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Perspective

A Comprehensive Approach to Water Literacy in the Context of Climate Change

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Abstract: Anthropogenic climate change is impacting human survival through its impact upon water quality and availability. An urgent ethical imperative is thus raised for education policy makers and schools, particularly in the Australian and Asia Pacific regions, to adopt a curriculum to help students mitigate and adapt to the dire consequences caused by a warming planet. Through a blue transdisciplinary school curriculum, students will better understand and respond to the broader aspects of what is referred to as the hydrosocial cycle. A school move towards a blue curriculum requires educational policy to mandate an emphasis on the climate change effects upon the water cycle. An effective shift to a blue curriculum also requires that teachers' ethical perspectives and sensitivities are sharpened through their tertiary education courses. This is needed so they develop confidence and pedagogy for teaching anthropogenic climate change generally, something still missing from Australian and other classrooms around the world, and, more specifically, for teaching the hydrosocial cycle. The Four Component Model of Ethical Decision Making is offered as a useful framework to guide teachers in examining their values and motivations when teaching potentially confronting topics such as the impacts of climate change upon the hydrosocial cycle.

Keywords: climate change; ethics; school; teacher; water cycle; hydrosocial cycle

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1. Introduction and Context

Anthropogenic climate change is having a dramatic impact on personal, global, and planetary health. Sea levels are rising and oceans are becoming warmer and more acidic [1] while sea ice is shrinking, causing further ocean warming. Ocean acidification puts at risk many valuable ecosystem services that the ocean provides to society, such as fisheries, aquaculture, and shoreline protection [2].

Published in 2019, the United Nations Environment Programme's sixth Global Environment Outlook (GEO-6) [3] documents the rapid deterioration of the global environment and stresses an increasingly closing window for action. The report urgently emphasises what has been communicated and understood by scientists for a long time, now more evident in light of the major natural disasters that have occurred since 2020, a year when hurricanes, cyclones, typhoons, and flash floods killed 570 people [4]. The report addresses the main challenge of the 2030 Agenda for Sustainable Development [5], namely that no one is left behind, that present and future generations should live healthy, fulfilling lives, reminding us that a healthy environment is both a prerequisite and a foundation for economic prosperity, human health and wellbeing.

Urgent challenges facing us and future generations include global population explosion, rampant urbanisation, natural disasters leading to large-scale migration and refugee surges, water quality and insecurity, in short, the wicked problems of our era [6–8]. Some of these challenges are direct and indirect results of climate change.

Future generations, the youth and children of today, must be prepared to respond to a world beset by such challenges to be able to make informed decisions that will support human health and wellbeing. Children and adolescents face and will suffer the consequences of climate change. They will lead societies facing global environmental problems.

Since the 1970s, students' emerging identities have been globally characterised as future consumers, workers, and taxpayers [9]. This places an obligation and clear ethical imperative on educators and teachers to ensure that their students are accurately informed and prepared to respond to decisions about matters that affect them across all domains of life. This ethical imperative emerges from notions of intergenerational justice—what do we, current generations, owe to future generations? [10]. This ethical imperative underpins the aims of this article. Namely, this article aims to stress to education policy makers, schools, and educators the need to mandate a curriculum that uses the hydrosocial cycle, a blue curriculum, across discipline areas to enhance water literacy of K–12 grade students in the face of climate change.

In the sections that follow, this article details various issue related to the need for a blue curriculum. First, I highlight the pivotal role of education for developing environmentally sustainable behaviours in students. Advocacy for a blue school curriculum incorporating systems thinking as a pedagogical approach follows. The next section is devoted to what is currently known about the water literacy of diverse groups, including teachers. A rationale for the use of the hydrosocial cycle in classroom teaching is then developed. Thereafter, some practical suggestions are listed on how to incorporate water-related learning activities across school disciplines. The penultimate section acknowledges the complexities that are inherent in teaching ethically charged topics such as the impacts of human actions upon water availability and quality in a period of climate change, and offers some ways for educators to reflect upon such pedagogy. A short discussion section concludes the article.

2. Ethical Imperatives and the Pivotal Role of Education

Intergenerational justice means that educators are ethically bound to empower their students to make informed decisions and learn new behaviours to protect their environment. Schools play a significant role in empowering students to be confident global citizens [11–13]. Schools are also instrumental in helping develop their students' character [14], a declared aim of the Australian Sustainable Schools Initiative (AuSSI), officially launched nationally in 2004, giving rise to Green or Eco-Schools.

Green Schools (also known as eco-schools or enviroschools) aimed to provide positive environments to help children develop eco-thinking and adopt environmentally friendly sustainable behaviours [15]. Extensive Green School initiatives were developed around the globe by international organisations and national programs, with numerous schools participating [16]. One of the largest international programs for Green Schools numbers 55 participating countries and 46,000 certified schools [17]. Green Schools are characterised by their focus on implementing a whole-school approach to environmental education, through the execution of an overall institutional green program, rather than one that depends on the initiative of individual teachers [18].

In Australia, when schools adopt a sustainability environmental focus by opting to be part of the network of Green Eco-Schools, they are provided with a framework for schools to become models for sustainability in their communities, by reorienting them towards sustainability practices, action planning, in-service teacher education, and stakeholder involvement in community sustainability decision making [19]. The resources framework includes a small section on water featuring the water cycle, water as a resource, and perhaps managing water supply. Indeed, prior studies suggest that students who attended Green or Eco-Schools present higher levels of environmental knowledge compared with their peers from other schools [15,16,20,21]. Kerret, Orkibi, and Ronen [22] posit that Green Schools exerted their influence through their effects on students' goal-directed environmental hope which in turn contributes to higher levels of pro-environmental behaviour and concomitant subjective wellbeing. However, all these benefits are predicated on an individual school opting to be part of the Green or Eco-School network, a voluntary, not mandated involvement in Australia and elsewhere. Because of this and other curriculum constraints in Australia, for example, Eco or Green Schools are now very rare.

3. Practical Imperatives for a Warming Planet: A Blue Curriculum Using a Systems Thinking Approach

The urgency presented by climate change impacts suggests it is now time for schools to focus on water. Since education based on pro-environmental tenets leads to pro-environmental behaviour [23], a blue curriculum using the water cycle, more specifically the hydrosocial cycle, is a springboard for strategies to adapt and mitigate the effects of climate change. In other words, through a blue curriculum, schools, like Green/Eco-schools of the past who focused on greening the curriculum, can help students in K–12 grades, the future generations, learn behaviours to protect water quality and conserve water, both issues known to be at risk as a result of climate change. This is important since, for example, as a result of cyclones/typhoons/hurricanes, electricity is often interrupted, potentially leading to intermittent water supply, frequently of questionable quality. A critical lack of primary and secondary treatment of the wastewater effluent, due to electricity outages, can leave large sections of the affected population exposed to contaminated water, possibly leading to serious disease spread such as typhoid [24]. Understanding when to boil water for consumption, whether to have bottled water available for disaster preparedness or when and how to conserve water in cases of drought is not always something that is intuitive. Understanding the flow of water in cases of floods, the potential for this flow to lead to sewerage seepage and other undesirable effects is also a matter of understanding the local geography and ensuring that appropriate measures are taken for children to avoid playing in contaminated waters. In arid and semi-arid areas, groundwater is an important source of water for agriculture, households, and industry. These areas are very vulnerable to more frequent weather extremes, erratic rainfall, and droughts. Managing groundwater resources in a warming climate for basic uses requires knowledge of the aquifer systems, their replenishment and interactions with rivers, wetlands, and terrestrial systems and variability. It also requires knowledge of the human interaction with the resource, and potential adverse impacts, for example, from excessive abstraction or from poor agricultural or land-use practices [25].

These examples highlight the need for a systems thinking approach to understanding the hydrosocial cycle. To that end, it is important to recall that Xu, Wang, Wang, and Zhang [26] posit that water knowledge and water attitudes are the main factors affecting citizens' water behaviour. Water attitudes consist of a sense of water, water responsibility, and importantly in the context of the hydrosocial water cycle, ethics, which drive behaviour. In a large study evaluating the relationships between water knowledge, water attitudes, and behaviour, Kang [27] found that water knowledge has a positive and significant influence on water attitudes and water attitudes positively and significantly impact water behaviour.

Poor understanding of the water cycle processes, and of the effects of human activity upon it, in other words, the hydrosocial cycle, seems to be world-wide and evident across levels of education, politics, and governance. Abbott et al. [28] analysed 464 diagrams of the water cycle from textbooks, scientific articles, teaching materials, advertisements, and agency reports from around the world, of which 114 were published in English, to find that only 15% of these diagrams depicted human interaction with water. Moreover, only 2% included the effects of climate change or water pollution—two of the central causes of the global water crisis. These findings strongly suggest misunderstanding of global hydrology by policymakers, researchers, educators, and the public [28].

The urgency for a better understanding of, and attitudes towards, water in Australian schools was recently highlighted by a program that was launched by Melbourne Water and ABC Education. To mark World Water Day, 22 of March, Melbourne Water developed The Story of Water video series, a nationally accredited, curriculum-aligned program available to teachers and aimed at primary and secondary school children (21 March 2024 https://www.melbournewater.com.au/about-us/what-we-do/news/melbourne-water-and-abc-education-partner-improve-national-water-literacy).

As the lives and livelihoods of billions of people depend on reliable access to water [29], it is critical that we safeguard the processes water availability depends on. In other words, future generations must understand how the quality and quantity of water are moderated by rising global temperatures. They need to understand that temperature rises cause increases in water evaporation, rises in precipitation, and concomitant flooding. Floods, in turn, cause run-off which flushes mud and/or fertilisers into bodies of water supply such as lakes and rivers. Run-off not only pollutes the water, it can cause algal blooms which are resistant to purification, impacting not only access to water but also causing fish death and death of other sea creatures through the toxins that accumulate as a result of the lack of oxygen in the water due to the algal blooms. The study of the hydrosocial cycle, a complex system, is not about just understanding evaporation, condensation, and precipitation but also about knowledge of water's changes of states and movement from one part of the system to another [30]. From elementary school onwards and before students start middle school, they should understand the interactions of Earth's major systems: the geosphere, the hydrosphere, the atmosphere, and the biosphere. Students need to understand that these systems interact in various ways, and the possible effects upon Earth's surface, materials, and processes. Water impacting food production is an economic resource whose security and sustainability affects human livelihood [31].

Despite the intimate connections of the water cycle, ecosystems, and human societies, contemporary water education through the school years often remains anchored in a traditional view of the water cycle as a physical process separated from humans' impacts. That is, the hydrosocial cycle is not considered. Meanwhile, surveys from various parts of the world show that students tend to confound mitigation and adaptation to climate change with unrelated environmental issues [32], while the knowledge gained at school often does not translate in everyday habits [33] due to current high school students' environmental literacy being inadequate [34] or because the contingencies of a crowded curriculum, as in the case of Australian schools, do not allow for deeper student immersion into the hydrosocial cycle. Therefore, as acknowledged by the United Nations Educational, Scientific and Cultural Organization (UNESCO; https://en.unesco.org/themes/water-security/hydrology/water-education, last access: 4 September 2023), there is an urgent practical and ethical need for schools to engage with the impacts of climate change across all environmental and social domains.

It becomes clear that a systems thinking approach is required to study the hydrosocial cycle, adopting multiple perspectives, to recognise the interactions, patterns, and interrelationships between the components, and consider the cause-and-effect relationships of the components in terms of temporal and spatial dimensions. Systems thinking is essential for increasing our ability to understand the challenges facing society, to develop solutions, and to take action as global citizens [35]. To be water literate, an understanding of the hydrosocial cycle processes and influences upon it is particularly critical for countries like Australia which has sustained over 16 cyclones and/or flood events since 2011, with damages amounting to trillions of dollars [36].

4. Water Literacy: Extensive Student and Teacher Gaps in Understanding

What does it mean to be water literate? This is an important question that needs to be considered when developing a blue curriculum. Published literature on the topic is not extensive; however, a number of articles accessed through Scopus, Web of Science, and Google Scholar offer some insights and highlight the need for a systems thinking approach.

Water literacy encompasses several key dimensions. McCarroll and Hamann [37] conducted a systematic review of literature in 2020 in order to distil what defines or describes 'water literacy'. Through 26 different sources, they identified four separate cognitive knowledge sets that underpin water literacy: science and systems knowledge, hydrosocial knowledge, local knowledge, and functional knowledge (p. 7). In addition to the cognitive domain, they isolated a behavioural domain, which consisted of individual action and collective action, and finally, an affective domain, that comprised attitudes and values (p. 7). McCarroll and Hamann [37] found a main emphasis on the cognitive learning domain in the literature, although the importance of the affective and behavioural domains is considered very important by water literacy practitioners. More recently, in 2022, Mostacedo-Marasovic, Mott, White, and Forbes [38] examined United States educational, governmental, and non-governmental organisations' water-related K–12 standards for teaching and learning about human dimensions of water systems to compile an inclusive, transdisciplinary perspective on water literacy education. Based exclusively in the context of the United States, their results echoed the findings of McCarroll and Hamann [37].

The different water literacy domains are key to a blue curriculum and are encapsulated by an understanding of what has been termed the hydrosocial cycle [39,40] which describes the relationship of water with society. This understanding is critical since we know that human water use, climate change, and land conversion have created a water crisis for billions of individuals and many ecosystems worldwide [28]. The hydrosocial cycle presents scientific understandings but also adds the social, economic, and political relations associated with water that are lost when the water cycle is not presented as the complex system it is, omitting to develop students' systems thinking [30]. Krause and Strang [41] illustrate these interconnected systems for teachers and teacher educators by pointing out that 'water flows are fashioned by a combination of topography, power relations, built infrastructure, institutional arrangements, property relations, money and market forces, ideologies, social networks, and the properties of water itself' (p. 635). The complexity of the hydrosocial cycle and its various systems is beyond the scope of this paper; however, the hydrosocial cycle illustrates the importance of taking a transdisciplinary teaching approach to water education through a blue curriculum focus using systems thinking.

Water education can take place through various ways and at different times, but for many, school education through the elementary and secondary years will constitute their primary opportunity to learn about water, pointing to the importance of developing students' water literacy during this time [42]. In 2023, Mostacedo-Marasovic et al. [42] reviewed the literature around water learning and found that school students exhibit a multitude of scientifically inaccurate ideas about water systems; this was also the case with undergraduate students and adults. Moreover, Mostacedo-Marasovic et al. [42] report that when thinking about the water cycle, elementary, middle, and high school students tended to be unaware of water elements that were invisible to them, such as groundwater, aquifers, atmospheric water, water molecules, and landscapes. Other studies also highlight gaps in water literacy.

In an empirical study, Lee, Gail Jones, and Chesnutt [30] found that teachers had problems applying systems thinking to the water cycle, echoing previous studies [43,44]. Their difficulties included identifying components and processes, difficulty identifying multiple relationships and interactions within subsystems, difficulty understanding the hidden dimensions of the system, and difficulty understanding the impact of humans on the subsystems of the water cycle, which was also true of Australian pre-service teachers [45,46]. It is therefore no surprise that students in various countries experience difficulties understanding and conceptualizing the interactions of the hydrological cycle and dynamic flow on Earth through surface and subsurface interactions.

Below are some recent examples from a range of countries highlighting that students' water understanding is inadequate. Spanish primary, secondary, and pre-university Baccalaureate students were found to lack understanding of the water cycle and the effects of climate change upon it [47]. Spanish students also have trouble identifying where water in nature moves or where tap water comes from to their homes [48,49]; German university freshmen held misconceptions about urban water cycles [50]; Australian secondary students have very limited understanding of the role of oceans and the water cycle in climate change processes [51], while similar gaps in understanding have been found in American elementary students [52]. And even when some schools adopt a focus on the marine environment, students still have misconceptions about the hydrosocial system's effects on the atmosphere and evaporation aspects of the water cycle [53]. Recent research therefore suggests that students' understanding of the water cycle, let alone the hydrosocial cycle, is generally too slight to be helpful for informed decision making for future or current global citizens. Additional research in the context of southeast Asia showed widespread water illiteracy [54]. Data examining the different dimensions of water literacy in Southeast Asia, the sources and consumption patterns, water governance and management, and sociodemographic elements and aspects of water-related challenges showed that a large proportion of Southeast Asian populations do not meet the standards of a water-sustainable society [54].

In light of the need for better hydrosocial cycle understanding, a Network of European Blue Schools was established under the EU4Ocean Coalition for Ocean Literacy to improve ocean and water literacy as an integral part of education and promote the understanding of the close connection between humans and environments among children and youth. As of May 2022, 150 schools and teachers in some European countries committed to bringing the ocean into classrooms, improve ocean and water literacy across school communities, and contribute to the Sustainable Development Goals (SDGs); in particular, to protect marine and freshwater ecosystems and biodiversity, and to prevent and eliminate pollution [55]. This initiative does not appear to be in place in other parts of the world including Australia where neither a blue curriculum or indeed Green or Eco-schools are now in evidence.

5. Water Literacy in the Context of Climate Change Redefined through a Hydrosocial Cycle Lens

The Blue Schools water–ocean literacy initiative now taking place in parts of Europe is very timely although like the Green Eco-schools' initiative, school participation is voluntary. A blue curriculum focus needs to be instigated in Australia and other places also beset by climate change impacts through mandated policy change, one that includes detailed climate change impacts upon the hydrosocial cycle.

The water cycle is supposed to be taught in Australian schools around Grade 7, embedded as it is in the science, humanities and social science (HASS), and geography National Curriculum, and in Grade 9 geography, although this might not be the case in all countries around the world; for example, it was not explicit in Moroccan curricula in 2023 [56]. Australian students are supposed to be introduced to the processes of the water cycle in the circulation of water through the Earth's atmosphere, its surface, and the sub-surfaces that tap into the vast ocean stores, the large bodies of ice and water basins deep within the ground. This cycle can also illustrate the regulation of smaller, sometimes temporary, yet life-sustaining, water stores in rivers and lakes, in the upper layers of soil and rock, as well as the water stored within animals and vegetation. However, particularly in Australia with its crowded curriculum, the water cycle is rarely, if ever, taught in the detail necessary for students to understand the hydrosocial cycle which includes the impact of climate change and involves systems thinking.

We know that water cycle processes have been dramatically affected by climate change through the greenhouse effect due to human activities in the last century, both indirectly through climate change responses to greenhouse gas emissions and aerosol particles, and directly through human manipulations of land surfaces, such as deforestation, for agricultural, industrial, and domestic use [57].

Rising world population, improving living standards, changing consumption patterns, and expansion of irrigated agriculture all lead to a rising global demand for fresh water. The extraction of water from the ground and river systems for irrigation and industrial or domestic use, and changes in land use, can alter the surface temperature and energy and water balances which can in turn affect the distribution of rainfall. Large-scale deforestation is associated with bigger streamflow and with changes in wind patterns and reduced precipitation and humidity locally [57].

Overall, the evidence from a diverse source of scientific data confirms that flux in the water cycle is currently leading to increased and heavier rainfall [57]. What that means is that amplified water transport and circulations between the atmosphere and Earth's surface are intensifying wet and dry seasons and intense weather events such as flooding, cyclones, typhoons, and hurricanes, as well as heat waves, wildfires, and droughts. These weather events are followed by a series of cascading effects upon the Earth's flora and fauna, with concomitant economic and political ramifications. In addition, water cycle effects are uneven as some areas of the world are becoming arid while others are inundated by flooding.

Effects of water cycle perturbations due to climate change are manifold and continue to be examined scientifically with greater accuracy and more sensitive modelling [57]. Nonetheless, based on our present sources of knowledge, we know some aspects of the effects of climate change on the water cycle unequivocally. Fresh water scarcity is experienced by 4 billion people, while two-thirds of the human population experience severe water scarcity, during at least part of the year. High water scarcity levels occur in areas with either high population density (e.g., Greater London area) or in the presence of much irrigated agriculture (e.g., High Plains in the United States), or both (e.g., India, eastern China, Nile delta) [58].

Water pollution also becomes an issue with flood water, or water scarcity, both effects of water cycle perturbations. For instance, in the aftermath of Hurricane Katrina, New Orleans residents were exposed to increased pollutants and pathogenic microbes including hydrocarbon fuel, aldrin, lead, arsenic, iron, chromium, pesticides, and faecal coliforms [59]. Floods and cyclones compound the runoff effects of rampant industrialisation, agricultural and domestic waste, radioactive and pesticide discharge into water, increasing water pollution and ill effects on all biological systems including humans. Typhoid, cholera, encephalitis, hepatitis, giardiasis, cholera, poliomyelitis, shigellosis, diarrhoea, and death are all linked to water pollution [60]. The composition of most living organisms is 70% water and around 70–80% of diseases are waterborne. The increased incidence of waterborne diseases due to climate change has been newly documented around the world, for example, in Canada, East Africa, New Zealand, the Baltic states, East Africa, and the USA [61], in China [62], in Nigeria [63], and several other places in the world [64].

The livelihoods of inhabitants depending on flood-affected regions are destroyed. Short-term effects of floods include the destruction of farmlands, soil erosion, and pollution of drinking water and fisheries resources, impacting inhabitants' health and wellbeing. In the medium-term, food reserves may be impacted leading to stretched hunger periods [65]. Economic and infrastructure effects are also common in developed urban areas. Damage to buildings and contents, vehicles, livestock, and crops; disruption to transport, loss of value added in commerce and business interruption, and legal costs associated with lawsuits; deaths and injuries, damage to cultural or heritage sites, ecological damage, stress, and anxiety due to living disruption, loss of community, loss of cultural and environmental sites, and ecosystem resource loss have all been documented [66].

The associations between the above examples and economic, health, and political consequences can therefore be best appreciated when viewed through the lens of the hydrosocial cycle. Schools which adopt a blue curriculum through a hydrosocial cycle lens are in a position to serve an ethical imperative to inform and prepare future generations to better adapt, mitigate, and shape political and economic directions into the future.

6. Turning School Curricula Blue across Discipline Areas

UNESCO has published a new blue curriculum toolkit to support policy makers, curriculum developers, and educational authorities in implementing ocean literacy into their national curriculum framework. Ocean Literacy is a tool, a framework, and more broadly, a set of guidelines, that aim to support teachers to bring the oceans into the arts, the sciences, citizenship, and ethics [67]. With the launch of the UN Decade of Ocean Science for Sustainable Development (2021–2030), this toolkit builds on the momentum of the global ocean literacy movement to support Ocean Decade Outcome 7—'An inspiring and engaging ocean'. It aims to advance ocean knowledge to preserve and care for ocean resources, and to support better decision making by society as a whole. However, it has limited hydrosocial content since it is squarely based on marine water.

Gaps in students' hydrosocial and functional knowledge can be minimised through greater development of transdisciplinary education [68] which is characterised by its focus on moral and ethical concerns and "wicked problems" like water availability and quality, and climate change, that need creative solutions, its reliance on stakeholder involvement, and engaged, socially responsible science that by necessity involves systems thinking. The future of water management and water justice needs citizens and leaders who firmly understand the numerous and complicated connections between water resources, human activities, and culture. A focus on the hydrosocial cycle and its corollaries can therefore be achieved through various and diverse curriculum areas. Curricula can become 'blue' across many school education areas. The science curriculum is an obvious springboard for discussion. There are nonetheless many other curriculum spaces where the water cycle and its perturbations due to not only climate change, but also industrial, agricultural, and energy impacts can be elaborated and debated.

Within the history curriculum, a 'blue' focus can include events that took place in a range of places linked to the school context to illustrate how the affected water cycle resulted in natural disasters with historically important human and infrastructure consequences. This is because water-related climate change impacts will vary and depend on local geographic and hydro-climatic conditions [69]. Using the key concepts of evidence, perspectives, interpretations, and contestability, continuity and change and significance, students can explore various aspects of 'blue' history. For instance, students can compare and contrast historical Queensland floods dating back to 1841 and examine their physical and socioeconomic effects.

Geography is another important discipline where the course of the water cycle can be illustrated, both before the impact of climate change and since. Through geography, students can engage in discussions of the effect of pollution and environmental degradation in special areas, such as the Great Barrier Reef, as well as the effect of weather and climate change on the water cycle, and vice versa.

Conservation and sustainability, as well as economic matters, also fit into the humanities. The literature and language curricula are perfectly suited to being taught through narratives and stories about the water cycle, through fiction that depicts past and future scenarios of water cycle effects and through creative writing about the climate change effects on the water cycle. Similarly, the visual arts are a strong vehicle to depict aspects of the 'blue', of freshwater spaces, or inundations or denudations due to water scarcities.

The mathematics curriculum can serve as a conduit for hydrosocial cycle elaborations. Problems and calculations involving water usage, capacities of bodies of water, and other calculations illustrating area, flow rates, volumes, and percentages in local context-based scenarios that are related to the hydrosocial cycle can be easily embedded into mathematics pedagogy.

Health and physical education are especially suitable to act as routes for water cycle activities. This is because waterborne diseases and polluted water, contraception education to understand how explosive population growth exacerbates water demands, as well as hygiene and water intake, are part of the health narratives. Water, its scarcity or abundance, is of course intertwined with food production, the human diet, as well as more general concerns about equitable availability of food.

Design and technologies can be utilised for innovative creations of artefacts that can conserve or purify water; students can make advertising slogans through social media blogs to help raise awareness about water conservation, pollution, and water use as well as more advanced politically based activities to inform and educate diverse audiences about the effects of unmitigated growth and population explosion on water security.

The importance of a focus on water appears to be finally gaining traction as a global concern as 22 March 2023 was designated World Water Day [https://www.worldwaterday.org/ (accessed on 10 May 2024)]. Interestingly, almost twenty years earlier, concern for water led to a city-wide program in Virginia, USA to help residents change their behaviour in relation to water [70].

7. Teachers: Pedagogical and Ethical Contingencies

The 2030 Agenda and the Sustainable Development Goals [5] have placed upon schools the social and educational responsibility to help create critical citizens committed to addressing environmental problems. Amongst the priorities that the 2030 Agenda proposes, Sustainable Development Goal (SDG) 4 pursues a 'Quality Education', specifically in Goal 4.7, which notes that, 'By 2030, we must ensure all learners acquire the knowledge and skills needed to promote sustainable development, including among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, the promotion of a culture of peace and non-violence, world citizenship and the appreciation of cultural diversity, and the contribution of culture to sustainable development' [5].

How well are these goals being met? In 2023, a review of literature from diverse countries conducted by the Academy of the Social Sciences in Australia suggests that teachers feel underprepared to deliver education for sustainability, and in particular, climate change education [71]. Review findings include that teachers claim their science content knowledge is insufficient to teach about sustainability and climate change, they see climate change in particular as less pressing than other curriculum areas, and may present their students with contradictory messages about the anthropogenic causes of climate change [71].

School curricula, whether blue or otherwise, are accessed by students via teacher conduits whose practice in the classroom is inextricably bound with ethics [72–74]. Because teachers deeply influence what and how students learn, they have an ethical responsibility to ensure not only that their teaching reflects the curriculum accurately but also the values and responsibilities deemed to be in line with their professional ethics. This is no trivial matter because we know that the knowledge, teaching style, and teacher philosophies that are modelled in the classroom influence student outcomes [75] and can shape the kinds of ethical capacities and dispositions students develop [76]. In other words, students' cognitive, behavioural, and affective engagement with the water cycle, and the hydrosocial cycle corollaries, is strongly influenced by the teaching they experience.

Teachers' appreciation of their ethical responsibilities in this context are important because the welfare of future generations in light of climate change requires unambiguous understanding so as to facilitate practical ways for equitable adaptation and resilience [77,78]. As already noted, inextricably linked to this proposition is the notion of intergenerational justice, which leads to the question: what do we owe to future generations? [10]. In the case of environmental care, imbued in blue curricula expounding the effects of climate change, philosophical methods and reflection can be used in the classroom to help students evaluate the various issues that have an impact on the Earth's and humanity's sustainability [79].

Associated with teachers' pedagogies around a blue curriculum are teachers' personal ethics, their ethical philosophies which invariably influence their teaching not only of the 'what' but also the 'how'. For example, past research has identified significant relationships between teacher beliefs, teaching practices, and student learning experiences in the context of science teaching [80–82]. Broadly speaking, personal teacher ethics, as well as codes of professional teacher ethics, are based in Western cultures on four normative ethical theories: deontology, consequentialism/utilitarianism, virtue ethics, and ethics of care.

Immanuel Kant defined deontology as one's moral duty according to "a priori" beliefs [83]. The rightness or wrongness of a given action depends on the nature of the motive, and the only acceptable motive is our goodwill to act by duty to a set of rules. These might be based on religion, or by a set of standards, such as the professional code of teacher ethics. This ethical disposition avoids subjectivity and uncertainty because one only has to follow set rules.

According to Jeremy Bentham, consequentialism/utilitarianism is characterised by a morally good, morally right action if that action promotes the greatest wellbeing (or happiness) for as many people as possible. An action which leads to the highest level of agreement for the greatest number of people affected by a given decision is the right or moral action [84].

Through the oldest theory of ethics, virtue ethics, Aristotle described virtues as bearing the marks of character traits which enable an individual to achieve eudaimonia (harmony/happiness). Eudaimonia is understood as harmony or happiness, sometimes wealth. A virtue is one's disposition of character guiding actions and emotions. Good actions are ones that embody virtuous character traits, like courage, loyalty, or wisdom [85].

Ethics of care differ from deontology and consequentialism which require the moral person to be unemotional, so that moral decision making is rational, logical, with a focus on universal, objective rules. In 2005, Noddings [86] formulated a theory of ethics that is relational. A caring relation occurs when one takes responsibility and attends to the needs of others. An ethic of care defends some emotions, such as care or compassion, as moral [87]. Real-life moral decision making is influenced by the relationships we have with those around us, since the caring moral agent may consider their duty to be greater to those they have bonds with, or to those who are powerless. This theory also differs from the focus on individuals' dispositions as described by virtue ethics. Teacher ethics based on ethics of care may lead them to face ethical dilemmas in the context of local individuals' welfare over broader global imperatives: for example, a coal mining community whose livelihood might be endangered when issues of greenhouse gases are raised by teachers.

Tertiary education providers must help teachers to recognise their own personal ethical drivers, so that along with appropriate professional development, teachers can be assisted to embrace values and enact pedagogies to facilitate their students' understanding of the issues involved in adapting to and mitigating the effects of climate change through a blue curriculum. To assist teachers to confidently engage and deliver a blue curriculum, imbued as it is with ethical considerations, they need to be ethically sensitive to the local issues and characteristics of their school communities.

To illustrate, consider the position of a teacher employed in an agricultural community that depends for its economy on beef production. In discussing the effects of climate change upon the water cycle due to the warming of the atmosphere caused by cattle's methane emissions, ethical sensitivity needs to be carefully exercised around how to approach their pedagogy.

A very useful framework for teachers to analyse their thinking, pedagogy, and ethics is Rest's Four Component Model of Ethical Decision Making [88]. This framework can guide a teacher's deliberations across scenarios commonly encountered in professional practice. Scenarios may be likely to raise an ethical dilemma because of context, that is, a teacher's local community structures and prevalent values and beliefs, or because of the teacher's own particular values and beliefs, that is, political or religious inclinations. Rest's model, with its four distinct stages of ethical reasoning, can help a teacher clarify their deliberations around their decisions and behaviour by considering a particular issue or pedagogical situation through the four components, or stages, outlined by the framework. Rest's four components, stages or lenses, outlined below, are hierarchical and need to be reflected upon sequentially.

1. Ethical sensitivity based on a recognition of the ethical issue(s) of a particular situation, and awareness of the possible actions and the effect on the parties concerned.
2. Ethical reasoning and judgment, around which course of action is ethically justifiable (i.e., what a teacher ought to do).
3. Ethical motivation and commitment, reflecting on integrating the codes of ethics of the professional discipline with one's own personal values and prioritizing professional values over personal ones, thus demonstrating moral motivation and commitment.
4. Engaging in ethical behaviour, which requires perseverance, competence, and courage to follow through on one's intention (i.e., implementing the chosen course of action) [88].

To illustrate the usefulness of Rest's framework for teachers facing a dilemma, consider how it might help when teaching about water quality in a community where fertiliser runoff leaks into a nearby river and onto a reservoir. The framework can be used to reflect upon how teaching might affect all stakeholders in the school community, the students, the parents, and the school staff more generally and what their reactions might be. This is the first reasoning stage, ethical sensitivity. A teacher then needs to decide in an unbiased way what is ethically justified based on all stakeholders' responses and the situation, which is the second stage of the framework. A teacher's personal views and beliefs must be examined next to ensure that they are not simply following personal ethics such as utilitarianism, whereby they prioritise the benefit to the greatest number of people, including those beyond their own community members. Rather, they must sift through a set of ethical professional precepts governing their duty to their students. Taking a long-term temporal perspective, they might opt to teach about the harmful effects of runoff into the river as the most justified pedagogical approach because it will benefit a greater number of people over time, including their students and community members, despite perhaps causing initial dismay to farmers in the community, possibly leading to personal confrontations with disaffected parents or administrative members. Finally, a teacher must consider whether they have agency, the competence, and courage to act on their decision, i.e., to teach accurately and sensitively about water quality and the damaging effects of fertiliser runoff for current and future generations.

To enable teachers to develop their classroom pedagogy so they can guide their students' deliberations around multi-factorial systems such as the water cycle with its attendant social factors and interactions [30], tertiary education providers must incorporate and emphasise courses that refine teachers' knowledge and skills to make decisions about pedagogy committed to the management of environmental resources, such as water, an urgent challenge of our time. In doing so, tertiary courses will assist pre-service teachers to develop their confidence to exercise their ethical responsibilities not only to reflect deeply about their students' present wellbeing but also to their development as informed citizens, empowered to respond to local and global challenges [89].

8. Discussion

Governments around the world have for over 20 years endorsed sustainable development as a policy goal accompanied by a range of international agreements, national strategies, and environmental laws [90]. Yet scientific monitoring over the same time shows the warming of the globe is continuing to rise and the world is only inching towards environmental sustainability. To avert catastrophe, change must occur from the ground level—by helping school students from an early age to grasp the importance of adapting to and mitigating climate change.

This article aims to highlight to government education policy makers, schools, and educators various ways to connect discipline areas to provide a blue curriculum focus using a comprehensive perspective of the hydrosocial cycle across K–12 grades to enhance water literacy in the face of climate change. Driven by the ethical imperative, we must help future generations adapt to a rapidly changing physical environment; thus, it is important to develop transdisciplinary instructional strategies to teach different dimensions of water, since water-related topics can be taught and elaborated across disciplines. Instruction based on constructivist, active-learning, student-centred, place-based, and problem-based approaches can support students' learning, promoting mitigation and adaptation to climate change.

In short, through the proposed adoption of a blue curriculum by schools, that is, a curriculum that is holistically illustrated through aspects of the water/hydrosocial cycle and the perturbations climate change imposes upon it, teachers can help prepare future generations to adapt to and mitigate the wicked problems of our era: water security and availability. We have an ethical obligation to assist children, who will inherit an Earth beset by wicked problems that our generation has created, to cope, achieve, and maintain a state of wellbeing. To help accomplish that aim, as outlined above, a mandated blue curriculum needs to be delivered skilfully and transdisciplinarily across schools which adopt a blue focus.

A blue curriculum will need to be presented by teachers from diverse disciplines who have undergone professional development in both environmental science and ethics.

To ensure that such a curriculum is able to be successfully incorporated into schoolwork programs through meaningful and authentic activities, tertiary education providers play a significant role. Tertiary institutions need to ensure that teachers are adequately prepared to teach students to understand and address water-related challenges by ensuring that they provide pre-service teachers with undergraduate STEM education that offers opportunities to learn, debate, problematise, and reason about issues currently impacting the hydrosocial water cycle [91]. Currently, such a focus in pre-service higher education courses, at least in English-speaking countries, is not commonly found if at all, even while broad courses in sustainability are often included in teacher education degrees [30,45,92].

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