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ARTICLE

Educating for Heat Literacy: A Material Challenge for Environmental Education

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Abstract
It's time to get serious about educating for heat literacy. Global warming (as one of the identified and globalised "crises" contributing to the prefix, "meta") is well underway. Dreadful heat both on land and in the seas is baked into our collective futures. Frequent and prolonged heatwaves are pushing communities to their limits. We take seriously the UNICEF warning that within 25 years, *all* children on Earth will be regularly experiencing heatwaves and dangerous heat conditions. Our argument is that heat education is necessary across all formal education sectors (early childhood, primary, secondary and tertiary), and at all community levels including informal education. In this article we explore the emergent concept of heat literacy. We consider what this encompasses by framing it as a survival literacy within the context of ongoing exposure to injury, risk or peril in a warming world.

Keywords: Care global warming; heat literacy; heatwave safety; thermodynamic reality

Introduction

Increasing heat (which is thermal energy) is an inescapable condition of the Meta-crisis. The thermodynamic chickens are flying home to roost, and dreadful heat both on land and in the seas is baked into our collective futures. This warming trend will continue for decades if not centuries (Fletcher et al., 2024). Frequent and prolonged heatwaves are pushing communities to their limits (Le et al., 2024) and we may look back at recent years as among the coolest of the 21st century (Goodell, 2023). Everybody is now facing a lifetime of exposure to severe heat (Grant et al., 2025). Despite efforts to reverse global warming, we have well and truly reached an "Oh-Oh" moment.

In terms of scientific evidence, research using satellite data show that the Earth's planetary-scale, thermal energy budget imbalance has doubled over two decades reaching an average 1.3 Watts/m^2 in 2025, increased from 0.6 Watts/m^2 in the early 2000s (see Mauritsen et al., 2025). These solar wattage data are worrisome because they show that lands and oceans are rapidly heating far beyond normal. Thermal energy imbalance is a measurement of how well humans are progressing in terms of bringing anthropogenic, global warming under control (Von Schuckmann et al., 2023). These planetary-scale data, which are explained for a public audience by King and Sherwood (2023), indicate that Earth safety conditions are breached. A measurement of 14 zettajoules of excess heat trapped in the atmosphere is taken up by oceans annually (Sherwood et al., 2025; Whitehouse, 2025). (A zettajoule is a mind boggling measure of excess thermal energy.) Underwater heatwaves now threaten all marine ecosystems (Lenton et al., 2025; Marcos et al., 2025) and the neologism "marine heatwave" has entered the public lexicon.

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Similarly, neologisms for heated air have appeared. Matt Simon (2025) writing in *Grist*, described the summer "heat dome" across North America as "a self-reinforcing machine of misery." The physiological importance of humidity is measured by a "Heat Index" (HI). Hand-held devices to measure heat, humidity and "wet bulb globe temperature" (WBGT) now assist educators and sports organisers to plan for the "heat safety" of outdoor activities. The "universal thermal comfort index" (UTCI) is used by municipalities across the planet to keep populations safe in heat events (see FEE, 2019; Nam et al., 2024). Educators conceptualise "Heat Ready Schools" (see Shortridge et al., 2022). "Thermal calculators" manifest on the internet (for example, Zulawinska, 2024). Researchers seek to know a healthy body capacity for "evaporative sweating" only to discover safety levels are lower than previously advised (Vecellio et al., 2022).

Heat is a global scale phenomenon, a threatening thermal reality, and a deeply embodied, personal experience. Excessive thermal energy is an outcome and a condition of living the Meta-crisis. Jonathan Rowson (2021) argues a preference for the prefix "meta" rather than "poly" in referring to proliferating crises on the basis that "meta" can refer to an interiority (meta within), a relationality (meta as between), and an opportunity to advocate and educate for "better ways" of being in the world (meta as beyond). For Rowson (2023, np), the cause of the Meta-crisis is a "persistent misunderstanding, misvaluing, and misappropriating of reality" – a statement which is relevant in reference to heat (as the transfer of thermal energy), entropy, and the laws of thermodynamics. Here is the complete quote:

> The Meta-crisis is the historically specific threat to truth, beauty, and goodness caused by our persistent misunderstanding, misvaluing, and misappropriating of reality. The Meta-crisis is the crisis within and between all the world's major crises, a root cause that is at once singular and plural, a multi-faceted delusion arising from the spiritual and material exhaustion of modernity that permeates the world's interrelated challenges and manifests institutionally and culturally to the detriment of life on earth.

Ours is an exploratory paper, a starting point. In the next sections of this paper, we outline our methodology and story how we came to think about heat literacy. We describe our preliminary thinking on what heat literacy is within environmental education and what it can encompass. Most, formal education systems have developed comprehensive heat advices within their respective health and safety policies. Though, there is not much on heat learning published in the environmental education research literature. There is no consensus on a unified definition of "heat literacy" (Johar et al., 2025). There is agreement that heat literacy and the new health education and communication corollaries such as "climate change health literacy" (Reismann et al., 2021) and "climate and health literacy" (Limaye et al., 2020; VanderMolen & Hatchett, 2024) are educational adaptations to global warming.

Effective heat learning requires knowledge of real life, human scale, physical phenomenon. This is why we produced a table of physical concepts related to heat / thermal energy to assist educators think about physical materialities. A small irony is that the least loved scientific area of curriculum (physics) is precisely that which people need to know and act upon to stay alive and keep their communities safe in worsening environmental conditions. As we conceive it, heat literacy is a survival literacy confronting the exposure to injuries, risks and perils faced by everybody (human and more than human bodies) in a rapidly warming world.

Our methodology

Our thinking on heat literacy emerged from personal experiences of heat fuelled perils and our knowledge that future perils will be faced as we age and become more vulnerable. Hilary lives adjacent to the Wet Tropics World Heritage Area in Cairns, far north Queensland, and has

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experienced a number of cyclones including the big ones, Cyclone Larry in March 2006, Cyclone Yasi in January 2011 and Cyclone Jasper in December 2023. Her unequivocal, shock point was in November 2018, when she witnessed the trauma of mass, Spectacled Flying Fox deaths from a heat stress event in the Cairns CBD. That first day, at noon, katabatic winds drove up temperature to 43 degrees Celsius in the shade. This is what she encountered:

> Hardly able to breathe and sweating profusely, I made my way to the roost and pressed video on my phone to record terrible scenes. The animals knew they were dying. Mothers were trying to protect their babies and they all edged closer to the ground and flapped their wings madly seeking relief. A few frantic wildlife carers were grabbing the live animals who dropped from the trees placing them in cages for transport. One desperate bat climbed up my leg, but as I wasn't immunised, I couldn't comfort him. The bodies of the dead were thrown into garbage bins. (Whitehouse, 2024, 4)

For Larri and Angela, their unequivocal reckonings came a year later during the Black Summer bushfires that occurred between December 2019 and January 2020. Larri lives on the New South Wales (NSW) south coast. She, her partner, and their two dogs, were forced to flee their home in Manyana during a terrible bushfire as their safety could not be assured. They first went to a friend's home in Nowra, but as these massive fires continued, they fled a second time and sought refuge in Sydney where the air over Australia's most famous city was filled with smoke and the corridors of hospitals overflowed with residents suffering respiratory ailments. That same summer, Angela was living on a rural property in Wamboin, NSW. When wild flames approached, she evacuated her desperately ill husband and their dog to a hotel in Canberra and then returned to her property to fight the fire. It was a close run thing. After her husband's death, Angela moved to Adelaide, where, she has recently lived the Meta-crisis through bitter drought and the massive algal bloom death event in South Australian coastal waters (see an account by Barrera, 2025).

Our heat thinking began from personal knowledge of thermal stress. Being affected by heat, we then thought on our "response-abilities" as environmental educators. Our inquiry turned to addressing the real-world consequences excessive heat is presenting to human and more-than-human communities. We found we were "thinking with" heat in alignment with Isabelle Stengers' (2018) methodology. We were allowing thermal phenomena to shape our own inquiry. Stengers' concepts of slow science, speculative pragmatism, and "thinking with" reverse *a priori* models of investigating physical phenomena. Heat has long been a phenomenon to be measured and explained (see our Table 1). In the Meta-crisis, heat grows in noticeability and importance. Heat intrudes into and shapes our actions and decisions. We can no longer afford to be deluded. Another small irony is that when humans experience extreme heat, our mental processes slow (Carias et al., 2024). So, methodologically, when we were "thinking with" the phenomenon of heat, in reality we were "thinking with" by "thinking within" our air-conditioned offices.

In seeking to conceptualise heat literacy as a survival literacy for the 21st century, we employed a desktop, document study method. We sought and examined published literature, not to conduct a systematic review, but to collect an idiographic set of materials with which to more fully understand the challenges of heat education. Starting with a suite of key words that included "heat," "literacy," "climate" and "education," we searched for contemporary reports, peer reviewed studies, curriculum documents and policy documents. In this article, we draw from research and grey literature in the fields of climate science, heat science, health science, science education, environmental education, state and national Australian curriculum, education policies, and public information, where scientific knowledge is re-interpreted for a general audience.

In "thinking with," we take seriously the prediction that within 25 years, *all* children on Earth will be regularly experiencing heatwaves and dangerous heat conditions (UNICEF, 2024). We have come to understand how heat education is necessary across formal education sectors (early childhood, primary, secondary and tertiary), at all community levels (where heat learning may

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Table 1. Scientific concepts for a curriculum of heat

Concept / term	Brief explanation
Energy	Energy is "the currency" of Physics' (IOP, 2025) Energy is a qualitative property defined and measured as the ability to do work or cause change. Heat energy is known as thermal energy.
Thermal energy	Defined as the total kinetic energy of moving particles of matter. The SI unit of measurement is Joule (J). Watt (W) measures the rate at which thermal energy is transferred.
Heat	**Heat is the transfer of thermal energy** which always moves from matter with greater thermal energy to matter with lesser thermal energy - from "warmer" to "cooler" substances seeking equilibrium.
The Sun (Our life source)	The Star at centre of our solar system is the primary source of thermal energy on Planet Earth.
Solar radiation	The Sun emits electromagnetic radiation (EMR) that differs in frequency and wavelength and travels at the speed of light (299,792,458 metres per second).
Electromagnetic spectrum (EMS)	The EMS is radio waves, microwaves, infra-red, visible light, ultraviolet, X-rays, Gamma rays. SI unit is Hertz (Hz) named after Heinrich Rudolf Hertz, the first European to conclusively prove the existence of EMR
Infra-red radiation (IR) (heat)	IR is invisible to human eye. We can detect "heat." 49% of solar radiation reaching the Earth's surface is in the infra-red spectrum of 300 GHz to 400 THz - wavelengths between 700 nanometres (nm) and 1 millimetre (mm).
Thermal radiation	The transfer of thermal energy by infra-red electromagnetic waves that travel through air or a vacuum. Radiation is the only means of thermal energy transfer that doesn't require atomic or molecular particles. All matter radiates thermal energy above 0 kelvin.
Entropy (A philosophical reason why thermal energy behaves as it does)	As it never decreases, entropy is why heat never flows from cold to hot. Energy stored in an orderly state has lower entropy. Energy stored in a more disorderly or dissipated state has higher entropy. The greater the disorder, the greater the entropy.
Change in entropy	Entropy change = energy supplied as heat divided by temperature at which transfer occurs Energy and heat contribute to changes in entropy.
Zeroth law of thermodynamics (We will all get hot together.)	If two thermodynamic systems are each in thermal equilibrium with a third, then they are in thermal equilibrium with each other.
Frist law of thermodynamics (Law of conservation of energy)	Energy can neither be created nor destroyed. It can only change forms. In any process, the total energy of the universe remains the same.
Second law thermodynamics (Entropy rules!)	The entropy of the universe tends towards a maximum. Entropy either stays the same or increases. The entropy in a system does not decrease.
Third law thermodynamics (A cold universe is no fun)	As temperature approaches 0 kelvin or −273.15°C (absolute zero) the entropy of a system approaches a constant minimum.
Temperature	The measure of the average kinetic energy of particles of matter.
Measures of Temperature (K, C, F)	Kelvin (K) scale, invented by William Thomson, Lord Kelvin, the first scientist elevated to the British House of Lords who chose his name after a river in Scotland. 0°K = minimum entropy Celsius (C) or Centigrade scale, invented by Anders Celsius based on the change of state of water. Water's freezing point is set at 0°C, and the boiling point is set at 100°C.

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Table 1. (*Continued*)

Concept / term	Brief explanation
	Fahrenheit (F) scale, invented by Daniel Gabriel Fahrenheit, who perfected the use of the mercury thermometer. 0°F is an equilibrium point of ice, water and salt. The freezing point of water is 32°F and the boiling point of water is set at 180°F.
Air flow	Flow of air is caused by a gaseous pressure differential. The direction of flow is from areas of high energy, or high pressure, to areas of lower energy or pressure.
Humidity	Humidity is the amount of water vapour in the air. Relative humidity is the amount of water in the air in relation to a maximum moisture. The higher the temperature, the more water vapour air can hold. 100% humidity means the air is holding as much moisture as it can at a given temperature. It is impossible to have 0% humidity.
Dew point	Is the temperature to which the air needs to cool to become completely saturated with water. If the air cools lower than the dew point, airborne water will condense in the form of dew (droplets of water). If the relative humidity is 100% then the dew point and the actual air temperature are the same.
Heat index (HI) or Apparent temperature (AT)	HI = temperature + humidity The heat index calibrates levels of heat stress on bodies linking the dangers of high temperature combined with high humidity. HI is also known as apparent temperature (AT). HI measures what heat feels like. HI (AT) is calculated in the shade. A safer measure for all educators, sports coaches and students is WBGT.
Wet bulb globe temperature (WBGT) (WBGT = 0.7Tw + 0.2Tg + 0.1Td)	WBGT is a specialised heat stress index and a means for calculating the potential effect of heat on a human body. WBGT accounts for temperature, humidity, sunlight (as radiant heat) and wind (air flow). Handheld digital metres for WBGT calculate safe thermal work limits and assess the thermal risk for any outdoor education setting. Measurements are usually taken in direct sunlight.
Universal thermal comfort index (UTCI)	The UTCI is human thermal stress index and an international standard to assess physiological stress on the human body in response to an outdoor thermal environment, such as a beach (Nam et al., 2024). The measure relies on a calculation of mean radiant temperature (MRT) from solar and longwave radiation, as well as air temperature, wind speed and humidity.
Heat stress (HS)	Heat stress is an example of entropy in action and is a mammalian body's response to high ambient temperature, humidity, and levels of physical activity exacerbated by inadequate hydration (fluid intake). HS is an elevation of core body temperature exceeding thermoregulatory limits. HS is the result of an imbalance between the internal heat produced by the body and the heat exchanged with surroundings.
Daytime & nighttime temperature effects	Daytime temperatures cause direct heat stress as mammalian bodies work to cool themselves, while high nighttime temperatures prevent recovery from this stress. Prolonged heat waves with higher nighttime temperatures cause cumulative effects and increased risks of illness and death.
Thermal delay (aka thermal lag)	This refers to the rate at which materials release stored heat as an ambient temperature lowers. Is affected by heat capacity (the ability to store heat); thermal conductivity; thickness of the material (thicker = longer thermal delay); and material type (stone and concrete have higher thermal delay/lag than wood and metals).
Thermal conduction	The transfer of thermal energy between particles of matter in direct contact. When particles of warmer matter bump into particles of cooler matter thermal energy is transferred. Thermal conduction is faster in certain solids and liquids that in gasses.

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Table 1. (*Continued*)

Concept / term	Brief explanation
Thermal conductor	Matter that has freely moving electrons and can transfer thermal energy rapidly, usually metals.
Thermal insulator	Matter that does not easily transfer thermal energy as its atomic or molecular structure impedes conduction.
Thermal convection	Convection is the transfer of thermal energy by particles moving through a gas or a liquid forming convection currents. Thermal convection drives currents in the atmosphere, oceans, and in molten rock.
Absorption	TThe process of absorbing thermal energy from surroundings, through electromagnetic radiation, convection, or conduction. The amount of heat absorbed by a material or body depends on its atomic or molecular properties.
Albedo	Is a measure of how much visible light a surface reflects on a scale of 1 (100% reflection) to 0 (complete absorption).
Skin evaporation (sweating)	Is the process by which liquid water (sweat) is changed into a gas (water vapour). As a gaseous state contains more thermal energy, sweating is a physiological mechanism to cool the body by removing heat from the skin using the body's own reserves of water.
Evapotranspiration (ET)	ET = evaporation + transpiration and refers to the loss of water by plants. The air cooling effects of large, shady trees is explained by evapotranspiration.
Air temperature (Td) (dry bulb temperature)	Td = the actual measure of air temperature using a dry bulb measurement and taken in the shade.
Wet bulb temperature (Tw)	Tw is measured by a thermometer with a wet wick, which reflects the cooling effect of water through evaporation. Tw measures the lowest temperature reached through evaporative cooling. This is typically higher than the dew point.
Globe temperature (Tg)	Tg is measured with a black globe thermometer that measures radiant heat and is used for outdoor work.
Land surface temperature (LST)	LST is called "the skin temperature of the ground" and is usually measured remotely by satellite. Is a critical indicator for understanding levels of heat on land.
Sea surface temperature (SST)	SST is a measure of ocean temperature 1 mm to 20 metres below the surface. Is measured by buoys and lines. SSTs are critical for understanding the effects of heat on coral reefs, kelp gardens and seagrasses.
Radiant heat	Radiant heat is thermal energy transferred as electromagnetic waves, or thermal radiation, that does not require any medium to propagate. It can go through a vacuum or air. As it can be dangerous, it has to be accounted for to keep people safer.

take the form of health promotion and risk management) and in informal education settings where we see potential for ad hoc heat learning in preparing for heat-related perils. Research shows the value of education in helping people interpret frequent and extreme weather events. In one study, Cologna et al. (2025) found that "subjective attribution" of the perception of perils linked to global heating was predictive of greater support for climate action policy.

Heat literacy as a survival literacy for C21

Heat literacy is a 21st century literacy precisely because we find ourselves in a thermodynamic mess. Heat literacy = heat learning + knowledge + capabilities to act for safety and survival in the

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face of life threatening conditions in a warming world. Inventive educators can create literacies to address the threatening materialities caused by relentless and careless pollutions - the externalities of global, hyper-capitalism. Creating new literacies and adapting curriculum, pedagogy and practices indicates a responsive, 21st century environmental education. As an adaptative response to global warming, there is need for people of all ages, locations, professions and lifestyles to be heat literate. What we propose in this article is applicable across all levels of formal, informal and community-based education.

We came define heat literacy as including heat numeracy through,

i. being able to understand (as best as possible in context) the scientific, health, social, cultural and place-based dimensions of extreme heat in conditions of global heating,
ii. being able to interpret credible information on heat risks,
iii. being able to keep oneself and others safe during extreme heat events; and
iv. being able to make informed, equitable, and adaptive decisions to reduce vulnerability to heat-related harm to oneself, one's human and non-human kin in the short, medium and longer term.

Place-based, functional literacy is a participatory literacy crucial for promoting better means, designs, practices and policies for desired political, social, cultural and environmental transformations. Writing in terms of "eco-literacy" – an older creative literacy developed by environmental educators – Julie Singleton (2024, np) asks: What do our students need to know to live quality lives not only in a global economy but also in their local communities? What is needed to learn to achieve sustainability? How can people learn to live well in their own places?

Heat literacy is a functional literacy that maps readily into *Agenda 2030* and to the United Nations Sustainable Development Goals. The purpose is to enable individuals and groups to make informed decisions and undertake actions. The term "functional" signifies the ability to understand, evaluate, and use knowledge to make informed decisions and take protective action. In addition to reading, writing and data interpretation skills, is the capacity to critically scrutinise the meanings of data, to recognise risk, to understand the safety warnings from trusted sources, and to be able to act on one's knowledge. Ideally the heat learning leads to constructive conversations, participatory actions, activism, and advocacy.

We conceive heat literacy within environmental education as sitting within or proximate to current conceptions of climate change education, climate justice education, climate literacy education, ocean (+ cryosphere) literacy education, and carbon literacy education, which can be collectively named as climate crisis education. Heat literacy as a proximate form of climate literacy is also a health literacy The first reason heat literacy is proximate is because heat doesn't only happen to other people. The phenomenon of excessive and prolonged heat is an embodied experience carrying known health risks, and for which the amelioration factors are well studied. Direct impacts include heat-related illnesses (e.g., heat cramps, heat exhaustion, heatstroke) with a high risk of dehydration and mortality. Indirect impacts include exacerbations of other perils, such as drought, fire, and higher levels of air pollution (VanderMolen & Hatchett, 2024).

The second reason for proximation is that heat education does not *necessarily* require personal acceptance of the fossil-fuelled causes of global warming. Heat is a topic that can be judiciously introduced to a classroom on science learning and/or health and safety grounds alone. Learning the direct causes of extreme heating does lead to higher measured levels of climate literacy in schools (Kumar et al., 2023), However, educators can find themselves working in highly politicised settings where open talk of the climate crisis is socially unsafe. Heat literacy is a less contentious term for educators to use when seeking ways to teach about the burgeoning perils of global warming

In developing specific competencies, capacities and capabilities, heat learning starts with developing knowledge of heat-related concepts, including the science of heat and its effects on

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health on human and on more-than-human bodies. We include an extensive list of science curriculum concepts in Table 1 along with a brief explanation of each of those terms. Heat learning starts with the Sun and includes the four laws of thermodynamics, and a consideration of entropy, the underlying principle that accounts for why we all get hot in hot weather. Literacy implies *knowing what do with heat knowledge* and knowing *how* to take up appropriate action including strategies for managing heat exposure and heat stress for humans and our biosphere companions. This is why our list of scientific concepts in the next section includes the recent innovations trying to measure and communicate thermal safety.

Climate literacy has been instrumentally defined as one's "understanding of how the climate system works, how human actions influence climate, and how climate influences people and other parts of the Earth system" (USGCRP, 2024, 2). In seeking a more values-based definition, the Center for Climate Literacy defines climate literacy as "Earth civics" –recognising the opportunity to harmonise "multiple ways of knowing ... into a lived, emotionally charged, and personally felt understanding of the mess we are in." Climate literacy is an individual and collective responsibility and a call to action "to stand up for everyone's biospheric inheritance" (CCL, 2025, np). The Carbon Literacy project promotes "awareness of the carbon costs and impacts of everyday activities and the ability and motivation to reduce emissions, on an individual, community and organisational basis" (CLP, 2025). Carbon molecule pollution drives air and ocean heating as the Sun's infrared energy is excessively trapped in the biosphere.

All the climate crisis literacies are related, and we don't favour one type over another. Our argument to educators, is that because excessive heat affects metabolic function, and the Earth's measured heat imbalance is accelerating, scientific literacy, numeracy and adaptive safe behaviours must form core components of heat education.

Concepts for heat literacy – it's not only physics

Science literacy is described in the Australian Curriculum 9.0 as, "being able to use critical and creative thinking skills ... to ask questions and draw evidence-based conclusions using scientific knowledge and practices." Importantly, literacy includes the ability to "engage meaningfully with contemporary issues, evaluate different points of view and make informed decisions" (ACARA, 2025a). Our systematic search of formal Australian state curriculums for heat related concepts revealed many opportunities for integrating heat learning into primary and secondary schools. Understanding how heat affects the environment, communities and individuals can be addressed by teachers in Science, HASS especially Geography, and English, HPE, and in the Australian Curriculum v 9.0 Design and Technologies Learning Area where students are encouraged to be discerning decision-makers, and "apply design and systems thinking and design processes to investigate, generate, evaluate, iterate and improve design ideas, processes and solutions" (ACARA, 2025b).

Within the Science Learning Area, heat constructs are introduced in Year 3, then developed across the Year levels particularly in Physics. The core knowledges are the science of heat, its effects on health and the environment, and key strategies for managing heat exposure (e.g. knowing how heat is generated and measured; recognising the risks of heat exposure, heat exhaustion and heat stroke; and knowing how to mitigate these risks where possible). Rapidly changing environmental conditions are partially recognised in formal curriculums either directly or indirectly.

There are few impediments to educators delivering heat literacy programmes in schools. The core physical concepts (see Table 1) are readily integrated into science, health and sports programmes and sit underneath occupational health and safety policies. Examples of this practice include the Queensland state government full policy on managing heat in schools (Queensland Education, 2024) and the Australian Bureau of Meteorology national heatwave service (BOM, 2026).

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The scientific content presented in Table 1 identifies a suite of heat concepts. The list is indicative, not definitive. What we hoped to achieve was a starting place. We have not mapped these concepts to state curriculums. The concepts are appropriately modifiable from Year 3 to Year 12 and can be covered in adult education settings. It may be only a few years before school systems are forced to mandate heat learning as an adaptation strategy as we cannot escape the four laws of thermodynamics.

Ecosystems and heat literacy

Heat is an ecosystem issue. Excessive heat degrades the sustainability of biodiversity in critical ways. Revegetation consultant, Glenn Christie (of Succession Ecology) points out the optimum heat range for most human and more-than-human life on Earth is within the thermal limits of 25°C to 32°C. This is commonly known as the "third Goldilocks zone" of recent history (King & Sherwood, 2023) where the temperatures are not too hot and not too cold for successful human habitation. Glenn advises that going beyond these limits, either lower or higher affects the interdependencies of ecological systems critical to planetary life (personal communication 2025). Thus, the capacity of agriculture, aquaculture, and "wild" places are threatened.

In a world of increasing climatic extremes, we need to consider how farming practices can accommodate the changed conditions and what educative processes are most useful. Food quality and quantity production is likely to decline. Increased temperatures affect grazing systems through complex interactions that effect plant growth, grazing management, vegetation, animal production (QDNRM, 2004). Vital soil microbes can stop functioning in soil temperatures greater than 60°C. Protein production in grains such as wheat is dependent on optimum moisture and temperature. For example, Australian wheat is high in protein, lower in yield and therefore more expensive compared to cooler climate Scottish wheat. Seeds germinate at optimum temperatures between 21° C to 24 °C. We know that bees and bats, critical for pollination, are heat sensitive. The optimal temperature range for honeybee survival is between 34.5°C and 35.5°C. Flying foxes, Australia's great forest pollinators at landscape scale are susceptible to extreme heat events having no sweat glands (Diengdoh et al., 2022). Heat literacy is (or will be) a factor in ongoing agricultural and primary production education; wildlife and wild places education; and environmental education.

Safety as an aspect of heat literacy

The scientific modelling predicts that extreme heat will shape our education practices decades into the future (ACF, 2025; Grant et al., 2025). The medical literature on heat illness education informs much of what we already know about heat as a biophysical threat. Heat is the number one weather-related killer event worldwide even in developed nations (Ballester & Turrubiates, 2023). In Australia, extreme heat is the number one cause of weather-related death in all parts of the mainland continent, with older, poorer and sicker people being the most vulnerable (Le et al., 2024). In less rich nations, infants are at the highest risk if they also suffer poor nutrition. Heat exposure is associated with negative developmental growth ("wasting" in medical terms) as well as higher mortality (Bonell et al., 2024).

Responsible governments and health advisory agencies have developed codified responses to try to keep populations safer (Powder, 2024) as heat stress can affect anybody spending time in hot environments. In Australia, heat risk communications are found in schools; local, state and federal government offices; within employer organisations; emergency services organisations; wildlife care and community volunteer groups (etc.) and the dangers of excessive heat and prolonged heatwaves are recognised within standard occupational health and safety (OHS) policies and procedures. For safety's sake, the Queensland Government (2025) advises that "everybody is at risk of heat-related health problems, and it's important to know the risks of heat, who is at risk,

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how to prepare, and how to protect yourself and others." This is a sensible policy approach given serious problems arise when higher humidity is thrown into the mix.

Heathy, fully grown adults can be at similar risk levels to sicker and older adults when the calculated wet bulb globe temperature (WBGT) exceeds 31° in low wind conditions (Vecellio et al., 2022). To reiterate these findings - the well-publicised, theoretical 35°C WBGT limit for healthy humans in extreme environments may be wrong (subject to further verification). Metabolically un-compensable heat stress in humid environments can occur in young, healthy adults at wet-bulb temperatures significantly lower than 35°C. Severely intolerable stress occurs at different WBGT's depending on ambient vapour pressure – the partial pressure exerted by water vapour in air at a given temperature and location (Vercellio et al., 2022). The rationale for *always* using wet bulb temperature as a more accurate measure of bodily comfort and risk (rather than only ambient air temperature) underpins the extreme heat policy published by Sports Medicine Australia (2021). Sports is a cornerstone of Australia life and extreme heat is a real threat to the pursuit of sports activities for active participants and observers alike. Understanding how and why to stay safe may be a generalised in relation to the science of heat, however being able to stay safe is locally specific (Johar et al., 2025). Place-based learning is acceptable for persons of every age (Singleton, 2024), and primary school children are perfectly capable of agency and of shaping their learning and responses to localised climate perils (Duhn et al., 2024).

Care, justice and heat literacy

Experiences of extreme heat are disabling and certainly disordering. Our bodies maintain stable internal temperature by sweating, a physiological process known as thermoregulation. But thermoregulation is challenged by heatwave perils. This is why heat literacy encompasses learning heat concepts and *then* knowing what to do in heat emergencies (short term actions); how to prepare for heat emergencies (medium term actions); and how to lower the risk of suffering and death in extreme heat events. Longer-term actions can involve considerations of sustainability visions and justice values and may include political activism as well as practical planning.

In arguing for greater educational attention to heat, we know there are powerful corporate, financial and political forces across the globe devoted to publicly denying the laws of physics in the pursuit of even greater levels of commercial profit. This does not make bio/physical nor financial sense – a fact recognised by actuaries and insurance companies, who are the risk assessment professionals paying close attention to thermodynamic reality. The most recent Institute and Faculties of Actuaries report (Trust et al., 2025, 9) cautions that, "our dominant economic model doesn't recognise a dependence on the Earth system, viewing climate and nature risks as externalities" and advises that, "Our current market-led approach to mitigating climate and nature risks is not delivering." The inevitable outcomes are that vulnerable people, animals and plants are the most badly affected by the climate crisis (Lenton et al., 2025; Trott et al., 2023).

Heatwaves expose existing inequalities while also giving rise to new ones (Le et al., 2024). Not everyone faces the consequences of heat equally; there are "many shades of heat inequality" (Mani, 2024, np). Gender, as a determinant of access to resources, is a globalised source of heat injustice. Women and girls are disproportionately affected by extreme heat in terms of work, pay and, access to healthcare. Protracted heatwaves exacerbate unequal education and economic opportunities (Mani, 2024). Additional factors that increase vulnerability for women and their families include access to safe and effective hydration; access to cooling (including vegetation cover and shade); age and health status; access to healthcare facilities; food security status; access to and level of educational attainment; immigration status or being a refugee; being an outdoor worker; belonging to a supportive and cohesive community; and the overall type of political and financial governance in place. In an actual heatwave, these are what Hansen et al. (2013) call non-modifiable risk factors. One modifiable factor to minimise risk over the medium and longer term

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is properly funded heat education and risk communication across all sections of the community (Johar et al., 2025).

Caring is an ethical inclusion because caring for everybody in heatwaves is vitally important to reducing mortality – this includes caring for wild and domesticated animals and plants. Heat exhaustion and heat stroke contribute to increased human population mortality (Ballester et al., 2023). However, these maladies are not confined to humans. Extreme heat compromises every bodies' ability to thermoregulate. Heatwaves damage the thermoregulatory capacities of wildlife, who cope (or not) with the increased frequency, intensity, and duration of heat often without adequate access to fresh water (Diengdoh et al., 2022; Walker et al., 2025). Ecological strategies such as green cities, vertical gardens, large parks and urban wild areas ameliorate the extremes of heat (Heaviside et al., 2017) for humans and urban wildlife. Restoration of tree and vegetative cover in rural landscapes increases shade and food resources. Rewilding programmes often have heat amelioration as well as anti-extinction benefits. Protecting and restoring the natural world is a foundation for human health (WHO 2024).

Four examples of hot learning for action

The Australian Conservation Foundation (2025, 4) reminds that, "the effects of extreme heat are deeply felt in daily life". At local scale, the educational response can be a curriculum component, a pedagogical practice and, given heat's extraordinary disordering effects on living bodies, an impetus for action. Here are four examples of Australian community and school based responses to increasing heat. Our present stance is, that given the work of many educators and health communicators around the world, an intending heat literacy educator will be able to find knowledge, education resources, ideas for engaging pedagogy and practical support from local and regional educational, charitable and/or government organisations.

The first, national Extreme Heat Awareness Day was launched February 5th, 2025, by Sweltering Cities, an advocacy not-for-profit (NFP) organisation founded in the aftermath of a dreadful heatwave in Western Sydney early in 2020. Sweltering Cities' data-driven priorities are cooler suburbs, inclusive justice, heat safe homes and community learning. As they point out, "people are struggling in hot homes, hot suburbs and hot workplaces. It's time we tell the full story of rising temperatures" (Sweltering Cities, 2025). Recent research reports reveal the mental, physical and emotional tolls heat-related perils are extracting from Australia's people, plants and animals (see ACF, 2025; Climate Change Authority, 2025; Parents for Climate, 2025).

An example of education research work on comes from the Cool Schools Initiative of Western Sydney University, Sydney, NSW. An excellent pedagogical and infrastructure resource for schools by Pfautsch et al. (2020) is titled *School Microclimates*. The researchers first unpack the negative effects of heat on learning before moving through a detailed set of procedures on how to cool schools across school grounds, both indoors and outdoors. This report provides more than 20 practical recommendations on how to reduce the impacts of outdoor heat, including how to redesign infrastructure. This work aims to assist principals, school managers, and teachers "to increase resilience and health of school children during increasingly hot summers and provide planners and architects with options that can improve the thermal performance of new and existing school infrastructure" (ibid. 10).

Another effective way to develop community-based skills for cooling urban environments is "Seeds for Change," an initiative hosted by the South Australian Chapter of the Australian Association for Environmental Education and funded by Green Adelaide. This initiative helps residents affordably reduce heat on their streets and homes by planting endemic drought tolerant species gardens, verges and parklands. Community connection grows through propagation and planting events, local biodiversity increases, councils spend less on roadside maintenance, and microclimates get cooler.

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In terms of whole-school practice, the South Australian Cowandilla Primary School and Children's Centre is a Climate Change Specialist School. From 2015, staff have been integrating climate change education and action into curriculum and daily operations. The school purpose is to equip students with the knowledge and skills to address climate change and foster optimism about the future. As stated on the website,

> Climate Change is the phenomenon that drives our learning in science and social studies. As the children progress through the years, they learn about our atmosphere, the greenhouse effect, how energy is generated, fossil fuels, greenhouse gases, weather, climate, the effects of global warming on the polar ice caps, acidification of the oceans, changes ocean currents, sea level rise, rainfall trends, biodiversity, melting of glaciers, agriculture and weather patterns. (see https://www.cowandilla.sa.edu.au/learning-programs.htm)

The school has a student group who lead activities to mitigate the effects of climate change, and the school shares its practices with other schools and educational leaders. The school deliberately focusses on conservation ethics and on the importance of care and caring. Climate change learning is woven into their science, mathematics, arts, technology, and humanities learning areas.

In summary

We publish our "speculative proposal" to urge environment educators and researchers to think more on heat within their own praxis. Heat literacy is a matter of care; an existential knowledge; and a set of survival skills for rapidly warming climate conditions. In this contribution on educating for and in the Meta-crisis, we have set out heat literacy emerging from our interpretation of a selection of recent published literature on extreme heat, thermal science education and environmental education. In the process of developing our thinking for this article, we have tested our concerns with many people who have added their anecdotal and professional insights. This has made us realise that heat literacy and numeracy is truly transdisciplinary and broadly implicated in fundamentally affecting life as we know it. We hope this article will contribute to a much wider, kinetic conversation among and between educators and researchers on the matter of heat and how best to foster the implementation of heat literacy education across our communities.

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