), mental health sequelae of displacement from these events, and the increase in aeroallergens and other pollutants. Children are especially vulnerable to climate-related exposures given that they are still developing, encounter higher exposures compared to adults, and are at risk of losing many healthy future years of life. In order to better meet the needs of generations of children born into a world affected by climate change, medical trainees must develop their knowledge of the relationships between climate change and children’s health—with a focus on applying that information in clinical practice. This review provides an overview of salient climate change and children’s health topics that medical school and pediatric residency training curricula should cover. In addition, it highlights the strengths and limitations of existing medical school and residency climate change and pediatric health curricula.

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**IMPACT:**

- Provides insight into the current climate change and pediatric health curricular opportunities for medical trainees in North America at both the medical school and residency levels.
- Condenses climate change and pediatric health material relevant to trainees to help readers optimize curricula at their institutions.

**INTRODUCTION**

With the unique set of risks that climate change poses to children of all ages, understanding the relationship between climate change and pediatric health is a key competency for current and future generations of medical trainees. As such, medical school and residency curricula must be tailored to prepare clinicians to meet the changing needs of their pediatric patient populations in the setting of a world increasingly affected by climate change.

In 2019, the American Medical Association (AMA) passed a resolution that acknowledged the necessity of integrating climate change education “across the medical education continuum”.<sup>1</sup> In the same year, the *New England Journal of Medicine* put forth its own call for climate action<sup>2</sup> and subsequently launched its online climate change and health hub.<sup>3</sup> Leading children’s health organizations such as the American Academy of Pediatrics have acknowledged climate change as a children’s health crisis. Per their 2015 “Global Climate Change and Children’s Health” policy statement: “Climate change poses threats to human health, safety and security.”<sup>4</sup> Children are uniquely vulnerable to these threats.”

In 2021, the American Board of Pediatrics published the module, “Impact of Climate Change on Pediatric Health Care” to assist pediatricians in incorporating climate change considerations into their clinical practice.<sup>5</sup> While growing, the uptake of such materials into medical schools and residencies is still limited.<sup>6</sup>

As of the 2020–2021 Liaison Committee on Medical Education (LCME) annual survey of topics included in medical school required and elective courses, climate change is included in the pre-clerkship offerings of 54 schools and in the clerkships of 20 institutions<sup>7</sup> which is a notable increase in at least reporting if not actual curriculum compared to just 3 years prior.<sup>8</sup> However, the 2020–2021 survey does not break down the scope of the materials covered in relation to each topic; it remains unclear how many institutions provide trainee education about climate change and pediatric health. A similar survey does not exist to assess climate change education in residency programs. No mention is made of climate change and health in the 2022 Accreditation Council for Graduate Medical Education (ACGME) Common Program Requirements document.<sup>9</sup>

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**Table 1.** Summary of key climate crisis effects on children's health.

Children's health topic	Effects of the climate crisis
Inequities	Disparities in the vulnerability to climate-related disease exacerbations and onset exist related to children's household income, race, and ethnicity
Asthma and allergies	Increase in frequency and intensity of asthma exacerbations with changes in seasonal weather Poorer air quality secondary to pollution, wildfires, and other climate events Increased air pollutants with global warming and changing wind patterns
Mental health	Direct effects including extreme weather events and existentialist dread of the climate emergency plus indirect effects including forced displacement, destruction of resources and resource scarcity can exacerbate existing psychiatric disorders, increase the incidence of relapses and flares, or incite the onset of new disorders, including eco-anxiety
Toxic exposures and infections	An increase in the prevalence and incidence of vector-borne infectious diseases due to increased seasonality, reproductive rates, and distribution of vectors Exposures to more pathogens and toxins with floods; contamination of water, food, and sewage with weather events; and increased algae in recreational waters with warmer temperatures that can exacerbate asthma
Nutritional deficiencies	Resource scarcity from extreme weather events can lead to malnutrition and failure to thrive High carbon dioxide emissions can lower protein, mineral, or vitamin composition in foods
Medication management	Antipsychotics, beta-blockers, diuretics, laxatives, and antihistamines can alter the body's ability to regulate temperature and can make patients more susceptible to dehydration, heat exhaustion, or heat stroke in the setting of increasing global temperatures
Disruptions to healthcare management	Extreme weather events can incapacitate hospitals by interfering with electricity, so climate-resilient infrastructure in the face of floods and extreme weather is needed The U.S. healthcare system emits nearly 10% of the country's greenhouse gas emissions, so sustainable practices are required at a systems level

Educational frameworks for climate change and health education have been proposed for medical trainees in specialties like internal medicine.<sup>8</sup> In this paper, we will review issues at the intersection of climate change and children's health and highlight several examples of institutions that have begun to incorporate these concepts into their curricula.<sup>10</sup>

To gather information, the authors searched through the websites of all 170 American and Canadian medical schools accredited by the AAMC for information about climate change and health curricula. This information was supplemented by the data gathered in the Planetary Health Report Card, an annual initiative that ranks medical schools worldwide on the quality and comprehensiveness of their climate change and health education.<sup>11</sup> For additional information, the authors reached out to faculty and trainees at these institutions for further clarification about the educational programming on offer.

### APPROACHES TO A CLIMATE CHANGE AND CHILDREN'S HEALTH CURRICULUM

In its 2019 resolution, the AMA specified that medical trainees should be provided with "a basic knowledge of the science of climate change"; and be able to "describe the risks that climate change poses to human health, and to counsel patients on how to protect themselves from the health risks posed by climate change". The fundamental goals of a climate change and pediatric health curriculum at medical schools and residency programs must include (1) making trainees aware of the diverse and interconnected effects of climate change on children and (2) equipping trainees with the skills to screen and identify patients who are at risk, and provide anticipatory guidance. Below, we outline a list of topics regularly encountered in clinical practice that should be addressed in a climate change and children's health curriculum, which are summarized in Table 1. It should be noted that the specific effects of climate change on communities will vary geographically, which should be taken into account during curriculum development.

### Inequities

While the well-being of all children is at risk due to climate change, some are and will continue to be disproportionately affected. As many as 850 million children worldwide reside in places where the effects of multiple climate change and environmental hazards, such as wildfires, flooding, and resource scarcity, compound.<sup>12</sup> In the United States, disparities persist in relation to income, race, and ethnicity. Per the Environmental Protection Agency's 2021 Climate Change and Social Vulnerability report, if the planet continues along its current warming trajectory, children with low income and/or no high school diploma are 15% more likely to be living in places projected to undergo the largest particulate matter-related increases in childhood asthma diagnoses.<sup>13</sup> The basis of this calculation is derived from a study published in the *Journal of the American Medical Association* that uses two different climate models to estimate the degree of warming through 2095; per one model, there is a projected rise of mean temperature from 1.5 to 4.7 degrees of warming and per the second, 2.0 to 6.6 degrees of warming.<sup>14</sup> In general, minority communities are over 50% more likely to reside in neighborhoods predicted to have the most significant spikes in asthma-related emergency room visits. Asthma rates in Black children are over double that of non-Hispanic White children.<sup>15</sup>

It is important for clinicians to be aware of the ongoing consequences of historical redlining. Discriminatory housing policies produced neighborhoods that are populated by minority communities and are far less climate-resilient given features such as little to no greenery, high-density buildings, factories, highways, and heat-trapping asphalt.<sup>16–18</sup> People living in these neighborhoods are exposed to worse air quality. Moreover, they are more likely to be affected by extreme heat and flooding.<sup>19</sup> As the Earth continues warming, children living in non-climate-resilient communities will be at the highest risk of climate-related morbidity and mortality. Clinicians must screen for and identify the needs of the most vulnerable among their patients.

### Suggested competencies:

1. Describe the impact of climate change on health inequities in the United States.

2. Provide anticipatory guidance to vulnerable patients on how to mitigate the impact of climate change on health.
3. Identify personal and professional climate change mitigation strategies.

### Asthma and allergies

As the most common chronic disease of childhood, asthma affects 7.8% of American children,<sup>20</sup> allergies are close behind at 7%.<sup>21</sup> Climate change exacerbates both of these conditions in various ways, including through natural disasters of increasing frequency and intensity, and changes to seasonal weather patterns. Children are uniquely vulnerable due to features of pediatric anatomy and physiology.<sup>22</sup> For instance, children are more susceptible to poor air quality because they have a higher minute ventilation and take in larger air volumes relative to body weight compared to adults.<sup>23</sup> Their smaller airways are more likely to become inflamed and obstructed. The risks start as early as in utero: poor air quality and extreme heat are both associated with increased risk of preterm delivery,<sup>24</sup> which in turn has been linked to higher rates of asthma development—possibly due to interruption of in utero lung development.<sup>25</sup>

The effects of climate change on air quality include rising global temperatures and changing wind patterns that can influence wildfire risk and the dispersion of pollutants.<sup>26</sup> These pollutants have been linked to increased asthma-related emergency room visits and hospitalizations. Similarly, the rising rate of natural disasters like wildfires associated with climate change provides yet another source of harmful air pollutants—most notably, fine particulate matter, which are tiny particles able to evade the mucociliary escalator and settle deep into the lungs where they damage bronchioles and alveolar macrophages.<sup>27</sup>

Changing temperatures also influence the seasonality and distribution of allergens like pollen and molds that can both induce and exacerbate asthma and allergies.<sup>28</sup> For example, over the past few decades, pollen seasons have lengthened by about 8 days, starting 20 days earlier, and the volume of pollen produced has increased significantly.<sup>29</sup>

Suggested competencies:

1. Describe the mechanism of how environmental factors influence the pathogenesis and exacerbation of asthma.
2. Identify triggers for asthma that are influenced by climate change, such as pollen distribution.
3. Provide anticipatory guidance to patients about how to manage their asthma in the setting of these changing risk factors.

### Mental health

The climate emergency amplifies the risk of mental health difficulties, increasing susceptibility to depression, anxiety, post-traumatic stress disorder, or other mental illnesses. While new variations and subsets of existing psychiatric conditions, such as eco-anxiety,<sup>30</sup> have emerged in the age of climate change, the climate crisis will compound established risk factors.<sup>31</sup> Children are already and will continue to be one of the populations most vulnerable to these effects from in utero through adolescence, in addition to women and indigenous communities.<sup>32,33</sup> According to a meta-analysis of 192 epidemiological studies, most psychiatric disorders are established during childhood.<sup>34</sup> Furthermore, children disproportionately carry the burden of psychiatric disorders, with nearly 50% of teens aged 13–18 in the United States who meet the criteria for a psychiatric diagnosis.<sup>35</sup>

Extreme weather events, including heat waves, wildfires, droughts, or floods, and other direct threats from climate change

can exacerbate existing psychiatric disorders in children, increase the incidence of relapses or flares, and incite the onset of new disorders. The existentialist threat stemming from the anticipated destruction associated with such extreme weather events can worsen a child's mental health.<sup>36</sup> Data are needed to quantify the extent to which climate change will increase the need for mental healthcare and impede access.

In addition, the other effects of the climate crisis—injury, chronic illness, an increase in the spread of vector-borne diseases, air pollution, allergy, and asthma exacerbations—and the disruptions in food, water, housing, or other vital resources associated with the loss of agricultural lands, droughts, and forced migrations and violence secondary to extreme weather events impact a child's mental state.<sup>37</sup> Children with pre-existing mental health diagnoses, children of farming or indigenous communities, children who live in fire- or flood-prone regions, and children who live in low-income communities predisposed to health inequities are at greatest risks for mental health decline.<sup>38</sup> All of these factors also influence the delivery of care for children with mental illness. For example, medication management can become complicated with heat waves as antipsychotic medications can increase patients' sensitivity to heat, resulting in serious illness or death.<sup>39</sup>

As the next generation of adults, children can play critical roles in combating the effects of the climate crisis if properly educated and empowered, and participating in climate action itself can potentially help combat eco-anxiety;<sup>40</sup> however, climate activism can also be an additional burden on children, particularly those from marginalized communities.<sup>41</sup> Pediatricians can support at-risk children by addressing care gaps in mental health, educating themselves and their patients and patients' parents about the climate crisis, and becoming climate activists.

Suggested competencies:

1. Describe the characteristics and causes of eco-anxiety.
2. Identify how environmental factors like heat interact with psychotropic medications.
3. Provide anticipatory guidance to patients about psychotropic medications and their relationship to environmental events like heat waves.

### Toxic exposures and infections

The climate crisis is anticipated to increase the prevalence and incidence of vector-borne infectious diseases through alterations in the seasonality of disease transmission, forced migration of vectors as extreme weather events change their ecological habitats, and changes to vector reproductive rates. For example, Lyme disease, spread by bites from infected blacklegged ticks, has an increased season of transmission as global warming increases the amount of warmer months, and northward expansion of the vectors.<sup>42</sup> Moreover, the developing immune systems of children are more susceptible to infection in the first place. Children will bear a significant health burden from these developments, with some projections anticipating nearly 50,000 additional deaths of children under age 15 from diarrheal illnesses by 2030.<sup>43</sup>

Warmer temperatures are also linked with phenomena such as increased algal blooms in recreational waters;<sup>44</sup> these blooms are not only toxic to aquatic life but also to children who may ingest them directly or be exposed via aerosolization, which in turn can lead to headaches and asthma exacerbations. In addition, contamination of water, food, or sewage is more likely to occur as extreme weather events reduce access to sanitary resources and disrupt critical infrastructure. Increases in heavy rainfall have been associated with increased pediatric emergency department visits for gastrointestinal illnesses.<sup>45,46</sup> Displacement and unsanitary conditions in the aftermath of natural disasters also predispose

children to develop infestations like scabies, which, when itched and excoriated, may seed additional infections. Lastly, risk of toxic exposures is elevated for children—particularly minoritized children—living in communities with legacies of industrial contamination and higher flood risks under the changing climate.<sup>47</sup>

Trainees can learn to mitigate these effects by familiarizing themselves with vector-borne diseases, such as Lyme and Zika, and to consider a broad range of differential diagnoses when evaluating their patients, even if they would be atypical presentations given the season, geographic region, or lack of remarkable travel history. They can also provide anticipatory guidance to patients and parents about identifying and minimizing their exposures to dangerous pollutants, through precautionary clean-up practices post-flooding and pre-disaster advocacy to reduce flood risk through prioritization of public works programs as now occurring in Houston.<sup>48</sup>

Suggested competencies:

1. Describe the changing distribution and seasonality of infectious diseases.
2. Demonstrate how to take an environmental history from a patient, including toxin exposure and travel history.
3. Generate a differential diagnosis for possible infectious disease presentations such as fever and diarrhea that is specific to the geographic area.

### Nutritional deficiencies

For growing children, access to adequate nutrition is vitally important for appropriate development. Malnutrition in children can lead to stunted growth, immune deficiencies, poor wound healing, and other effects with lifelong ramifications.<sup>49</sup> About 1 in 10 American households experienced food insecurity at some point during 2021.<sup>50</sup> Although multifactorial in nature, food insecurity is exacerbated by climate change. Extreme weather events like droughts, heavy rainfall, and wildfires damage crops and livestock.<sup>51</sup> In addition to disrupting food production and access, food grown in the setting of an increasingly polluted and warming planet is more likely to be deficient in nutrients. When grown under high carbon dioxide conditions, some foods contain lower quantities of protein, minerals (e.g., iron and zinc), and certain vitamins.<sup>52</sup>

Suggested competencies:

1. Describe how climate change affects food security.
2. Identify vitamin and mineral deficiencies that children may be susceptible to in the setting of climate change.
3. Describe the clinical presentation of malnutrition.

### Medication management

For the millions upon millions of people who take medications on a regular basis, climate change is increasing their risk of suffering side effects in certain conditions. For example, common medications such as beta-blockers, diuretics, laxatives, and antihistamines alter the body's ability to regulate its temperature. They also affect water homeostasis.<sup>53</sup> These combined effects render users more susceptible to dehydration, heat exhaustion, and heat stroke in the setting of extreme weather events like droughts. Patients taking medications for their mental health may be especially vulnerable. This increased vulnerability may be due to the combined effect of these patients struggling to make behavioral adaptations during changing weather conditions and the thermoregulatory disturbances induced by antipsychotics, anticholinergics, and other common psychiatric medications.<sup>54</sup> Temperature can also affect the pharmacology of various medications. Increased temperatures affect the dosing of drugs like albuterol.<sup>55</sup>

Medical trainees need to be aware of how climate influences their patient's medications so they can better optimize their regimens and provide anticipatory guidance in advance of heat waves.

Suggested competencies:

1. Identify medications that are affected by environmental factors like heat.
2. Describe the mechanisms of medication-environment interactions.
3. Provide anticipatory guidance to patients taking these medications in the setting of environmental events like heat waves.

### Health system resilience

Extreme weather events can decimate a health system's ability to deliver key services. In the aftermath of Hurricane Sandy, which hit New York City in 2012, major hospitals serving millions of people, like Bellevue and NYU Langone, were forced to evacuate without electricity or electronic medical record access due to infrastructure failures.<sup>56</sup> Other institutions in the city fared better, such as Shorefront Center, which was built with a careful eye toward mitigating flooding damage. Its climate-resilient infrastructure not only kept the center functional, but enabled it to provide aid to other facilities during the disaster.

In addition to compromising infrastructure, extreme weather events also make it more difficult to access supplies critical for patient care. After Hurricane Maria struck Puerto Rico in 2017, the United States faced a shortage of the supply bags needed to administer intravenous fluids and liquid medications to patients.<sup>57</sup> Having to navigate supply shortages and unfamiliar protocols puts an additional strain on physicians working in environments affected by natural disasters. But the example of Hurricane Maria, in which an event in one part of the United States affected healthcare delivery throughout the country, also highlights the scope of the impacts of climate change.

Medical trainees must be familiar with the mounting challenges to healthcare delivery in the face of increasingly frequent and intense extreme weather events. They need to be prepared to safely evacuate their hospitalized patients and leverage what resources they have in limited settings to optimize patient care. It is also valuable for trainees to learn of the role that the health system itself plays in perpetuating the pollution that is accelerating climate change. The American health sector is responsible for almost 10% of national greenhouse gas emissions, making it the second most energy-intensive sector in the country.<sup>58</sup> Healthcare-associated emissions in the United States are projected to contribute up to 381,000 disability-adjusted life years in adverse health effects in the future. To that end, it would be valuable for trainees to learn about how health system decarbonization can promote health system resilience in the face of environmental disasters, decrease emissions, and even save costs without compromising the quality of healthcare delivery.<sup>59</sup>

Suggested competencies:

1. Describe the contributory role of healthcare to environmental pollution and climate change.
2. Describe the effects of health system decarbonization on the environment, healthcare resilience, and health outcomes.

### CLIMATE AND HEALTH EDUCATIONAL INITIATIVES AT MEDICAL SCHOOLS AND RESIDENCIES

Formal training opportunities for climate change and health have been steadily expanding for medical trainees in recent years since



a 2020 survey revealed that only 15% of medical schools worldwide incorporated this material.<sup>60</sup> However, to the best of our knowledge, the majority of institutions have yet to formalize a climate change and health curriculum for their students that spans all 4 years of medical school. In addition, much like the rest of the medical school curriculum, the focus of most climate change and health content is focused on adults.

Similarly, there is no standardized climate change and health curriculum implemented in pediatric residency training programs. There are no ACGME requirements that are tied to climate change and health. An important step forward to promoting curriculum development in medical schools and residencies would be to integrate climate change and health-based competencies into LCME and ACGME program accreditation requirements.

### Climate change and pediatric health in medical schools

Of over 80 international medical schools evaluated by the Planetary Health Report Card,<sup>11</sup> only two institutions managed to score higher than a “B”. The report card evaluates all facets of climate change and health-related offerings at medical schools, including curriculum content, interdisciplinary research, and student interest groups.

The Penn State College of Medicine offers a 2-week elective course for fourth-year medical students.<sup>61</sup> The curriculum includes sessions meant to provide broad introductions to the subject, such as “Health Impacts of Climate Change” and “Sustainability & Climate Smart Healthcare”. It includes one seminar dedicated to exploring how climate change contributes to health inequities among the pediatric population: “Environmental Justice: Climate & Child Health”.

Since 2020, the Stanford University School of Medicine has offered an elective course entitled, “The Impact of Climate Change on Human Health”. The 10-week, guest lecture-based series has 1-h-long session that focuses on how climate change affects children’s health, including the unique vulnerabilities of children to air pollution and natural disasters. Attendees have the opportunity to work through case studies in interdisciplinary groups to apply their learning.

The Emory University School of Medicine—the highest-scoring institution—is in its second year of integrating climate change and health-related content, including children’s health, into lectures and small group discussions. It will follow by expanding that initiative to all 4 years of the curriculum.

### Climate change and pediatric health in residencies

There are no climate change and health-related competencies established by the ACGME. While some pediatric residencies are working on developing climate change and health content, none have yet to formalize a comprehensive curriculum. Given the time constraints and busy schedules of residents and attendings, finding opportunities to integrate climate and health content has been challenging.

At the Stanford University pediatrics residency training program, there is a month-long rotation in the first year of residency entitled “Community Pediatrics and Child Advocacy”. It involves content such as sustainability and the relationship between climate change and health equity. In addition, there are 2 weeks in the second and third years of residency dedicated to advocacy, in which trainees may do climate change and health-related work.

A few residencies are also working toward integrating climate change and health content into specific residency tracks. For example, at the Emory University pediatric residency,<sup>62</sup> a climate curriculum was launched in 2018 specifically for residents who are training in the Pediatric Global Health Track.

Another example is the pediatrics residency program at Seattle Children’s Hospital. The program features four lectures dedicated to climate change and health-related topics. In addition, multiple Grand Rounds presentations are focused on the subject every year.

## CONCLUSION

As a global health emergency that will take a disproportionate toll on children, it is imperative that medical trainees begin learning about climate change and children’s health early on in their careers. The scope of topics that must be covered ranges from natural disaster preparedness to cardiovascular pathophysiology to medication management, each of which can be seamlessly integrated into existing training curricula. Although there are medical schools and pediatric residency training programs that recognize the importance of climate change and pediatric health, few offer comprehensive opportunities for trainees to develop the knowledge base and skill set needed to care for this vulnerable patient population in a world increasingly impacted by climate change.

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## AUTHOR CONTRIBUTIONS

A.G. and J.G. made substantial contributions to conception and design, drafting the article or revising it critically for important intellectual content. B.E., M.G., L.P., V.S., P.G., and J.G. drafted the article and revised it critically for important intellectual content. K.C.N. approved the final version of the manuscript to be submitted.

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The authors declare no competing interests.

## ADDITIONAL INFORMATION

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