Enabling STE(A)M in Sustainability Education Through Dialogic/Dialectic Reconciliation

Ingrid Schudel
ORCID no. 0000-0001-6206-4681
Rhodes University
i.schudel@ru.ac.za

Abstract

In the context of a need for finding and enabling alternatives to unequal and extractivist perspectives on development, growth, and human well-being, this positioning paper explores possibilities for STEAM (science, technology, engineering, arts, and mathematics) education with an education for sustainable development focus that counters disciplinary alienations particularly between the arts and the STEM (science, technology, engineering and mathematics) disciplines. The paper argues that unnecessary alienations between cultural-emblematic and mathematical-logical epistemes, especially those linked to narrow interpretations and restricted developments in dialogism and dialectics, respectively, are influenced by restricted understandings of epistemological, ontological, and praxiological philosophical drivers in meaning making and responsive action. In response, the paper develops a series of philosophical principles that, it argues, could usefully underpin STEAM education practices. These are a) iterations of epistemological expansion and contraction (in response to monologic meaning making), b) an expansive and deepening ontology (in response to ontological collapse in describing the world), c) critical and judgmental rationality (finding a middle ground between radical relativism and dogma), and d) concrete utopianism (in response to idealism and additive holisticism). The emergence of the four philosophical principles is developed through illustrative examples of a broad range of arts (fine art, performance art, photography, film, poetry, prose, and music).

Keywords: STEAM education, education for sustainable development, dialectical critical realism, dialogism, transformative pedagogies

The history of our species is the history of forgetting. Our deepest existential longing is the longing for remembering . . . cosmic belonging, and the work of creativity is the work of reminding us. We may give the tendrils of our creative longing different names—poetry or physics, music or mathematics, astronomy or art—but they all give us one thing: an antidote to forgetting, so that we may live, even for a little while, wonder-smitten by reality. (Popova, 2022b, para. 2)

Introduction to Education for Sustainable Development in STEAM Education

Science, technology, engineering, and mathematics (STEM) are believed to collectively play an important role in economic growth, sustainable development, and the shift to a knowledge economy (Kahn, 2022). However, of these, economic growth has been pinpointed as problematic in international debate since as far back as the first Club of Rome report (Meadows et al., 1972). The growth critique has been raging since the 1970s, particularly with respect to unequal distribution of wealth and resources, but realisation of planetary boundaries as an additional and integrated concern has taken time to gain traction and broaden into more fields in international debate. And in 2020, for the first time in the 30-year history of its Human Development Report, the United Nations Development Programme (UNDP) argued that material resources can be made to matter more "when fairly distributed and within planetary boundaries because they expand people's opportunities, from one generation to the next" (Conceição, 2020, p. 6).

As an alternative to the prevailing hegemonic discourse of economic growth, Daly (1993) suggested the establishment of a steady state economy that "can be expressed in terms of a constant stock of physical capital, capable of being maintained by a low rate of material throughput that lies within the regenerative and assimilative capacities of the ecosystem" (Jackson, 2009, p. 77). Yet, despite Daly's (1990) and others' repetitive reminders of, and elaboration on, sustainable growth as an *impossibility theorem*, society remains in the grip of increased ecological and social vulnerability (Price & Lotz-Sisitka, 2015). This highlights a need to protect both people and planet in a way that can "integrate environmental protection and ecological integrity, economic viability, and social and human development" (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2016, p. 3).

Jackson (2009) provided useful insight into a way forward that does not trap us in a push-and-pull between planetary health and human well-being. He acknowledged the role of growth in addressing inequalities where material possessions ensure critical elements of well-being such as participation in society, education, health, resilience, and the development of human capability. But he challenged growth that is bundled in macro-economic policies that depend on, and perpetuate, unbridled consumerism in which we use the language of goods to communicate our social status, identities, social affiliations, feelings for each other, and more. Jackson's social-ecological thinking problematised a world that prioritises the protection of economies over human and planetary well-being.

Building on the coupling of equal distribution of resources with planetary and ecological sensibilities, in countries where poverty, social exclusion, inequality, and environmental risk and injustices abound, STEM needs to take a critical stand on development and growth that ensures that human development and well-being—as well as planetary well-being—are respected and protected. Jackson suggested the importance of

investments in public infrastructures, sustainable technologies and ecological maintenance and protection. [This] new macro-economics for sustainability must abandon the presumption of growth in material consumption as the basis for economic stability. It will have to be ecologically and socially literate, ending the folly of separating economy from society and environment. (2011, p. 10)

In the 2022 Human Development Report, the UNDP argued that "our social, economic and political choices—about where innovation can be directed, to what priorities and to serve which people— determine how technology changes and how innovations advance human development (Conceição, 2022, p. 160). This new way of thinking about human well-being and planetary health calls for "talent, ingenuity, compassion and creativity"—qualities of STEM that enable humanity to confront "the challenges of the post 2000 'Age of Crisis'" (Kahn, 2021, p. 7). To extend the potential of these integrated sciences to rise to 21st century challenges, this paper considers the complementary role offered by art where "A" is added to STEM education to support the development of "agency, creativity, innovation, and problem-solving skills" in the practice of STEAM education (Yang et al., 2023, p. 2).

Simply adding the "A" to our acronym is not necessarily going to push thinking in the challenging ways that are needed for the dilemmas described above. Mejias et al. (2021, p. 210) lamented that "the pedagogy and moniker of STEAM have sometimes been deployed in ways that do not fully consider the epistemological potency or educational potential of deep integration of STEM and the arts." In other words, there is insufficient emphasis on strengthening knowledge in educational contexts. Those authors were concerned with offering "new ways of doing and knowing in the arts and STEM fields, often with emancipatory and critical pedagogical approaches to learning that can be at odds with an economistic focus" (Mejias et al., 2021, p. 210).

This paper focuses on transformative ways of doing and knowing in the context of social-ecological risk as discussed above. Such new ways can better serve historically marginalised and underserved populations, emphasising development practices that do not simply serve the inequality and extractivism of the current socio-ecological status quo. Such approaches to STEAM can "contribute to social change and promote a more sustainable and equitable world" (Yang et al., 2023, p. 3) particularly in the light of UNESCO's Sustainable Development Goals.

The next section discusses the trans- and interdisciplinary meaning-making potential of STEAM. Education for Sustainable Development (ESD) is strongly dependent on such meaning making (Schudel & Lotz-Sisitka, 2021) and, similar to STEAM education, is a driving force in guiding transformative educational responses to social-ecological risk (O'Donoghue, 2014; Schudel et al., 2021) in a "quest to achieve social-ecological justice, resilience and sustainability through educational interventions" (Price & Lotz-Sisitka, 2015, p. 2). Thus, this common interest in trans- and interdisciplinary meaning making, plus a common interest in social-ecological change are the drivers in the pairing of STEAM education with ESD in this paper.

The paper is particularly topical for the South African context (from which I write) given the Department of Basic Education's recent call to consider ESD a cross-cutting priority as part of its 2024 curriculum strengthening initiative and its commitment to integrating and "mainstreaming of ESD into policies and curriculum, and institutional activities" (2023, p. 164) in response to South Africa's commitment to developing a national strategic framework for ESD in the context of UNESCO's (2020) ESD for 2030 framework. It is also in support of the South African general curriculum aim of "demonstrating an understanding of the world as a set of related systems by recognizing that problem solving contexts do not exist in isolation" (Department of Basic Education, 2011, p. 5), which is aligned with the STEM/STEAM emphasis on integrated learning and on real-world problem-solving.

The paper argues that one of the challenges for exploring the practice of STEAM education is perceptions of the incommensurability of (traditional) dialectic reasoning and dialogic processes, with the former embracing a mathematical-logical episteme and the latter a cultural-emblematic episteme. It furthermore explains how narrow perceptions of science and arts create unhelpful antagonistic

ontological, epistemological, and praxiological tensions. The main aim of this position paper is to is to seek a conciliatory space for these historically divisive discourses particularly in the face of social-ecological challenges in ESD that require "considerable tolerance for ambiguity and uncertainty, autonomy for making judgments, and the confidence and insight to challenge conventional wisdom" (Stevenson, 1987, p. 77). The methodology employed is one of tracing the philosophical roots of arts and sciences using illustrative examples and vignettes posing problems at the nexus of these broad disciplinary groupings. The theoretical framing of Bhaskar's (1993) dialectical critical realism and Bakhtin's (1984) dialogism provide lenses for viewing the tensions and synergies between the disciplines. The paper concludes by describing four reconciliatory philosophical principles as potential philosophical guides for STEAM education with an ESD focus.

Beyond Historically Divisive Discourses

Histories of disciplinary development have often pitted the arts and the STEM disciplines against each other, thus posing a challenge for the deep integration of these disciplines as described above. Lähdesmäki and Fenyvesi (2017) explained how mathematics and the arts are represented in a dualistic way with argument over whether the universal laws of mathematics or culture-bound narratives and symbols best represent the world. They gave insight into this disciplinary divide by explaining how the fields of science and the arts, since the Renaissance, have experienced reduced interaction and dialogue due to a misguided perception of the sciences and arts as dependent solely on mathematical-logical and cultural-emblematic epistemes, respectively. Lack of dialogue between these two knowledge-building strategies has resulted in them being seen as "two incompatible modes of 'grasping' the world" (Lähdesmäki & Fenyvesi, 2017, p. 6). However, pointing to an interdisciplinary turn in understanding the world in context, Scharf (2021, para. 6) highlighted how, in the 21st century, we are "starting to see real erosion of those artificial [disciplinary] walls, so that it's less and less unusual to be an "interdisciplinary" researcher (see also Bhaskar, 2010 from an environmental and climate change perspective).

Similarly, dialectics and dialogism have distinct differences with the dialogic tradition focused on "voices, utterance, speech genres, polyphony" and the dialectic tradition focused on "contradiction, development, the distinction between understanding and reason" (Dafermos, 2018, p. 14). I suggest that the cultural-emblematic knowledge-building strategy (most often, and problematically, associated only with the arts) is commensurate with dialogism—and the mathematical-logical knowledge building strategy (most often, and problematically, associated only with the sciences) is commensurate with dialectical reasoning.

Despite significant resistance to the possibility for cooperation between dialogism and dialectics, groundwork for the reconciliatory space between these two meaning-making traditions has already been made by other authors (Dafermos, 2018; Daniels, 2012; Mah y Busch, 2014). This paper further explores this reconciliatory space through vignettes and illustrative examples demonstrating the complementarity of dialogism and dialectics. An additional contribution to new knowledge by this paper is to consider the role of dialectics and dialogism in a STE(A)M ESD context (with ESD being the focus of all the vignettes and illustrative examples).

The vignettes and illustrative examples also illustrate the importance of inter- and transdisciplinary opportunities through STEAM education, with transdisciplinarity ("a perspective that transcends the limitations of disciplinary boundaries") being different from interdisciplinarity ("a cumulative perspective from different disciplines") (Schudel & Lotz-Sisitka, 2021, p. 36). The paper explores STEAM's potential for contextual understandings and real-world problem solving with reference to social-ecological issues and risks in ESD as the trans- and interdisciplinary point of interest at the cusp of STEM and the arts.

Resolving Philosophical Problems

This paper achieves its reconciliatory aim by constructing a philosophical base on which to argue the falsity of the incommensurability of the arts and sciences as knowledge building strategies, and by demonstrating dialogism and dialectics as complementary and integrated forms of making meaning in the world. The sections below consider four philosophical problems that set different ways of engaging the world (dialectic and dialogic) at odds. Through critical and non-dualistic treatment of philosophical problems, the paper suggests that reconciliation between unnecessarily opposed epistemes enables possibilities for dialogue, transformation, and change in a world in social-ecological crisis. The posed problems and reconciliations are:

- Narrowing intentions and monologism in meaning making reconciled through epistemological expansion and contraction in meaning making.

- Ontological collapse and monovalence reconciled through an expansive and deepening ontology.

- Radical relativism reconciled through critical and judgmental rationality.

- Idealism and additive holism, reconciled through concrete utopianism.

Epistemological Expansion and Contraction in Meaning Making

In meaning-making processes, the double-edged sword of words is that they can tease out, clarify, and identify unknowns—but they can also tighten, contract, or restrict. As elaborated by Mah y Busch (2014), words can be useful in concisely describing and summarising a situation but over-dependence on the linear, bounding, and binding use of words can sometimes be detrimental to expansive opportunities in meaning-making processes.

In an argument for a more open-ended use of words, Bakhtin described what he saw as problematic monologic readings of Dostoevsky's novels where closed-off discourse using words that expect no answer (because of an assumption that there is only one logical answer) drove Bakhtin's call for alternative readings of these novels. That is, readings that acknowledge Dostoevsky's intention for promoting "dialogically oriented discourse" (Bakhtin, 1984, p. 63).[1]

Following this paper's interest in exploring the possibilities for STEAM education, I have drawn Bakhtin's ideas on the novel into a conversation regarding the arts in relation to the STEM disciplines. In this case, reflections on the arts are drawn from fine art, performance art, photography, film, poetry, prose, and music. This strategy embraces Bakhtin's view that "in dialogue a person participates wholly and throughout his whole life: with his eyes, lips, hands, soul, spirit, with his whole body" (1984, p. 293).

Like words, photographs and fine art in the sciences can capture moments in space and time (for example, an insect wing in mid-flap), detail form and function (for example a fuzzy bee pollinating a flower), detail complex ecological interactions as did Maria Sibylla Merian in her depictions of insect–plant relationships (Heard, 2016), or honour an object of beauty (for example, an intricate clock mechanism). Equally, the arts can document cases where science has been misused and abused. For example, Cornelia Hesse-Honegger's paintings of wildly mutated insects in the wake of the Chernobyl

---

[1] Important to understand about dialogics, is that the notion is not about speech per se, and that it also should not be conflated with dialogue (Mah y Busch, 2014).

nuclear disaster (Suchin, 2000), and photographs that reach us daily in the news depicting science in the service of war and war crimes and which can be used to rally necessary protest (Thompson, 2023).

But not all artists seek such definition or conciseness in their work. For example, in a series of interviews led by Paul Cronin with the filmmaker, Werner Herzog, Herzog dismissed a banal, superficial, or accountant's truth in favour of a "poetic, ecstatic truth," that is, a truth that is "mysterious and elusive, and can be reached only through fabrication and imagination and stylisation" (as cited in Cronin, 2002, p. 301). That is, not to deny histories in filmmaking, but to see the art form as opportunity for reflection on historicity rather than "a claim that one is experiencing something authentic, trans-historical or even 'essential'" (Prager, 2007, pg. 46)

This problem of the "surety" of truth and the associated danger of positions of closure limiting creative moments of possibility is one of the positions of tension between dialectics and dialogism, that is, a tension linking to the problem of monologism. However, a space for reconciliation between dialectics and dialogue was opened for me through Mah y Busch's metaphor of the pedagogic heartbeat in which he argued for both moments of contraction (not monologic but synthesising and clarifying) and expansion in meaning-making processes. He suggested that:

> *The primacy of words in critical dialectics threatens over-contraction. Arrhythmia. Such forms of awareness, though necessary, can get trapped in the extended tightening of language and its linear logic, which, like a sentence, valorizes the world of the subject's action. Words yearn to clarify. They need to grasp, always distinguishing and specifying. But what if something is beyond the reach of language? (Mah y Busch, 2014, p. 122)*

Before responding to Mah y Busch's question, I need to address Bakhtin's reservations about monologism in the work of Hegel. Bakhtin argued that a "unified, dialectically evolving spirit, understood in Hegelian terms, can give rise to nothing but a philosophical monologue" (1984, p. 26). However, the dialectical tradition is long and varied and Bhaskar developed a critical realist dialectic which he described as "the 'great loosener,' freeing up our concepts from fixated or excessively fixed meanings and usages" in a process that over-reaches but does not transcend analytical thought (2016, p. 124). By this, he implied concern regarding interpreting a situation based purely on tight, reproducible, analytics. He implied that such analytics should not be ignored but can be expanded. With this broader perspective of dialectics there appears to be room for a much more complementary role between moments of letting go/feeling the way (expansion) and others of refining, reworking, re-describing (contraction) in open-ended and exploratory iterations between dialogism and dialectics.

An example of a great loosener can be seen in the work of the conceptual artist Mark Wilby (2014), as described in Vignette 1. Wilby explained that he wanted to see if creating a story (through an elaborate performance piece and subsequent choreography of a reality encounter around the crisis of rhino poaching) could be more effective than the conventional anti-poaching campaigns in response to the crisis (personal communication, December 8, 2023). While such campaigns might be considered to be essential in the short term and a necessary response to a serious crisis, we would be well-advised to question the wisdom of "combatants rumbling into confrontation . . . not always with sufficient pause for the complexities involved, or the unintended consequences" (Wilby, 2014, para. 1) so that maladaptive resilience[2] (Lotz-Sisitka et al., 2015; Sriskandarajah et al., 2013) becomes our only recourse.

---

[2] For example, resilience that perpetuates or exacerbates an oppressive or exclusionary status quo.

Vignette 1
Story of the Cliptivists

On the 18th of October 2012 a small-town newspaper published an article titled: Take our toenails not our rhino (Grocott's Mail, 2012). They reported how Grahamstown artist and filmmaker Mark Wilby, responding to the devastating discovery of four poached rhino at a nearby private game reserve, had walked into the reception area of *Grocott's Mail* and clipped his toenails. He had then put the clippings into an envelope and posted it to the Chinese Embassy in Pretoria with "To whom it does concern" written neatly across the top. The article explained this seemingly bizarre action, describing the slaughter of almost 400 rhinos in that year, when rhino horn, according to scientists, has none of the miraculous properties its proponents claim. Instead, scientists argue that rhino horn is made up of inert and useless keratin – the same polypeptides making up the outer layer of human skin, hair, fingernails and toenails. The newspaper reported Mark lamenting the conflicting beliefs about the powers of rhino horn and his frustration with the sea of petitions and franchised charities, saying: "Given the urgency of the crisis, anti-poaching tactics are essential. But this addresses the symptom, not the cause." (text adapted from the Grocott's article).

After the toenail clipping campaign, Mark provocatively emulated a media reality show, and assembled a disparate group of people (a university computer engineering student, a community activist, a lecturer in media law, a retired teacher and practicing Buddhist, and a drama educator) under the name of 'The Cliptivists' to explore the complexity of rhino killings in South Africa. Through visits to game reserves, a talk with a local wildlife veterinarian, some fitness training (tongue-in-cheek preparation for anti-poaching patrols) and mediated deliberative sessions discussing different conservation initiatives and possible interventions; Mark facilitated a different kind of dialogue for The Cliptivists.

From a STEAM education perspective, the Cliptivist challenge could be emulated with research across disciplines: the sciences (ecology, pharmacology), technology (conservation technologies), mathematics (calculations of who and where the profit margins of rhino poaching lie), and arts (fine art, poetry, and prose exploring social-ecological relationships, for example, Owen, 2013).

An Expansive and Deepening Ontology

Both the arts and science are committed to describing events and experiences in the real world. That is, they have an ontology (an understanding of what is real) committed to aspects of the world that are actualised and empirically detectable. An example is the documentation role played by science and art described above (either through measurable scientific closed lab experiments, or more open-ended and contextualised fieldwork, or artists' realist representations of phenomena).

However, dialectical critical realism presents an expansive ontology that moves beyond the description of events through experience and insists that the sciences are necessarily both broader and deeper than this. Equally, the examples provided below will attempt to illustrate the complementary role played by the arts in revealing an expansive ontology including:

- Laminated ontological *breadth*

- Ontological *depth* and unactualised possibilities

The first—ontological breadth—is detectable via critical realism's concept of *laminated totality*. For an example of laminated totality in use, as an ESD practitioner, I was invited to work with the Cliptivists (Vignette 1 above) to help them to make sense of the complexities they were facing. In workshopping the rhino crisis in our local area, the contradictions and tensions between a) traditional and scientific claims on the properties of rhino horn, b) consumption and conservationist/ecologist arguments, c) human rights and animal rights values, d) cultural and scientific beliefs (see the right hand side of Figure 1) were mapped against laminations of reality adapted from application in other contexts (see the left hand side of Figure 1; Bhaskar & Danermark, 2006; Bhaskar et al., 2018; Parker, 2010). This workshop highlighted how anti-poaching strategies (military-style defence and moralising by one group towards others) were clearly insufficient in the face of the complexity or "conjunctive multiplicity" of the crisis (Bhaskar, 2010, p. 14).

Figure 1
Interpreting the Rhino Crisis Through the Lens of Laminated Totality
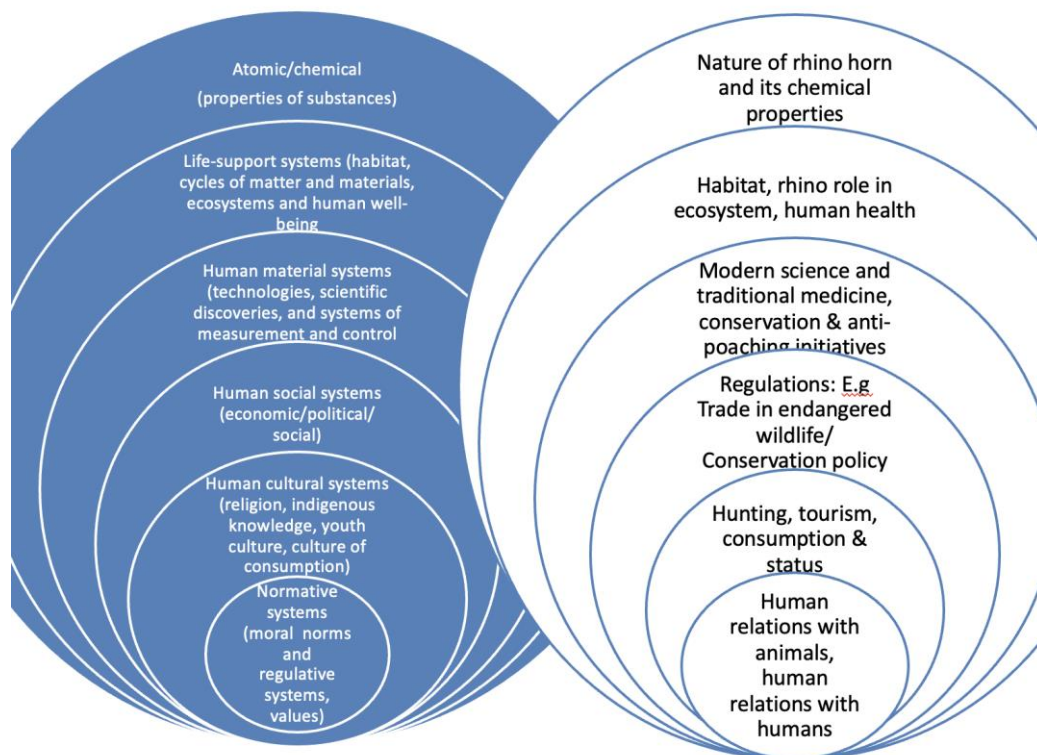
Another example of the power of the arts in alerting us to complex realities is the musician David Kramer's (2004) intensely moving song about the Karoo (Vignette 2), with its historical entanglements of belonging and loss. These lyrics from his song *Dans Mettie Dood* [Dance with the Dead] translate as

People come from overseas

And the farmers just build BnBs

They drive up and down with cameras and 4x4s

Everyone is searching for the old Karoo

If you want to see it, just look in my eyes

The world changes before you rub your eyes.

The unsustainability of the obvious commodity fetishism (see concerns raised by Jackson, 2011, above), landscape use change (from farming/food production to tourism), and land misuse (by 4x4 vehicles) show further conjunctive multiplicities that provide insight into the cycles of poverty evident in the Karoo today. Slabbert described Kramer's music as a form of eco-criticism, demonstrating how "nature and animals become commercial objects exploited for human entertainment" (2011, p. 118).

Vignette 2
Extract from *Dans Mettie Dood* by David Kramer (2004)

Mense kom van oorie see
En die Boere bou net b en b.
Hylle ry op en af met kameras en vier-by-vier.

Almal is op soek na die ou Karoo;
As jy daai wil sien, kyk net in my oë ...
Die wêreld verander voor jy jou oë uitvee

Laminated totality offers an ever-broadening scope for describing the world—requiring input from the natural sciences (biology, chemistry, geographical sciences, physics) and the social sciences which describe both social systems and their embeddedness in the natural world (agricultural sciences, anthropology, economics, human development geography, politics, etc).

The second important tool in an expansive ontology is Bhaskar's (1978) notion of stratified ontology, which affords ontological depth in real-world meaning making, and which acknowledges that reality is inclusive of both actual events and unactualised possibilities that could come to be, given the right circumstances and context. The role of natural and social sciences can be described at both a surface level (for example, description and classification of the natural world or description of policies or different farming methods) and at a deeper level explaining these underlying structures and mechanisms, as well as the contingencies that influence the actualisation (or not) of their real powers (Bhaskar, 1978; Danermark et al., 2002). For example, chemicals may have properties and tendencies, but only react under certain conditions; policies may present ideal situations and practices but are contingent on public support, resources, infrastructure and more; and farming methods may work in one social-ecological context, but not in others. Critical realists thus insist on contingent, non-linear, open-ended interpretations of the world and can identify "both necessity and possibility or potential in the world—what things must go together, and what could happen, given the nature of the objects" (Sayer, 2000, p. 11).

This understanding is significant for ESD because it opens new possibilities for change. Change is not only about what should not be done. Instead, it should include consideration of "real, but non-actualized, possibilities inherent in a situation, thus inspiring grounded hope to inform emancipatory praxis" (Bhaskar, 1998, p. 112). The role of the arts in STEAM for ESD in supporting disruptive thinking

for new possibility is significant here. For example, McGarry described his work with "uncanny artifacts" which he used to "to encourage generative, emergent, and empathetic learning encounters" (2022, p. 95). Illustratively, he presented us with an (uncanny) two-handled shovel to suggest the need for "solidarity and co-defining matters of concern" (2022, p. 97); and he presented an uncanny perspective on a bank note which instead of "a materialist tunnelvision that forgets the profound wealth of the social, the wealth of friendship" can be poetically re-imagined as holding "no material wealth, rather surety that we will catch you in sickness and health" (2022, p. 102).

Another arts-based stimulus for new possibility can be found both in dystopian novels (considering the world that could be, but which we do not want) or utopian novels (an idealistic or imagined place). An example of the former is reminiscent of the open-ended role of dialogism as introduced above. In a post-human world, Paolo Bacigalupi's biopunk science fiction novel, *The Windup Girl,* presents a futuristic earth of "posthuman beings and un-natural ecology" (Bacigalupi, 2009, as cited in Hageman, 2012, p. 293) where the boundaries between nature and technology (both plant and animal and including humans) are blurred. The main setting of the novel is a small country (a 23rd century Thailand) struggling in vain to remain independent and to isolate itself from world-wide environmental catastrophe; a world overrun by mega agri-corporations, and beset with biodiversity loss, fossil fuel collapse, and moral degeneration in relation to human and more-than-human rights and dignities. The parallel lives of the characters in the novel display

> a rigorous focus on contradictions rather than portrayals of false consciousness, nostalgic naïveté, or willful hypocrisy. All of the characters struggling to match their perceptions to the blistering speed of economic and ecological shifts appear caught in a space between a disintegrating paradigm and a still amorphous paradigm yet to emerge in its place. (Hageman, 2012, p. 293)

From a STE(A)M perspective, it is important to consider how fiction often takes poetic license regarding scientific possibility and impossibility (see Margot, 2005, on a little-known play by Jules Verne: *Journey Through the Impossible*) treading lines between science fantasy and science fiction. *The Windup Girl* has controversially been critiqued as another case in point (Schaller, 2015).
There are other meticulously researched fiction novels such as Richard Powers' *The Overstory* (2018), which envelops the reader in the extraordinary world of trees, ecology, and the many layers of activism, appreciations, and dependencies that humans have in relation to the forest giants of the plant world. The controversies in these fiction stories (and any challenges posed to their poetic license) can provide interesting scientific research possibilities in STEAM education contexts with an ESD focus.

These arts-based opportunities can be used in support of enriching ontologies and human engagement with these in dialogic and dialectical STEAM processes to live gladly, as Popova suggested:

> To live wonder-smitten with reality is the gladdest way to live. But with our creaturely capacity for wonder comes a responsibility to it—the recognition that reality is not a singularity but a plane. Each time we presume to have seen the whole, the plane tilts ever so slightly to reveal new vistas of truth and new horizons of mystery, staggering us with the sudden sense that we had been looking at only a fragment, framed by our parochial point of view. (2022a, para. 1)

Critical and Judgmental Rationality

The poem by Robinson Jeffers (Vignette 3) suggests the coexistence of myth, metaphor, and theory in the evolution of knowledge and the entanglement of science and art in describing the world. In Stanza 1, the scientific theory of the moon's once-connection to the Earth after a process of fission is

described and then reinforced with descriptors of the moon as a "cold white stone" and "haggard with loneliness." The accepted theory of the gravitational pull of the moon creating the ocean tides on Earth is described in Stanza 1 as the moon "dragging the sea-tides after her." This sense of nostalgia created by the idea of past connection makes the theory ever more compelling. But acknowledgement of the fallibility of science is introduced with the second stanza, which suggests that Jeffers was likely aware of alternative theories of the origin of the moon: as capture, as co-creation with Earth, or as the result of collision between Earth and a protoplanet.[3]

Vignette 3
Poem reproduced from Robinson Jeffers (1963, p. 11, poetic form maintained as much as possible))

The great Wound

At the near approach of a star-huge tides
Agitated the molten surface of the earth.
The tides grew higher as it passed. It tore from the earth
The top of one great wave: the moon was torn
Out of the Pacific basin: the cold white stone that lights
us at night
Left that great wound in the earth, the Pacific Ocean
With all its islands and navies. I can stand on the cliff
here
And hear the half-molten basalt and granite tearing apart
and see that huge bird
Leaping up to her star. But the star passed,
The moon remained, circling her ancient home,
Dragging the sea-tides after her, haggard with loneliness.

The mathematicians and physics men
Have their mythology; they work alongside the truth,
Never touching it; their equations are false
But the things work. Or, when gross error appears,
They invent new ones; they drop the theory of waves
In universal ether and imagine curved space.
Nevertheless their equations bombed Hiroshima.
The terrible things worked.
                              The poet also
Has his mythology. He tells you the moon arose
Out of the Pacific basin. He tells you that Troy was
burnt for a vagrant
Beautiful woman, whose face launched a thousand ships.
It is unlikely: it might be true: but church and state
Depend on more peculiarly impossible myths:
That all men are born free and equal: consider that!
And that a wandering Hebrew poet named Jesus
Is the God of the universe. Consider that!

---

[3] This last (and favoured today) theory was proposed in the 1970s (after Jefferson's poem was written) but at the time of writing, competing theories would likely have been a topic of scientific debate.

Dialectics originate in the Socratic method of "hypothesis elimination that takes the form of a question–answer dialogue [which] brings out the contradictions in the interlocutor's arguments" (Dafermos, 2018, p. 5). One could easily describe the process scientists undertook to arrive at the acceptance of both wave and particle nature of light, and to settle on a favoured (collision) theory of the origin of the moon (Lotzof, n.d.) in terms of dialectics. Yet Jeffers' poem above suggests that the evolution of knowledge (which must contend with "terrible things"—Stanza 2—and "peculiarly impossible myths"—Stanza 3) is a complex process of "mythology" and products of invention and of the imagination that can be proved "false" and fraught with "gross error" (Stanza 2). Thus, knowledge building moves beyond the dialectics' "famous formula 'thesis–antithesis–synthesis' [which] represents a very schematic and over simplistic description of the dialectical understanding of development" (Dafermos, 2018, p. 6).

ESD is a notoriously contested knowledge space (Lotz-Sisitka et al., 2015; Schudel & Lotz-Sisitka, 2021) and, particularly when ethical deliberations around terrible things are engaged, it is hard to make peace with conflicting viewpoints. Relativism[4] is proffered by some critics as a problematic outcome of dialogic processes. But the concept of relativism needs careful analysis. Tensions within the concept parallel the tensions between expansion and contraction in intellectual processes introduced earlier in the paper. For example, "on the one hand, relativism appears to promise tolerance, flexibility, co-existence, an individual's right to self-fashioning; on the other, it holds forth the specter of a value-free universe with no shared or coordinating norms" (Emerson, 1999, p. 140).

The pathway for reconciliation is set for this paper by Dop (2000, pp. 14–15) who traced Bakhtinian dialogism to Plato's (earlier expression of) dialectic, which was constituted by a twofold process: "to examine closely, and enquire into fact (anacrisis); that which has been 'separated, compared, and compounded anew' (syncrisis)."

This suggests a process analogous to cycles of dialogic, dialectic, and (deepening) dialogue. It is also consistent with Daniels' (2012, p. 70) "vision of dialectical processes which embody internal and between person dialogues." Through this relational and reciprocal perspective on dialogism/dialectic, Dop indicated distrust of the characterisation of dialogism as "subjectivism and radical relativism— a world in which no truth is possible, because it contains only the discourses of various interlocutors, a world in which all opinions are equally valid" (Todorov, 1998 in Dop, 2000, p. 7).

The necessity of acknowledging relativism (not a radical relativism as suggested above but as a moment within a dialectic/dialogic interaction) is strengthened by critical realism's insistence on the existence of epistemological relativism (Bhaskar, 2016). This requires us to acknowledge that the distance between an object and knowledge of it will necessitate multiple interpretations and understandings, and to deny such relativism would be to create unhelpful blind spots in social spaces of working through social-ecological issues and risks in ESD contexts. However, this is not to deny the existence of the thing on which interpretations are based and the existence of powers and tendencies of that thing that transcend these interpretations.

This position was supported in the words of photographer Tim Flach, who explained in an interview for Photoshop.com:

> *I might have an image of a neck of a horse: at one level it is a horse, in another way people might see it more as a mountain, but having heard people discussing it, I see they can find*

---

[4] Relativism is the notion that knowledge, truth, and morality are defined by culture, society, or historical context, and are therefore not absolute.

other associations. Photographs have this potential for layering, many interpretations, ambiguity, which makes photography very special. But still it has this ultimate strength, in that something existed at some point in front of the lens; if that ingredient is maintained, respected, then you have the potential for people to find a lot of connections out of that original moment that you may never have anticipated, that you could never anticipate. (Flach, n.d., in Slye, 2013, para. 18)

It is the commitment to the essential thingness of an object that means that critical realism does not expect all interpretations of a situation to be defensible as valid. Dialectical critical realism suggests that, while it is important to acknowledge the many voices and conflicting stances on an issue, knowledge is fallible and open to critique (Bhaskar, 2016). Similarly, Emerson (1999, p. 150) presented Bakhtin as "a tolerant man" up to a point. He described Bakhtin's resistance to a "value wilderness" and his belief that "evaluation is not an afterthought but a central component of the cognitive process. There could be no virtue in announcing, therefore, that all positions, in principle and as yet not examined in context, have equal rights to exist" (Emerson, 1999, p. 150).

An important aspect of the dialectic/dialogic partnership being proposed in this paper is that dialectics should not become dogmatically set on the necessity of finding one single truth. At the same time, dialogism should not become radically relativist in the sense of accepting that any position has validity and therefore anything goes. Possibility for such partnering was suggested by Bakhtin's analysis of Dostoevsky's authorial voice:

He keeps his feet firmly on the ground, he has faith, he knows how to let go of an authoritative voice and thus how to share gratitude and wonder, both with his fictional characters and with his readers. This is possible (Bakhtin would say) because those two ghostly, unpalatable extremes, relativism and dogmatism, are separated by a long inhabitable stretch of space, which is dialogue. (in Emerson, 1999, p. 157)

Concrete Utopianism

An emergent problem with acknowledging the existence of epistemological relativism and Emerson's "long inhabitable stretch of dialogue" described above is that some may "use complexity as a scapegoat for inaction that ultimately protects the status quo" (Jickling et al., 2021, p. 272). Both arts and sciences though, need to be associated with transformation and newness to be useful in ESD practice. From a dialogic perspective, that means an ability to "frame dialogues with others as creating new knowledge, where question leads to answers leads to questions to generate newness" (Chappell, 2022, p. 496). Bhaskar et al. did not exclude scientists from these dialogic processes either, describing the genesis of new ideas by creative scientists acting in interdisciplinary contexts as "a bit like cognitive magpies, picking up interesting resources (in the form of analogies, metaphors, and models) wherever they can find them in order to construct an explanation that fits with the new kind of reality they have unearthed" (2018, p. 48).

A failure to see possibility for newness can paralyse our ability to act because "how can we act if we cannot choose between better or worse?" (Price, 2007, p. 107). Above, I have highlighted both Bhaskar's and Bakhtin's insistence on epistemological relativism and on the necessity for critiquing the validity of truth claims. Challenges for making truth claims are a rejection of empty moralising in which we seek to provide judgement from a moral high ground that fails to engage adequately in the world with the issues and concerns; and avoidance of a naive position that "assumes that whatever is agreed to be good will come into being" (Sayer, 2000, p. 178). This begs the next question, which is about *how* to make the (non-dogmatic) judgements necessary to move forward, to act.

Mah y Busch expressed doubt about the capacity for "whole sight and harmony" (2014, p. 125) to help us in making these judgements. Similarly, not all dialectics accept idealist notions of reconciliation. Contrary to Hegel's idealist response to contradiction as simply "failure of reason," dialectical understanding needs to include the epistemic, ethical, and ontological domains as possible explanations for contradiction and difference and acknowledge that any of these can constitute "the underlying generative mechanisms or structures that represent the grounds for ideas" (Norrie, 2010, p. 73) and which influence possibility for action. If attempts to gain insight into social-ecological complexities continue to trim and cauterise "onto-epistemological rootedness and entanglements" (McGarry, 2023, p. 18), it is unlikely that any productive way forward can emerge.

Examples of ontological realities that influence possibility for change are: When using arts-based pedagogies in an educational project exploring the social-ecological complexities of water access and health with youth from disparate communities in Cape Town, Anna James was led to reflect that "the possibility across space of performing environmental activism differs drastically" (2018, p. 215). This emerged from a discussion she had with youths about climate change activism at the time of the climate change protests. She compared one youth who suggested she (Anna) should not bring her bicycle (a typical alternative to driving as a climate change response) to his home community because it would get stolen, with another whose father encouraged her to ride to school in a safer community, and with yet another who expressed fear of moving between school and community in the wake of a violent rape and murder highly publicised in Cape Town at the time.

The issue of safety was also raised in an international study employing arts-based pedagogy (youths created photonarratives of days in their lives). This study compared transport possibilities and choices (along with other aspects of well-being) amongst youth in seven cities across the world. Stark contrasts were shown between youth from Christchurch, New Zealand who felt safe cycling and walking because of dedicated lanes and lighting, and youth from Makhanda, South Africa who chose not to walk because of fear of personal safety. Epistemologies influencing freedom of travel in cities included gender stereotyping restricting women and girls because of the opinion that "'women do not know how to drive' and 'do not drive safe'" (Nissen et al., 2020, p. 7).

These examples all illustrate that there are times in the dialogic/dialectic iterations when a sense of stuckness can emerge in a particular space, time, and context. James described the problem as "collapsing the need for active praxis into ossified ideologies fails to engage with the reality of the socio-material context and how it is dialectically linked to our consciousness (a sense of learning)" (James, 2018, p. 11).

However, significant changes emerging from dialogic/dialectic iterations in arts-based projects are not impossibilities. For example, Gavin Krastin's interdisciplinary project, *12 Labours,* at the 2022 South African National Arts Festival challenged understandings of heroism and masculinity through the performance/actions of "a group of queer artists-come-garden-gnomes, in collaboration with local artisans, civil servants, gardeners and contractors who collectively perform[ed] a series of actions centred around notions of repair, community building, gratitude and transgressive joy" (National Arts Festival, 2022, para. 1). Amongst the 12 labours were the creation of an indigenous rock garden at a derelict traffic circle in Makhanda, painting a bus stop gold (like a throne), fixing of potholes, growing sweet potatoes, and more.

In the field of ESD, Dylan McGarry (2023) integrated an alternative form of theatre that he called empatheatre into the discipline of marine science through an interactive performance called *Lalela uLwandle* [Listen to the Sea]. In this piece, the participants explore "themes of intergenerational environmental injustices, tangible and intangible ocean heritage, ecological grief, the role of marine

science in governance, and the myriad threats to ocean health" (McGarry, 2023, p. 20). This art-based intervention has been pivotal in involving and integrating the voices of marginalised groups into ongoing public conversations on ocean governance.

Just as this paper has needed to examine the concept of relativism, it must also present a careful analysis of holism. Mah y Busch (2014) critiqued a holisticism suggested in the epistemology of dialogism in which different knowledges simply coexist without consideration of their relationality (2014). While raising the issue of such unreflective additive holisticism, Mah y Busch (2014, p. 128) argued "the dialogic is inherently more relational and multidimensional than a dialectic, and therefore also seems more immediately whole and harmonious." But, to challenge this perspective on dialectic, once again, we need to return to Bhaskar's particular critical realist process of dialectic in which relationality and multi-dimensionality are central tenets.

The ontological multi-dimensionality and open-ended nature of dialectical critical realism have been presented above. That is, a dialectic in search of patterns rather than linear, ordered interpretations of the world, and which emphasise laminated systems with "relationships of dependency and interdependency, and of their characteristic patterns of interaction and intra-action" (Bhaskar, 2010, p. 14). That is, an "open and multiform dialectic" more able to reflect the world's "contextual disorder," its "material meshwork of causality, space and time in an open future" and its "messiness, its perturbation and change, and its unfinished character, not one that cleans everything up and provides it with a linear ordering" (Norrie, 2010, p. 65).

Based on the above, I suggest that a relational and integrative holism within an open-ended multiform laminated totality can give critical ontological grounding to make informed judgements on a way forward.

Further thinking around the question of integrative holism has to do with the questions around the possibility of universal or generalisable ways of describing the world and the danger of imposing idealised outsider directives for change on others. Mah y Busch (2014, p. 128) suggested that an integrative holistic standpoint "transcends the particular, the presumed location of difference." At the same time, dialogism is not fixed in an abstracted space as indicated by Dop's (2000, p. 11) interpretation of Bakhtin's work that "the proper understanding of an object, or a concept such as truth, lies in the necessary determinate relationship between the particular and the universal." By emphasising the relationship between the universal and the particular in an integrative holism, dialogism thus suggests strategies for avoiding the imposition of theories of change on others through idealised holisticism.

Discussed above, were dystopian and utopian novels in literature. Other genres that may be of use in STEAM education contexts with an ESD focus are those exploring ecotopias—often from a feminist perspective, and solarpunk which intertwines "issues of race, gender, sexuality, class, and colonialism with an ecological ethic" (Johnson, 2010, para. 1). Another consideration is Garforth's (2005, p. 418) description of certain (but not all) "green utopias" which present "vivid and experiential suggestions of what an inhabitable green future might be like," and which require that we "deconstruct the linear visions of future progress and abundance that continue to saturate public discourse and haunt the Utopian tradition, and to dislocate dreams of an organic interdependency with nature from escapist nostalgia and social conservatism."

The notion of concrete utopianism was developed in Bhaskar's dialectical critical realism. His suggestion of a dialectical relationship between the concrete singular (particular) and the concrete universal is consistent with the experiential suggestions of green utopias described above. The

emphasis on concreteness is what enables dialectical critical realism to move beyond idealism to the idea of a concrete utopianism. Bhaskar (2016, p. 125) explained that "Concrete Utopianism involves a differentiation within the domain of possibilities of those that are real form those that are not. 'Real' here means 'realisable' and designates which possibilities may be actualised given a particular constraint". Additionally, concrete utopianism is rooted in grounded possibility and dependent on the depth and breadth ontologies described above. Bhaskar (1993, p. 209) also explained that concrete utopianism plays a "role of creative fantasy . . . that yields at once hope and possibility" thus playing an important role in developing non-idealist new ways of doing and knowing in dialectical/dialogic relational processes.

Conclusion

The intention in this paper has been to further conversations about dialogue and cooperation across disciplines by drawing the arts into STEM education as a non-siloed and integrated approach to trans- and interdisciplinarity. Through reference to a broad range of arts-based practices responding to issues of relevance to ESD, the paper has explored the philosophical roots of this trans- and interdisciplinary space through reconciling dialogism and dialectics where the one neither subsumes nor sublates the other. The reconciliation is theoretically informed by Bhaskar's critical realist specification of dialectics (and distinguishable from other forms in historical developments of dialectics) and particular interpretations of Bakhtin's dialogism.

In summary, the paper has explored four points of tension between dialectics and dialogism and from this has developed four philosophical principles and synergies in which these ways of engaging the world can find common ground, and which enable them to partner each other productively without fundamental contradictions.

The paper has demonstrated the necessity of truth seeking in both Bhaskar's dialectical critical realism and Bakhtin's dialogism and shown the potential richness in cycles of expansion and contraction in meaning making in exploring complex phenomena (the first philosophical principle). In response to the problem of monologism (a critique of Hegelian dialectics), the paper has argued the impossibility of absolutism and surety of specific truth claims.

The second philosophical principle is one of expansive and deepening ontologies. Through critical realist descriptions of laminated reality (ontological breadth), and the importance of understanding a depth ontology for recognising unactualised possibilities, the paper has argued against ontological collapse. This has been backed by dialogism's potential for expansion of ideas, and the role that dialogism and the arts play in extending the perspectival palette and in enabling creative and grounded fantasy.

The third philosophical principle is one of critical judgmental rationality. In the paper, both dialogism and dialectics were shown to acknowledge (and indeed depend on) epistemological relativism for creative re-imagining and acknowledgement of multi-voiced engagement in phenomena. Both, also, cannot allow dogmatic interpretations and propositions in real-world engagements. At the same time, neither tradition supports a radical relativism in which anything goes, and both insist on the fallibility of knowledge and the need for criticality in exploring phenomena.

The fourth philosophical principle is one of concrete utopianism. Concrete utopianism recognises the fallibility of idealised and additive holisticism. Both dialogism and dialectics were shown to appreciate both the universal and the particular, the necessity to work in and out of context, and the necessity of

embracing epistemic, ethical, and ontological domains in facing contradiction and difference in real-world ESD contexts.

Through the reconciliatory work between dialectics and dialogism, the paper has demonstrated complementarity between mathematical-logic and cultural-emblematic epistemes, that is, their respective knowledge-building traditions. Ultimately, the paper has demonstrated that neither the sciences nor the arts need to be exclusively tied to either of these two epistemes, nor to either dialogic or dialogical meaning making. Instead, the paper has demonstrated the potential for complementary work to be done across the arts and STEM disciplines in ways that strengthen their capacity for responding to social-ecological complexities in STEAM education with an ESD focus. The paper suggests STEAM education pedagogies that:

- Require that scientific facts and concepts, case studies, and scientific research as well as literature, photographs, films, and drama be brought as resources to teaching and learning situations to engage learners in consideration of non-idealised concrete possibility and exploration of unrealised possibility in the world.

- Encourage scientific inquiry and discovery as well as descriptive and imaginative exploration in both known and new contexts through developing learners' own talents for using multiple scientific and artistic tools and expressive media.

- Integrate problem-solving and futures thinking tasks that require critical thinking and creativity and which naturally embrace and explicitly develop mathematical-logical as well as cultural-emblematic epistemes as integral to both sciences and arts, but not exclusively specific to either.

- Create assessment tasks that ensure a relational flow between moments of expansion and contraction in meaning-making contexts.

With these considerations of how to bring the sciences and arts into a dialectical/dialogic exchange, I suggest that complex social-ecological problems in STEAM education with a focus on ESD can achieve more reliability, criticality, depth, breadth, and opportunity for facilitating necessary change in the world. I further recommend empirical studies testing these pedagogical ideas in relation to capacity for supporting quality STEAM education in ESD contexts.

Acknowledgements

References

Bakhtin, M. (1984). *Problems of Dostoevsky's poetics*. University of Minnesota Press.

Bhaskar, R. (1978). *A realist theory of science*. Humanities Press.

Bhaskar, R. (1993). Dialectic: The pulse of freedom. Verso.

Bhaskar, R. (1998). *Possibility of naturalism* (3rd ed.). Routledge.

Bhaskar, R. (2010). Contexts of interdisciplinarity: Interdisciplinarity and climate change. In R. Bhaskar, C. Frank, K. G. Hoyer, P. Naess, & J. Parker (Eds.), *Interdisciplinarity and climate change: Transforming knowledge and practice for our global future* (pp. 1–24). Routledge.

Bhaskar, R. (2016). Enlightened common sense: The philosophy of critical realism. Routledge.

Bhaskar, R., & Danermark, B. (2006). Metatheory, interdisciplinarity and disability research: A critical realist perspective. *Scandinavian Journal of Disability Research, 8*(4), 278–297. https://doi.org/10.1080/15017410600914329

Bhaskar, R., Danermark, B., & Price, L. (2018). Interdisciplinarity and wellbeing: A critical realist general theory of interdisciplinarity. Routledge.

Chappell, K. (2022). Researching posthumanizing creativity: Expanding, shifting, and disrupting. *Qualitative Inquiry, 28*(5), 496–506. https://journals.sagepub.com/doi/10.1177/10778004211065802

Conceição, P. (2020). *The next frontier: Human development and the Anthropocene: Overview*. United Nations Development Programme. https://www.undp.org/serbia/publications/next-frontier-human-development-and-anthropocene

Conceição, P. (2022). *Human development report 2021-22: Uncertain times, unsettled lives: Shaping our future in a transforming world*. United Nations Development Programme. https://hdr.undp.org/content/human-development-report-2021-22

Cronin, P. (Ed.). (2002). *Herzog on Herzog*. Faber & Faber.

Dafermos, M. (2018). Relating dialogue and dialectics: A philosophical perspective. *Dialogic Pedagogy, 6*, 1–18. https://doi.org/10.5195/dpj.2018.189

Daly, H. E. (1990). Sustainable growth: An impossibility theorem. *Development, 267*(3/4), 45–47. https://tinyurl.com/4jbkh2ns

Daly, H. E. (1993). Introduction to *Essays Toward a Steady-State Economy*. In H. E. Daly & K. N. Townsend (Eds.), *Valuing the earth: Economics, ecology, ethics* (pp. 11–53). MIT Press.

Danermark, B., Ekstrom, M., Jakobsen, L., & Karlsson, J. (Eds.). (2002). *Explaining society: Critical realism in the social sciences*. Routledge.

Daniels, H. (2012). Dialectic and dialogic: The essence of a Vygotskian pedagogy. *Cultural-Historical Psychology, 8*(3), 70–79. https://psyjournals.ru/en/journals/chp/archive/2012_n3/56309

Department of Basic Education. (2011). *Curriculum assessment policy statements*. https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20English%20HL%20GRADES%20R-3%20FS.pdf?ver=2015-01-27-154201-167

Department of Basic Education. (2023). *Annual report: 2022/2023*. https://www.gov.za/sites/default/files/gcis_document/202402/dbe-202223-annual-report-final.pdf

Dop, E. (2000). A dialogic epistemology: Bakhtin on truth and meaning. *Dialogism: An International Journal of Bakhtin Studies, 4*, 7–33.

Emerson, C. (1999). Isaiah Berlin and Mikhail Bakhtin: Relativistic affiliations. *Symplokē, 7*(1/2), 139–164. https://www.jstor.org/stable/40550456

Garforth, L. (2005). Green utopias: Beyond apocalypse, progress, and pastoral. *Utopian Studies, 16*(3), 393–427. https://doi.org/10.2307/20718762

Grocott's Mail. (2012, October 18). *Take our toenails, not our rhino*. https://grocotts.ru.ac.za/2012/10/18/take-our-toenails-not-our-rhino/

Hageman, A. (2012). The challenge of imagining ecological futures: Paolo Bacigalupi's *The Windup Girl*. *Science Fiction Studies, 39*(2), 283–303. https://doi.org/10.5621/sciefictstud.39.2.0283

Heard, K. (2016). *Maria Merian's butterflies*. Royal Collection Trust.

Jackson, T. (2009). *Prosperity without growth? The transition to a sustainable economy*. Sustainable Development Commission. https://tinyurl.com/5bahb6ka

James, A. (2018). The transformative potential of intersecting with arts-based inquiry and environmental learning in urban South Africa: A focus on socio-ecological water pedagogies. [Unpublished doctoral thesis]. Rhodes University, South Africa.

Jeffers, R. (1963). *The beginning and the end*. Random House.

Jickling, B., Lotz-Sisitka, H., Olvitt, L., O'Donoghue, R., Schudel, I., McGarry, D., & Niblett, B. (2021). *Environmental ethics: A sourcebook for educators*. African Sun Media. https://doi.org/10.52779/9781991201294

Johnson, I. (2010). "Solarpunk" & the pedagogical value of utopia. *The Journal of Sustainability Education.* http://www.susted.com/wordpress/content/solarpunk-the-pedagogical-value-of-utopia_2020_05/

Kahn, M. (2021, August 11–13). *Science, technology, engineering and mathematics education* [Paper presentation]. 4th HRDC summit: Skills required for the 21st century, Midrand, South Africa.

Kahn, M. (2022). The status of science, technology and innovation in Africa. *Science, Technology and Society, 27*(3), 327-350. https://doi.org/10.1177/09717218221078540

Kramer, D. (2004). Dans mettie dood [song]. On *Huistoe*. Blik Music.

Lähdesmäki, T., & Fenyvesi, K. (2017). Bridging art and mathematics: Introduction. In K. Fenyvesi & T. Lähdesmäki (Eds.), *Aesthetics of interdisciplinarity: Art and mathematics* (pp. 1–25). Springer.

Lotzof, K. (n.d.). *How did the moon form?* Natural History Museum. https://www.nhm.ac.uk/discover/how-did-the-moon-form

Lotz-Sisitka, H., Wals, A. E., Kronlid, D., & McGarry, D. (2015). Transformative, transgressive social learning: Rethinking higher education pedagogy in times of systemic global dysfunction. *Current Opinion in Environmental Sustainability, 16*, 73–80. http://dx.doi.org/10.1016/j.cosust.2015.07.018

Mah y Busch, J. (2014). A pedagogical heartbeat: The integration of critical and contemplative pedagogies for transformative education. *The Journal of Contemplative Inquiry, 1*(1), Article 5. https://digscholarship.unco.edu/joci/vol1/iss1/5

Margot, J-M. (2005). Jules Verne, playwright. *Science Fiction Studies, 32*(1), 150–162. https://www.jstor.org/stable/4241325

McGarry, D. (2022). Suitably strange: Re-imagining learning, scholar-activism, and justice. *Critical Studies in Teaching and Learning, 10*(1), 93–115. https://10.14426/cristal.v10i1.511

McGarry, D. (2023). When ancestors are included in ocean decision- and meaning-making. In T. Shefer, V. Bozalek, & N. Romano (Eds.), *Hydrofeminist thinking with oceans: Political and scholarly possibilities* (pp. 15–32). Routledge.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). *The limits to growth*. Yale University Press.

Mejias, S., Thompson, N., Sedas, R. M., Rosin, M., Soep, E., Peppler, K., Roche, J., Wong, J., Hurley, M., & Bell, P. (2021). The trouble with STEAM and why we use it anyway. *Science Education, 105*(2), 209–231. https://doi.org/10.1002/sce.21605

National Arts Festival. (2022, May 10). *Gavin Krastin.* https://nationalartsfestival.co.za/young-artist/gavin-krastin/

Nissen, S., Prendergast, K., Aoyagi, M., Burningham, K., Hasan, M. M., Hayward, B., Jackson, T., Jha, V., Mattar, H., & Schudel, I. (2020). Young people and environmental affordances in urban sustainable development: Insights into transport and green and public space in seven cities. *Sustainable Earth, 3*(17), 1–12. https://doi.org/10.1186/s42055-020-00039-w

Norrie, A. (2010). *Dialectic and difference*. Routledge.

O'Donoghue, R. (2014). Think piece: Re-thinking education for sustainable development as transgressive processes of educational engagement with human conduct:, emerging matters of concern and the common good. *Southern African Journal of Environmental Education,* (30), 7–26. https://www.ajol.info/index.php/sajee/article/view/121961

Owen, H. (Ed.). (2013). For rhino in a shrinking world: An international anthology. The Poets Printery.

Parker, J. (2010). Towards a dialectics of knowledge and care in the global system. In R. Bhaskar, C. Frank, K. G. Hoyer, P. Naess, & J. Parker (Eds.), *Interdisciplinarity and climate change: Transforming knowledge and practice for our global future* (pp. 205–226). Routledge.

Popova, M. (2022a, June 2). Octopus blues and the poetry of the possible. *The Marginalian*. https://www.themarginalian.org/2022/06/02/octopus-poem/

Popova, M. (2022b, June 14). The beginning and the end: Robinson Jeffers's epic poem about the interwoven mystery of mind and universe. *The Marginalian*. https://www.themarginalian.org/2022/06/14/the-beginning-and-the-end-robinson-jeffers/

Powers, R. (2018). *The overstory*. Vintage.

Prager, B. (2007). The cinema of Werner Herzog: Aesthetic ecstasy and truth. Columbia University Press.

Price, L. (2007). A transdisciplinary explanatory critique of environmental education: Business and industry [Unpublished doctoral thesis]. Rhodes University, South Africa.

Price, L., & Lotz-Sisitka, H. (2015). Why critical realism, environmental learning and social-ecological change? In H. Lotz-Sisitka & L. Price (Eds.), *Critical realism, environmental learning and social-ecological change* (pp. 1–17). Routledge.

Sayer, A. (2000). *Realism and social science*. SAGE.

Schaller, E. (2015, October 18). The problem with cheshires: Where Paolo Bacigalupi's *The Windup Girl* fails. *The New York Review of Science Fiction* https://www.nyrsf.com/2015/10/eric-schaller-the-problem-with-cheshires-where-paolo-bacigalupis-the-windup-girl-fails.html

Scharf, C. (2021, Sept 15,). What is life? *Nautilus*. https://nautil.us/what-is-life-238301/

Schudel, I., & Lotz-Sisitka, H. (2021). Strengthening environment and sustainability subject knowledge: Curriculum challenges and opportunities. In I. Schudel, Z. Songqwaru, S. Tshiningayamwe, & H. Lotz-Sisitka (Eds.), *Teaching and learning for change* (pp. 25–48). African Minds. https://doi.org/10.47622/9781928502241

Schudel, I., Lotz-Sisitka, H., Songqwaru, Z., & Tshiningayamwe, S. (2021). Engaging education for sustainable development as quality education in the Fundisa for Change Programme. In I. Schudel, Z. Songqwaru, S. Tshiningayamwe, & H. Lotz-Sisitka (Eds.), *Teaching and learning for change: Education and sustainability in South Africa* (pp. 3–21). African Minds.

Slabbert, M. (2011). Animals and nature: Mapping storylines and metaphors in David Kramer's narratives. *Literator: Journal of Literary Criticism, Comparative Linguistics and Literary Studies, 32*(1), 99–120. https://doi.org/10.4102/lit.v32i1.5

Slye, T. (2013, Mar 18,). *Tim Flach: Animal photographer.* https://spankystuff.wordpress.com/2013/03/18/tim-flach-animal-photographer-2/

Sriskandarajah, N., Bawden, R., Blackmore, C., Tidball, K. G., & Wals, A. E. (2013). Resilience in learning systems: Case studies in university education. *Environmental Education Research, 16*(5/6), 559–573. https://10.1080/13504622.2010.505434

Stevenson, R. (1987). Schooling and environmental education: Contradictions in purpose and practice. In I. Robottom (Ed.), *Environmental education: Practice and possibility* (pp. 69–81). Deakin University Press.

Suchin, P. (2000). An aesthetic of dissent: Cornelia Hesse-Honneger. In J. Stallabrass, P. V. M. Broekman, & N. Ratnam (Eds.), *Locus solus: Site, identity, technology in contemporary art* (pp. 126–137). Black Dog Publishing.

Thompson, D. (2023, Dec 12,). Scientists mobilise against "weaponisation" of research . *University World News* https://www.universityworldnews.com/post.php?story=20231212074254878#

United Nations Educational, Scientific and Cultural Organization. (2016). *Global Education Monitoring Report 2016: Education for people and planet: Creating sustainable futures for all*. https://uis.unesco.org/sites/default/files/documents/education-for-people-and-planet-creating-sustainable-futures-for-all-gemr-2016-en.pdf

United Nations Educational, Scientific and Cultural Organization. (2020). *Education for sustainable development: A roadmap*. https://unesdoc.unesco.org/ark:/48223/pf0000374802

Wilby, M. (2014). The Cliptivists: A pilot*. Vimeo.* https://vimeo.com/93345535

Yang, W., Kewalramani, S., & Senthil, J. (Eds.). (2023). Science, technology, engineering, arts, and mathematics (STEAM) education in the early years: Achieving the Sustainable Development Goals. Routledge.