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ORIGINAL ARTICLE

A transdisciplinary model for teaching and learning for sustainability science in a rapidly warming world

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Abstract

Transdisciplinary sustainability science integrates multiple perspectives, promotes internal reflexivity and situated learning, and engages with multiple stakeholders to solve real-world sustainability challenges. Therefore, transdisciplinary approaches to teaching and learning for sustainability science have traditionally focused on promoting core skills such as systems thinking and science communication. However, as the socio-ecological crises grow in intensity and complexity, so too must our conceptualisation of the core tenants of transdisciplinary sustainability science. To this end, we propose a model for teaching and learning that considers the contemporary pressures of sustainability science praxis. We highlight how social science perspectives can be used to situate considerations of power, justice, and historical responsibility at the centre of sustainability discussions while helping students understand the drivers of transformative change at the individual and societal levels. We outline the benefits of using arts-based approaches in the classroom to facilitate participation and opportunities for creative expression and peer and co-learning. We also discuss the importance of and provide strategies for supporting students in dealing with anxiety and ecological grief. We provide suggestions for assessment strategies that can be used to develop a range of competencies in students, including systems thinking, empowerment and collaboration. In a novel way, we model transdisciplinarity by drawing on insights from the disciplines in which we have expertise, including education, psychology, health, sociology, communications, social work, and science. We also provide an actionable, adaptable model for teaching and learning sustainability science in a rapidly warming world.

Keywords Transdisciplinarity · Higher education · Teaching and learning · Sustainability science · Science education

Introduction

We are in an era of unprecedented ecological and social crises. Human activity has led to the transgression of six of the nine planetary boundaries—including the novel entities

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boundary, which refers to geological changes that could have large-scale impacts that threaten the integrity of the Earth system processes (Persson et al. 2022; Wang-Erlandsson et al. 2022). This environmental degradation has driven one in five species to extinction (IPBES 2019).

Further, warming-induced extreme weather events, such as drought, wildfires and flooding, have increased in number and intensity, resulting in widespread suffering and loss of life (Clayton 2020). Despite political commitments, most governments are failing to take the necessary actions to ensure that the global average temperatures do not surpass 1.5° warming above pre-industrial levels. Alarmingly, global fossil CO_2 emissions continued to increase in 2021 and 2022 after dipping by 5.4% in 2020 due to widespread COVID-19 lockdowns (WMO et al. 2022). Furthermore, 2015 to 2022 were the eight warmest since the instrumental record began in 1850, despite 3 consecutive years of a cooling La Niña (WMO 2023).

Pathways that limit warming to 1.5 °C will require transformations of our energy, economic, social and cultural systems, including education (Agusdinata 2022; Kelly et al. 2022a; McCowan 2020). Students increasingly demand such changes, as the School Strike 4 Climate movement exemplifies. This movement creates new imperatives for climate change education in primary and secondary education (White et al. 2021a) while increasing pressure for tertiary education to adapt to these ongoing and increasing learner needs (UNESCO 2022). Notably, the latest Intergovernmental Panel on Climate Change (IPCC) Working Group III report on Climate Mitigation and Adaptation highlights the critical role of education and training to accelerate the social and cultural change required to implement demand and supply-side mitigation strategies. Particularly relevant to tertiary-level education, the authoritative report calls for an increase in analytic frameworks from multiple disciplines, including social sciences, to effectively "assess the drivers of barriers to and options for mitigation action" (IPCC 2022a, p. 9).

The discipline of sustainability science has emerged as an important component of higher education's response to escalating socio-ecological crises (Kates 2011). Transdisciplinary approaches explicitly focus on integrating different disciplinary perspectives to generate new understandings of how practices can be collectively transformed to address sustainability challenges, including biodiversity collapse, global warming, income inequality and climate-induced displacement (Adler et al. 2018; da Rocha et al. 2020; Funtowicz et al. 1998; Hirsch Hadorn et al. 2006).

In line with the shift to mode-2 science, many proponents of transdisciplinarity stress the importance of the "participation of extra-scientific actors" as a key component of the approach (Aeberhard and Rist 2009; Baumgärtner et al. 2008; Hirsch Hadorn et al. 2006; Klein 2004; Mobjörk 2010). Others stress the importance of integrating "internal reflexivity", namely, the ability to look inwards and question underlying assumptions, epistemologies and beliefs (Miller et al. 2008). Barth and Michelsen's influential paper on how educational theory can contribute to sustainability science highlighted how sustainability as a concept "invites disciplinary contributions from a broad range of disciplines to research within sustainability science," (Barth and Michelsen 2013, p. 109) and found that one important educational contribution linked to transdisciplinarity is the concept and practice of situated learning in Communities of Practice.

Based on a review of definitions, Jahn et al. (2012) define the aim of transdisciplinarity as follows:

> "To contribute to both societal and scientific progress, integration is the cognitive operation of establishing a novel, hitherto non-existent connection between the distinct epistemic, social–organisational, and communicative entities that make up the given problem context" (Jahn et al. 2012, p. 9).

Despite a widespread appreciation for the merits of transdisciplinary approaches within sustainability science, progress towards implementation in research, teaching, and practice has been slow (Barth and Michelsen 2013; da Rocha et al. 2020; Vasbinder et al. 2010; Let's Work Together 2020).

Disciplinary silos, which can be partly explained by the logistical challenge of combining academic cultures, traditions, and field practices (Hilger and Keil 2021; McClam and Flores-Scott 2012) in bureaucratic organisations (Eigenbrode et al. 2007; Klein 2004) have been identified as key barriers. Moreover, scholars and students continue to be incentivised to adhere to the discipline-oriented system through institutional evaluation systems that promote competition rather than collaboration and integration (Butera et al. 2021a; da Rocha et al. 2020; Schuitema and Sintov 2017), which in turn reproduces discipline-specific professionalisation processes (Bosch 2018). Others argue that innovative approaches to teaching and learning in sustainability science have been hindered by a lack of engagement with educational theory and practice (Barth and Michelsen 2013). Even in those programs where a transdisciplinary approach is taken, there is much heterogeneity in how transdisciplinary approaches to teaching and learning are implemented (Hilger and Keil 2021; Salovaara et al. 2020). For example, a recent qualitative content study of 45 master programmes associated with sustainability science finds that systems thinking, anticipatory, strategic, interpersonal, and normative competencies were frequently mentioned as content and learning outcomes in the curricula and are firmly present and widely employed in sustainability education

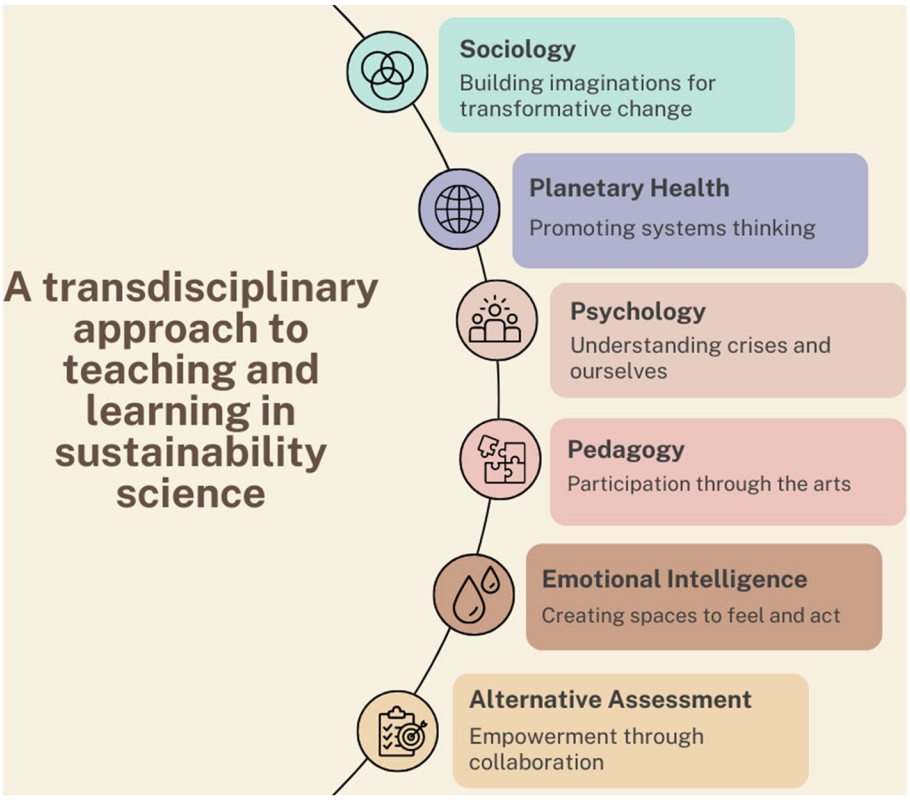

Fig. 1 A transdisciplinary apprach to teaching and learning for sustainability science

(Salovaara et al. 2020). More recently, researchers have identified an additional challenge for sustainability science practitioners, namely upholding positive interactions with various stakeholders in an escalating environmental crisis without the necessary support or training to attend to personal aspects of well-being and self-care. To ease some of these challenges within the academic context, Sellberg et al. (2021) propose integrating care for self, science, and society within the practice of sustainability science.

Considering these challenges, we present a model for teaching and learning in sustainability science as an example of how educators might prepare students for the contemporary pressures of sustainability science praxis. Our model is informed by the disciplines we have expertise in, including education, psychology, health, sociology, communications, social work, and science. We add to the literature in several ways. First, we exemplify transdisciplinarity by combining perspectives from diverse disciplines to create a novel approach to teaching and learning in sustainability science. Second, we pay particular attention to integrating insights from social sciences as these have been historically marginalised from sustainability-related research and teaching (Overland and Sovacool 2020; Shah 2020) and are critical to the development and successful implementation of climate change mitigation efforts (IPCC 2022b). Further, we propose re-imagining teaching and learning to foster self-care and peer support through artistic and collaborative pedagogical and assessment tools while allowing students to process their grief and other emotions (Fig. 1).

We acknowledge that this framework could include many other perspectives. For example, economic theorists, philosophers of science, and theorists of well-being have been usefully employed to advance the theoretical foundations of sustainability science (Daly and Farley 2011; Massenberg 2019; Nagatsu et al. 2020). Further, we appreciate that educators face various institutional and individual constraints. For example, instructors have many aspects to consider when designing their courses to achieve these aims. They must decide or adhere to existing guidance on which content areas of the curriculum to cover, which skills to develop, how to facilitate opportunities for co- and peer learning and consider developing community partnerships. Instructors must also be reflexive of their parameters/boundaries and consider what personal and institutional supports are available. Management structures, policies and processes, employment conditions, and social norms that resist new approaches often limit instructors. For instructors, the successful design and implementation of transdisciplinary programs based on previously discrete academic endeavours require a re-imagining with a focus on collegial collaborations to design new and innovative teaching and learning opportunities. Given these realities and consistent with Lang et al.'s (2012, p. 27) definition of a transdisciplinary approach to research, the model we present should be considered as an "ideal–typical

approach" intended to spark further consideration of the core tenants of transdisciplinary sustainability science praxis in the contemporary context.

The paper proceeds as follows. We begin by highlighting how perspectives from environmental sociology can be employed to place considerations of power, justice, and historical responsibility at the centre of sustainability discussions. We demonstrate how insights from health sciences can strengthen students' understanding of the dependence of human health on planetary health. We present psychology perspectives that can help students understand the drivers of human behaviour, support students to overcome their cognitive barriers and be better equipped to design interventions to influence sustainable behaviour.

In the next section, we consider pedagogical approaches more explicitly. We highlight the benefits of using arts-based approaches in the classroom to facilitate participation and opportunities for peer creative expression and peer and co-learning. We discuss the importance of making space in the curriculum for students to deal with anxiety and ecological grief. This is particularly important when addressing sustainability issues due to the potential for emotional responses and connection to students' personal lives. We discuss the benefits and potential challenges of including or modifying teaching methodologies to address this effectively.

Finally, we turn to assessment strategies. Attempts to integrate reflective and critical pedagogical approaches are a challenge across disciplines at the tertiary level (Hassan 2015), including sustainability science and Education for Sustainable Development (Huckle and Wals 2015). Part of this has been an over-emphasis on competition and normative assessment in educational systems and an underemphasis on emotional responses. To help overcome these challenges, we highlight the limitations of traditional normative assessments and provide suggestions for assessment strategies that can be used to develop a range of competencies in students, including systems thinking, empowerment and collaboration.

Sociology: Building imaginations for transformative change

Historically, the responsibility for teaching environmental-related issues tended to fall on natural science educators, whose focus has generally been on communicating objective facts about ecological degradation and climate change. These communications are generally framed within an objectivist episteme using rational scientific arguments in a not unreasonable belief that humans will act when told a fact. Despite the vast and long-standing evidence base on the activities—such as fossil fuel extraction—the environmental crises are intensifying due to our failure to change destructive behaviours at all levels (Aguirre 2017). As a result, we live in an era of mass extinctions and are enduring a climate catastrophe that reveals unspeakable horrors every day (Bendell 2018). Transdisciplinary approaches to sustainability science are typically solutions-oriented. In addition to understanding technical fixes, sustainability challenges require graduates to have a nuanced understanding of social structures and institutions, cultural values and beliefs, technologies and social practices that mediate human-environmental relations (Dunlap and Brulle 2015).

Sociological perspectives, and in particular environmental sociology, are helpful in this regard because they are dedicated to unpacking the drivers of human behaviour as well as connections among people, institutions, technologies, and ecosystems (Dietz et al. 2020; Jorgenson et al. 2019; Longo et al. 2021; Norgaard 2018). To illustrate the utility of sociological perspectives, we present how C. Wright Mills' foundational concept of the sociological imagination can be employed in the classroom to generate fruitful discussions on the drivers and potential solutions to global environmental problems.

In the foundational sociological text, *The Sociological Imagination*, Mills (1959) wrote that the abundance of available information had come to overwhelm the individual capacity to assimilate it. He proposed that by developing a "quality of mind"—an imagination—individuals are better equipped to address complex problems. In the contemporary context, in which the accumulation of scientific data regarding the impact of humans on the non-human world has not resulted in the structural reform needed to stem the climate crisis (Boström et al. 2018; Lockie 2016; Longo et al. 2016), engendering such a quality of mind among students is a critical task.

In practical terms, Mills argued that it was possible to help individuals understand complex issues by applying three sets of questions to any interest point. Engaging with these questions when discussing societal responses to sustainability challenges can help students identify barriers to climate solutions, empower them to identify critical levers of change, and develop their competencies in systems thinking, which are critical for future sustainability science practitioners (Brundiers et al. 2021).

The three sets of questions are as follows.

(1) *What is the structure of this particular society as a whole? What are its essential components, and how are they related to one another?…*
(2) *Where does this society stand in human history? What are the mechanics by which it is changing? What is its place within and its meaning for the development of humanity as a whole?…*
(3) *What varieties of men and women now prevail in this society and this period? And what varieties are coming*

to prevail? In what ways are they selected and formed, liberated and repressed, made sensitive and blunted?

Mills' first set of questions provides students with a framework for mapping key institutions and their interdependencies within a given society or setting. This is an important first step towards understanding the climate crisis drivers and our responses to them. Climate change "solutions" are often conceptualised in individualised actions (Shove 2010; Webb 2012). In addition to being insufficient (Rosa et al. 2015), an over-reliance on such responses can exacerbate the responsibilities of those already multiply burdened (Auyero and Swistun 2008; Bryson et al. 2001; Dzialo 2017; Kelly 2020). In contrast, these questions encourage structural thinking and can generate fruitful discussions that move students beyond focusing on individualistic drivers and/or technical solutions to sustainability challenges.

The second set of questions creates space for students to question the taken-for-granted nature of our socio-economic system. For example, by asking, "Where this society stands in human history," it is possible to appreciate the scale of our growth-oriented capitalist economic system's unprecedented impact on the natural world. Moreover, contextualising the prevailing socio-economic order within the history of human civilisation illuminates the extent to which social, political and economic systems are socially constructed and, therefore, subject to change. There are opportunities to couple these discussions with an introduction to macro-sociological theories such as the treadmill of production, the treadmill of destruction (militarism), ecologically unequal exchange, world systems theory, and the metabolic rift, which provide a helpful framework for understanding the problematic relationship between a growth-oriented economic system and environmental degradation (Jorgenson et al. 2019; Rudel et al. 2011).

Questioning "*the mechanics by which society is changing*" allows students to explore the possibility of reforming social systems collectively. This sense of empowerment is critical for overcoming the psychological/conceptual barriers in responding to climate change (Norgaard 2009), as we explore further in the next section.

Finally, the third set of questions interrogates sources of power within society. By identifying these forces, it is possible to understand better the political factors inhibiting the necessary structural changes to address the sustainability crises (Brulle 2018; Farrell 2018). These discussions can be enhanced through film and multimedia such as documentaries which highlight how the fossil industry undermined and stalled domestic and international pro-environmental policy efforts by distorting and minimising the impacts of climate change and funding environmental countermovement. These films can be coupled with the academic literature on climate change countermovement obstructionism and denial (Brulle et al. 2020; Dunlap and McCright 2015; Grasso 2019; McKie 2019).

Mills also encourages us to question "*who it is that is liberated or repressed*" *at this stage.* These questions raise important climate justice considerations, namely how the distribution of resources and harm varies across national, race, gender, class and ethnic divides and their intersections (Pellow 2016; Pellow and Brehm 2013). This set of questions opens opportunities to introduce students to key theories, perspectives, debates, methods, and case studies with environmental justice literature (see Agyeman et al. 2016 for a full review). Lastly, exploring "*what varieties are coming to prevail*" can foster a sense of hope about shifting the balance of power towards those who seek to promote human flourishing through transformative and inclusive social action (Glazebrook and Opoku 2018; Johnson and Wilkinson 2021). The prospect of the diffusion of power can enhance students' ability to challenge problematic structures, construct new social imaginaries (Amsler and Facer 2017) and consider how they might work towards making these a reality.

Planetary health: Understanding interdependencies and promoting systems thinking

Planetary health refers to 'the health of human civilisation' and the natural systems on which it depends (Whitmee et al. 2015). It is centred on the interconnectedness of human health with the state of all natural systems (Foster et al. 2019; Whitmee et al. 2015) and draws on a wide spectrum of academic disciplines—from evolutionary biology to ecology, from public health to earth sciences (Foster et al. 2019; Frumkin 2020; Myers and Frumkin 2020; Whitmee et al. 2015). At its heart lies the importance of protecting the ecosystem as the foundation for human well-being. Therefore, introducing students to this perspective allows them to make the key connections between different interrelated topics and explore interdependencies between human-natural systems. In doing so, students develop system thinking skills critical to understanding and addressing complex sustainability problems (Salovaara et al. 2020).

The first principle of the seminal 1992 United Nations Rio Declaration on Environment and Development (UN 1992) emphasised health and well-being as a key objective of sustainable development by stating: "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature". Sustainable development cannot be achieved when there is a high prevalence of debilitating illnesses, and population health cannot be maintained without ecologically sustainable development. Key academic reports

(Watts et al. 2015; Whitmee et al. 2015; WHO 2021) highlight climate change as one of the major health threats of the twenty-first century. For example, the 2015 UCL-Lancet Commission on Health and Climate Change (Watts et al. 2015) stated that the effects of climate change are being felt today. Future projections represent an unacceptably high and potentially catastrophic risk to human health, and that the threat to human health from climate change is so great that it could undermine the last 50 years of gains in development and global health.

Similarly, the WHO (2021) stresses that climate change is already impacting health in myriad ways and poses humanity's single biggest health threat. Climate change can result in a wide range of health impacts ranging from direct risks such as increased heat stress and weather extremes to indirect impacts through adverse changes in air pollution, the spread of disease vectors, food insecurity and under-nutrition, displacement, and mentally ill health (Cissé et al. 2022; Huynen et al. 2013; Romanello et al. 2021; Watts et al. 2015; Whitmee et al. 2015; WHO 2021). These climate change impacts on our health are often mediated by complex interacting social, economic, environmental and institutional factors.

Climate change is expected to amplify key health risks that we are already struggling with today (WHO 2021). For example, estimates for 2020 reveal that about 30 million people were displaced due to climate- and weather-related events (such as storms, floods, landslides, wildfires, and extreme temperature) (IDMC 2021; IFRC 2021), and climate change can significantly amplify this problem in the coming decades (IFRC 2020). Highlighting these facts enables students to link climate change to various existing and often interrelated health threats (e.g., food insecurity, emerging infectious diseases) and explore the underlying relationship and interdependencies between social and ecological systems.

Another important topic that can be included in a sustainability science curriculum is the health co-benefits of mitigation measures. Climate policies can provide health benefits that are additional to the policy's primary goal, because addressing the current drivers of climate change (mainly associated with the burning of fossil fuels) will also tackle other (non-greenhouse gas) health problems (Hamilton et al. 2021; WHO 2021). The WHO (2021) states that achieving the goals of the Paris Agreement would save millions of lives every year due to the multiple health co-benefits of implemented climate mitigation measures. For example, limiting fossil fuel combustion will not only tackle greenhouse gas emissions but will also improve local air quality [e.g., particulate matter (PM), ground-level ozone] and will bring immediate and localised ancillary human health co-benefits (Thurston and Bell 2021). A recent modelling study by Sampedro et al. (2020) showed that the health co-benefits associated with improved air quality could even exceed the mitigation costs across different scenarios for energy supply technologies. Given climate change benefits are often longer term and diffuse, these health co-benefits of climate mitigation can bring an immediate "return on investment" and may play a significant role in fostering climate policies and increasing their acceptability (Thurston and Bell 2021; Workman et al. 2018). Given the considerable health co-benefits, the UCL-Lancet Commission on Health and Climate Change (Watts et al. 2015) concludes that climate change mitigation could be "the greatest global health opportunity of the twenty-first century". Despite the above, health considerations are still not given sufficient attention in debates about climate mitigation. Human health has remained elusive in its influence on developing ambitious climate change mitigation policies for many national governments (WHO 2021; Workman et al. 2018). Teaching climate change from a planetary health perspective would stimulate a broader system perspective and the inclusion of health co-benefits in climate mitigation discussions and decisions.

Such framing of climate change in terms of public health may make climate change more personally relevant and emotionally engaging to segments of the public who are currently disengaged or even dismissive of the issue. This is an important communicative strategy for sustainability students to understand. As argued by Maibach et al. (2010): 'Re-defining climate change in public health terms should help people make connections to already familiar problems such as asthma, allergies, and infectious diseases experienced in their communities while shifting the visualisation of the issue away from remote Arctic regions, and distant peoples and animals. Hence, a public health perspective has the potential to unite all actors behind a common cause—the health and well-being of our families, communities, and countries.' For many, including students, these concepts are far more 'tangible and visceral' than tonnes of atmospheric CO_2 or melting ice sheets and are understood and prioritised across all populations irrespective of culture or development status (Watts et al. 2015).

From a pedagogical perspective, many helpful classroom resources exist. For example, the Planetary Health Alliance developed the Planetary Health Education Framework (Guzmán et al. 2021), which can also guide the integration of health considerations into climate change education. The framework has five foundational domains representing the essence of planetary health knowledge, values, and practice: (1) interconnection within nature, (2) the Anthropocene and health, (3) systems thinking, (4) equity and justice, and (5) movement building and systems change.

Equipping students with a planetary health lens will enable them to have an understanding and appreciation of the interactions between environmental systems and human health and to subsequently recognise and explore how human stewardship of the earth is a primary determinant

of our future well-being (Stone et al. 2018). It illustrates that problem-driven education around complex and multi-dimensional sustainability issues can promote crucial systems' thinking skills and collaboration across and beyond disciplines.

Psychology: understanding sustainability crises, others and ourselves

There is a growing appreciation that inadequate responses from societies to the intensifying sustainability crises can partially be attributed to psychological factors. For example, human beings tend to be less responsive to risks that appear long-term in nature or are not evident in our everyday lives (Clayton et al. 2015), have a limited capacity to apprehend the complexities of climate change (Gifford 2011; but see Atkinson and Jacquet 2022, for a critical view of the psychologistic approach of human inaction), and tend to attribute responsibility for causing and mitigating climate change to others (Lorenzoni et al. 2007). By becoming familiar with the psychological drivers of human behaviour sustainability science, students can be supported to overcome their cognitive barriers and be better equipped to design interventions to influence sustainable behaviour in others (Clayton et al. 2015).

Environmental psychology shows us that knowledge and awareness are important preconditions for engagement and action. Still, knowledge alone is often not enough to change behaviour (Abrahamse et al. 2005; Ajzen et al. 2011), even when coupled with environmental concerns (Huddart Kennedy et al. 2015), particularly if changes in perception and lifestyle are at odds with long-held identities or worldviews (Clayton et al. 2015; Newman et al. 2018). Research emphasises the complexity of the drivers of human behaviour. Specifically, people's willingness to engage in climate change actions, e.g., how much energy they use, how they transport themselves, and whether they purchase organic products, aim to reduce household and food waste or support climate change policies varies depending on different factors, including values, norms, emotions, attitudes, and awareness (Capstick et al. 2015). Further, compared to education and communication strategies, direct experiences with the consequences of climate change directly impact people's willingness to take action and support green policies (Rudman et al. 2013). This can be explained by the level of psychological distance that people experience, which is the degree that someone feels removed from climate change (O'Neill and Nicholson-Cole 2009; Spence et al. 2012). Psychological distance can be related to time (climate change is in the future) and distance (climate change affects other places worldwide). Reducing psychological distance can increase engagement and action on climate change (e.g., Loy and Spence 2020).

Such understandings of one's own biases, awareness and existing social norms are important for sustainability science professionals because policy interventions designed following principles of cognitive psychology are more successful in the long term (van der Linden et al. 2015). Hence, successfully overcoming cognitive, normative, and emotional barriers to fully appreciating the implications of the sustainability crisis can prepare students for the interactive stage of the learning process. However, stressing such barriers may result in students experiencing higher levels of climate anxiety (McDonald et al. 2015). Climate anxiety refers to anxiety, fear, and worry about the consequences of climate change for our collective futures and is increasingly common among children and adults (Baker et al. 2021; Clayton 2020; Holden and Hicks 2007). A certain level of concern and worry about climate change is an appropriate response to the current scenario and, indeed, can motivate action. However, high anxiety levels can overwhelm students and compromise their well-being. Furthermore, such emotions can hold students back from engaging further with important issues (Clayton 2020). Therefore, it is important that with information and reducing psychological distance, coping mechanisms for climate anxiety are integrated into the educational method, as discussed in the next section.

Emotional intelligence: creating spaces to feel and act

Many people, including students and educators, are experiencing a deep sense of loss when engaging with environmental issues (Graham et al. 2020). This phenomenon, sometimes characterised as ecological grief, refers to emotions that are "… felt about experienced or anticipated ecological losses, including the loss of species, ecosystems and meaningful landscapes due to acute or chronic environmental change" (Cunsolo and Ellis 2018, p. 275). Preston (2013) suggests that to cope with these emotions, we first need to acknowledge our grief to confront and adapt to our changed circumstances. Acknowledging deep emotions, heart-aching despair, and existential terror requires the creation of spaces to feel. Spaces that facilitate deep listening, unhurried time, and deep empathy. These practices are part of preventative self-care, an important skill for sustainability professionals to maintain hope and agency in the face of structural barriers to their work, which can lead to frustration and burnout; including these skills as part of sustainability education is key in building resilience (Brundiers and Wiek 2017). These practices and skills are also key for transdisciplinary researchers, who are dealing with competing demands of academic rigour and excellence, societal impact and

engagement, and self-care, which is often de-prioritised due to the pressures of academic cultures and metrics of success (Sellberg et al. 2021).

Insights from social work pedagogy can also be helpfully engaged to guide such exercise and to promote internal reflexivity among instructors and students, thereby promoting a holistic student experience. This pedagogy holds a deep understanding that the most significant change happens when messy, deep emotions are acknowledged and experienced (Jones and Davison 2021; Ruch et al. 2018).

Creating spaces to feel can be as simple as a conversation with students where ecological grief is normalised. Such conversations allow students and instructors to connect and experience catharsis (Westoby and McNamara 2019). There are a variety of pedagogical tools to achieve this end. For example, these may involve collaboration and creativity spaces to reflect on the "ecological failings of Western culture" (Gaard 2016, p. xxv). It may also include a process-focused exploration of the self in the company of others. Such exercises can involve questions such as; What is it that we think, feel and know as individuals? What are the epistemological assumptions of how we make sense of and feel in the world? What is it each discipline pays attention to that flourishes and what has been ignored, left to wither unseen and unacknowledged in the academy? What is it we are feeling in this time of ecological degradation?

Reflective and emotionally intelligent teaching, learning and action research requires a safe place where subjective and objective experiences and multiple world views could come together through interactive experiences (Steelman et al. 2019) and with appropriate institutional supports. Going slowly and carefully with love and care in a neoliberal academy is an act of resistance. Such work also includes building and developing restoration-oriented spaces where students can learn new roles, identities and relationships with each other as collectives but also with natural systems and non-human life (Bailey et al. 2018). Engaging with emotions is also critical for personal well-being and professional development and is part of the process of engaging in "internal reflexivity". Reflexivity is the process whereby students and scholars ponder the origin and value of the knowledge they possess, which is critical to advancing meaningful and sustainable transdisciplinarity education and research (Miller et al. 2008). Research has found that emotional intelligence training builds student skills in communication and conflict resolution, which are critical for those undertaking sustainability-related professions (Tejedor and Segalàs 2018). Providing such training and support across the higher education sector will require significant institutional commitment and investment.

Finally, building emotional intelligence and awareness provides opportunities for facilitating staff development and institutional learning (Pharo et al. 2014), both of which are essential for developing alternative research practices to create a more sustainable future (Trott et al. 2020). In the classroom, such an environment can be created and introduced through curricular approaches, including arts-based pedagogies, as introduced in the next section.

Pedagogy: Participation through the Arts approaches

A central pillar of transdisciplinarity and sound classroom pedagogy includes co-learning opportunities between instructors and students and peer learning between individuals and groups. Many traditional lecture-style approaches to teaching and learning can create a hierarchy of intellect that can block dialogue between various publics, and between teachers and students. When developing meaningful dialogue around climate change and other sustainability-related issues, it is, therefore, necessary to create an environment where these hierarchies can be levelled and the understanding and opinions of all can be fully expressed. Creating such an environment also helps build trust and ensure that those affected are drivers of change rather than recipients of actions over which they had no ownership.

One way to establish dialogue, build agency and trust, and co-create potential solutions is through arts-based approaches (Hsu et al. 2022; White et al. 2021b). Such approaches are effective in levelling hierarchies of intellect by creating a shared sense of vulnerability, removing the notions of 'experts' and 'non-experts,' thereby valuing multiple stakeholder perspectives, and instead creating a space where all voices can be heard and acted upon. Examples of such an approach include the use of poetry (Illingworth and Jack 2018), theatre making (Jordan 2020), drama and science pedagogy (Raphael et al. 2021), and games (Illingworth and Wake 2019); all of which have been utilised to engage various publics by monitoring, deliberating, and responding to their attitudes towards the negative effects of anthropogenic climate change.

Adopting arts-based approaches to teaching sustainability science at the tertiary level is beneficial to students, as it enables explorations into perspectives and potential solutions while deepening understandings of the challenges of both levelling hierarchies of intellect and the benefits of communicating climate change with various publics. Furthermore, introducing students to these approaches can facilitate transdisciplinary learning by prioritising alternative theoretical perspectives, worldviews, and knowledge, offering a greater appreciation of the broad range of epistemological perspectives and practices that enable inclusive, collaborative efforts between publics (Yeh 2016). Learning and refining skills are needed to challenge the hegemonies of scientific discourse (Heras et al. 2021). Learning and refining such skills helps

students to challenge the hegemonies of scientific discourse (Heras et al.2021) and can enhance their capacity for reflexivity, which is a critical component of both transdisciplinarity (Miller et al. 2008) and sustainability science (Knaggård et al. 2018). Further, through experiencing participatory and creative classroom practice, students are better equipped to recreate such environments in their professional roles. This is critical, as implementing a sustainability agenda will require skills to bring diverse actors together in engaging ways (Lavery 2018). Importantly, many instructors will need institutional support to build their own capacities, or establish collaborative relationships, in order to introduce these methods into their classes.

Alternative assessment: Empowerment through collaboration

Several programs address the challenge of teaching climate change. Mostly, they focus on how such teaching should be implemented in content, support, channels, media, pedagogy and community. These teaching features are crucial if future educators want to make a difference, and several initiatives are well underway (Kelly et al. 2022b).

In addition to this endeavour, teaching climate change requires adapting the structures in which it takes place. In particular, teaching climate change, whether in school or at university, is still teaching, and, as such, it is followed most of the time by some form of assessment. Whatever the degree and the educational system, normative assessment (grades/marks) is the most used and pervasive form of assessment (Knight and Yorke 2003). Grades allow instructors to make selective and competitive decisions–such as retention, awards, and ranking—more easily and with a seemingly more objective criterion. Grades provide a simple and straightforward method of comparison, hence, their use as "norm-referenced" or "normative" assessments (Pulfrey et al. 2011). More generally, educational institutions are steeped in competitive structures (grading, tracking/streaming, numerus clausus) and produce competitive goals and values in students (Butera et al. 2019, 2021a).

Such a state of affairs confronts education with a quite peculiar paradox. On the one hand, teaching climate change—and promoting behaviour aiming at mitigating it—leads instructors to explain to students the importance of the common good (Hardin 1968), the interdependence of social, economic and environmental factors (Roychoudhury et al. 2017), the necessity to develop a common superordinate goal (Sherif 1958) to elicit the feelings of collective efficacy (Fritsche et al. 2018) that might translate into collective action in favour of the environment (Amel et al. 2017), as well as many other notions that enhance the need for cooperation. On the other hand, normative grading (and the other competitive structures of education) create a competitive climate among students in which the other students are viewed as adversaries and not as potential collaborators (Butera et al. 2021b). The irony is, therefore, that instructors end up teaching content that promotes cooperation and system thinking in an otherwise individualistic and competitive educational structure. Cooperation in educational systems is not the default behaviour among students. It needs to be taught and implemented (Buchs et al. 2016). However, teaching cooperation is ineffective if the assessment system is based on competition.

An alternative to normative assessment might include reflections on partnerships with community groups working with multi-stakeholder partners. Knowledge acquisition alone will not change attitudes, behaviours, or values (Kollmuss and Agyeman 2002) and as Dewey (1938) described, the importance of place-based, action-orientated, socially engaging learning opportunities is paramount. Therefore projects that tackle socio-ecological challenges and sustainability practices or that engage with local industry or groups and key professionals can provide rich learning opportunities for students, developing learning experiences that ensure skills and learning occurs in context (Agusdinata 2022). Further, the involvement of extra-scientific actors is a defining feature of transdisciplinarity (Scholz 2020). Similarly, interactions with people/professionals working in contexts add relational dimensions to the learning experience that reach well beyond classroom or textbook examples and may bring intergenerational opportunities to learning. Such approaches require careful consideration and implementation guidelines. Planning is key. Fortunately, several successful implementation guides exist[1] (Perry 2004; White 2012).

Another alternative form of assessment could include allowing those students that are involved in environmental activism in some form to reflect on their experiences. Activists act in public ways, motivate others to take action, or socially organise for change (White 2023). "[E]veryday acts of defiance" (Baumgardner and Richards 2000, p. 283), often with collective action (Hunt and Benford 2004), have reformed policy and practice in societies around the world and in these Anthropocene times, there is much to (re)consider. Taking action to redirect, intervene, and change social practices and/or address issues may take many forms and aspire to a variety of outcomes, from raising consciousness to encouraging others to change practices or to influence the redesign or enactment of policy (White 2023). Allowing student groups to engage in activism as part of the learning process can provide students with coping strategies for climate anxiety (Clayton 2020; Verlie 2021). Activism can be

[1] See for example the Action Learning Group Project (https://sites.google.com/site/actionlearninggroupproject/step-2).

a solution-focused activity that can give individuals a sense of control and are, therefore, more effective than emotion-focused coping strategies alone (O'Brien et al. 2018; Ojala 2015). For example, research from the Swedish context shows that solutions-focused activities in combination with meaning-focused coping, where the goal is to evoke positive feelings such as trust and optimism, are positively related to environmental engagement (Ojala 2012). However, when activism is not leading to any change, and these solutions are not perceived as effective, and climate change remains, it can also increase anxiety (Clayton 2020; Ojala 2012).

Taking action can also raise important discussions related to intergenerational responsibility. Students may challenge the responsibility of their generation to act in favour of the environment and to mitigate climate change, as they are the ones who will have to deal with the consequences of climate change (Kim and Shin 2017). In other words, they may see it as the responsibility of their parents' and grandparents' generation to fix the damage they have caused. One strategy for dealing with this issue is to create a classroom environment that fosters a sense of intergenerational positive interdependence. Otherwise stated, they are "all in the same boat", and all generations must cooperate to achieve a common, superordinate goal (Fritsche et al. 2018). Recent research has shown that the more youth consider that generations are tied by a common obligation to act for the climate, the stronger their commitment to pro-environmental behaviours is. Cultivating a sense of positive intergenerational interdependence can also enhance the learning processes (Sarrasin et al. 2022).

Conclusion

The window to control global warming is rapidly closing. On the current trajectory, humankind is set to cause an average temperature rise of 2.8° by the end of the century (UNEP 2022). In this context, the work of sustainability scientists is becoming increasingly important and challenging. In light of this reality, we argue that we must reconsider the core tenants of transdisciplinary sustainability science. To this end, we propose a model for teaching and learning sustainability as an example of how we might adapt our approach to the pressure of the contemporary context. In a novel way, we model transdisciplinarity. This paper is the product of the Education in a Warming World Research Consortium, supported by Worldwide Universities Network. The consortium comprises university academics with broad expertise in education, sociology, climate change, science communication, health, sustainability, and human behaviour. Our group members share a commitment to transdisciplinary work dedicated to understanding the evolving role of education in this era of rapid climatic change and overlapping socio-ecological crises.

We provide suggestions and examples of how instructors can raise questions of power justice by fostering student imaginations for alternative futures. The social science theories we engage in this framework also explain the intransigence of these environmental issues by highlighting perspectives that help unpack individual and social level barriers to transformative social change, thereby opening up opportunities to devise strategies to overcome them. Then, we provide tools to promote a pedagogical approach that melds together the cleaved halves of emotionality and rationality and welcomes the whole human within their ecosystem through transdisciplinarity. Skill-building through each phase of the framework layers dimensions of increased capability for learners to engage through real-world scenarios to understand their future role as practitioners and change agents. For example, applying arts-based learning strategies encourages learning from multiple perspectives and takes the learner beyond their own experience into broader or different epistemological practices. Similarly, inquiry-based learning provides opportunities for students to engage with ideas and perspectives, enriching their learning capacity (Tytler and Prain 2021).

We provide suggestions for creating space to process emotions arising from living with the destruction of our ecosystems, thereby promoting instructor and student care (Sellberg et al. 2021). Educational theory suggests that constructivist and sociocultural practices provide learning opportunities that engage and enthuse learning in many students (Tytler et al. 2019). To that end, we provide suggestions for moving towards a collaborative learner-centric mode of assessment. For example, engaging in activism can create new ways to practice being in the community and can help students overcome feelings of paralysis. In these challenging times, it can be difficult to re-imagine how we educate for uncertain futures (White et al. 2021a). The context in which we now exist must be considered an important backdrop to all educational opportunities.

We acknowledge the challenges that individual educators face in meeting growing student and personal needs stemming from the escalating socio-ecological crises while also navigating prevailing academic structures, cultures and success metrics. We offer this model as a contribution to the ongoing efforts to promote new, innovative, and meaningful actions by institutes of higher education towards addressing the environmental crisis through teaching and learning and beyond. Further research investment and deliberation are needed at the sectoral and institutional levels to foster enabling and supportive conditions for instructors and the broader university community committed to this agenda.

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