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Towards an understanding of how sciences and arts meet and matter for sustainable futures

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Reframing STEAM by Posthumanizing Transdisciplinary Education: Towards an Understanding of How Sciences and Arts Meet and Matter for Sustainable Futures*

Pamela Burnard**, Laura Colucci-Gray***

Abstract

Too often, STEAM education remains confined to singular understandings of arts-infused science teaching. Much less understood, developed and drawn upon are alternative epistemologies and material-discursive practices in education that decentralize the human from knowledge production, and acknowledge transdisciplinary intersections across the different areas of scientific and artistic ways of knowing and being in the natural world. This paper draws upon the effort of a group of international scholars who came together in a recent book, *Why science and art creativities matter*, edited by the authors of this article and featured in the recent ICAS conference. Contributors drew upon a wide range of backgrounds – anthropology, humanities, philosophy, visual and performing arts, sciences and education – to discuss and redefine the theoretical basis of STEAM in the context of a future-making education. Many of these scholars make visible new kinds of material-discursive realities that have important pedagogical consequences. Through a form of collective, diffractive reading of educational settings and data, this paper explore ways of mapping transdisciplinarity through space and time and creating collaborative cartographies that are not merely representational. Collectively, the juxtaposition and continuous diffractive exchange of theoretical stances and framings helps to not only surface the structures and cultures that often go uninterrogated, but also for rethinking STEAM as transdisciplinary education; a future-making understanding of how sciences and arts meet and come to matter for sustainable futures.

● Keyword: Posthumanism, STEAM, Transdisciplinary Education, Mattering, Sustainable futures

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** First Author, Professor of Arts, Creativities and Educations, University of Cambridge, UK

*** Corresponding Author, Senior lecturer in Science and Sustainability Education, University of Edinburgh, UK, E-mail: Laura.Colucci-Gray@ed.ac.uk

After a certain high level of technical skill is achieved, science and art tend to coalesce in esthetics, plasticity, and form. The greatest scientists are always artists as well.

Albert Einstein

I . Introduction

Creativity discourses in education remain, for the most part, limited by singular and individual human-centric notions. A posthumanist move which emphasizes matter, materiality and mattering (making) resists being forced into one dimension or generic type. Rather, multiple creativities, as with multiple intelligences, literacies and ways of knowing, are material-discursive entanglements involving differentiated forms of authoring, mediating modalities and language practices.

Framed through the lens of transdisciplinary creativities, the acronym STEAM, commonly understood as Science, Technology, Engineering and Mathematics with Arts, can offer new opportunities for rethinking the field of educational theory and practice. While a growing body of literature is set out to define the nature of STEAM education (Belbase et al., 2021), the term STEAM is as contested in its understanding as it is diverse in its practice. For example, countries such as South Korea have taken the lead on targeting STEAM practices in primary and secondary educations (How & Hung, 2019). However, understanding the role of creativity in reconfiguring disciplinary learning in ways that transgress disciplinary boundaries and offer a productive space to work within transdisciplinary modes remains critical.

Too often, STEAM education remains confined to singular understandings of arts-infused science teaching (Marshall, 2014). Much less understood, developed and drawn upon are alternative epistemologies and material-discursive practices in education that decentralize the human from knowledge production, and acknowledge transdisciplinary intersections across the different areas of scientific and artistic ways of knowing and being in the natural world.

This paper draws on the effort of a group of international scholars who came together in a recent book, *Why science and art creativities matter*, edited by the authors of this article and featured in the ICAS conference. Contributors drew upon a wide range of backgrounds – anthropology, humanities, philosophy, visual and performing arts, sciences and education – to discuss and redefine the theoretical basis of STEAM in the context of a future-making education.

Many of these scholars make visible new kinds of material-discursive realities that have important pedagogical consequences. Through a form of collective, diffractive reading of educational settings and data, they enabled us to explore ways of mapping transdisciplinarity through space and time and creating collaborative cartographies that are not merely ‘representational’ (Bozalek & Zembylas, 2017, p. 120). Collectively, the juxtaposition and continuous diffractive exchange of theoretical stances and framings helped to not only surface the structures and cultures that often go uninterrogated, but also turn a critical lens back onto itself for the enactment of paradigm-shifting moves of rethinking STEAM as transdisciplinary education.

First, we articulate our epistemological stance. We build on the work of Kerry Chappell (2018, p. 286), who first introduced the notion of ‘posthumanizing creativity’. Chappell (2018) recognizes/emphasizes the non-human contributors (e.g., technology, plants, animals, objects, ecosystems) with whom we collaborate. By moving beyond the belief that the human species can be understood as separate from nature or the environment, Chappell (2018), informed by Braidotti, advances a posthumanist move beyond individualism. As Braidotti (2013, p. 192) argued, in “the pursuit of collective projects aimed at the affirmation of hope, rooted in the ordinary micro-practices of everyday life”, we offer a future-making understanding of how sciences and arts meet and come to matter for sustainable futures.

Secondly, we will provide some examples and illustrations from chapters of the book and from our own experimental practice through “snaplogs” (Bramming et al., 2012, p. 55) – a visual documentation method within qualitative research which is a contraction of ‘snapshot’ and ‘log’, used for foregrounding aspects of practice in a process of framing. Here we challenge linear and instrumental assumptions of future-making as something that can be engineered or predicted; instead, we draw upon the field of geographies and future studies that recognize “education as a site in which visions of the future proliferate” (Facer, 2011, p. 1). These are implicit and enacted in educational spaces, disciplines, curriculum subjects and the relationships between teachers and students: “On a day to day level, we constantly ask children to project themselves into the realm of the not yet, asking them to imagine what they might be, what they might want to do, how they might get there” (Facer, 2011, p. 1).

By reframing STEAM through a posthumanist lens, we enact a paradigm-shifting move, as Harris (2021, p. 77) has recently argued, toward thinking with nature in ways that can embed sustainability and ecoawareness in a new generation from early years. By adopting posthumanism’s core beliefs of decentring the human from its pre-eminent position in the

hierarchy of planetary beings, matter and needs, primary education has the opportunity to rethink practice through a lens of making-with, becoming-with and experiencing-with, rather than ‘teaching’ or ‘learning’ as separate activities occurring in subjective and or geo-political silos and separations.

This is the case made in this paper, which provides testimonies and further theorizing of posthumanist transdisciplinarity in ways that will come to matter for sustainable futures.

The article will unfold in multi-modal dialogue with the theoretical multiplicity of transdisciplinarity as a pivotal component of STEAM – defined by powerful transdisciplinary knowledges – and a commitment to changing educational futures for future-making education.

II. Scientific and Artistic Meetings

Sciences, like arts, are really manifestations of ‘natureculture’ – a process of coordinating a set of actions against a set of unknown constraints from nature. Natureculture constitutes entangled and interconnected worlds where the observer and the observed are always enmeshed. Rather than accepting the fabricated dualism of nature and culture, which asserts a reductionist position of scientific ‘knowledge’ (of mind and reason) as transcendent over nature, Kirby (2017) argues for a more science-friendly humanities where intra-actions between nature and culture are furthered by more-than-human relationalities. These offer alternative methodologies for understanding, knowing and producing knowledge. In the first instance, such understanding challenges conventional approaches to scientific inquiry, which are set to reduce the original, relational experience between observers and observed.

Central to an understanding of modernist Western science (and thus to how it may be reconfigured) is the act of producing a ‘code’. Conventionally, a scientific code, like an idiom in a shared human experience, ‘stands in’ for features that are amenable to physical or biological recording. In science, the act of coding is dependent upon the process of demarcation, which is important for reasons of social status; most notable is the demarcation between expert and lay knowledge, which sets clear and distinguishable boundaries between different ways of knowing and relating to the natural world. It is upon such boundaries that a disciplinary scientific focus on phenomena is defined – described in range, scale or intensity – and it is according to such focus that a particular scientific narration of nature is also established (Colucci-Gray et al., 2014). Through demarcation, a choice of focus or ‘frame’ is

adopted in order to code a portion of relational experience. Yet such an approach – which is that of a series of isolated objects standing against a background (Bergmann, 2018) – is one that is almost exclusively rooted in a humanist and exclusivist stance, as it favours a human (and largely visual) perception of reality.

Codification and demarcation also occur in the arts, but they are not what drives the empirical effort there. Unlike the either/or approach of reductionist scientific inquiry, whereby boundaries are set for exclusion, artistic inquiry is led by questions and interventions that aim to produce ever-richer versions of reality. As Wassily Kandinsky encouraged the arts to do, the new task for the new century is to focus on the ‘and’: to end the conflicts, separations and oppositions that characterized the nineteenth century (Bergmann, 2018).

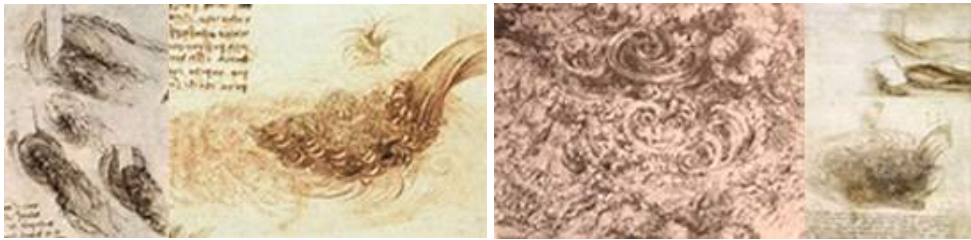
This equates to replacing the old way of thinking, not only of increasing specialisation, but also of the mechanisation that caused separation amongst people (e.g., the designer and the artisan, the architect and the maker) and between people and places (Greenstead, 2005):

Machinery, we are told, has broken up the old traditions of design and manufacture. Machinery has disturbed the contact between artisan and the object of manufacture; it has checked the handicrafts by specialising the different phases of the craftsman’s labours [...]. (Sedding, cited in Greenstead, 2005, p. 21)

Synthesis is offered as an alternative, whereby, according to Bergmann (2018, p. 26), the artist should explore the ‘and’, in the form of relations and harmonies between one and the other, as well as the ‘in’, or how the one dwells within the other. However, by taking this view, we also argue for a different stance on the relations between the arts and the sciences, as both ways of thinking can be rather like a continual accretion of multiple descriptions of nature and can, in line with nature’s way of working, produce redundancy.

In Science, order and creativity, David Bohm and David Peat (1987) emphasize the role of creativity and communication both for science, and beyond science, for humanity as a whole. Creativity in science stems from metaphorical thinking that, by equating two different kinds of things, establishes an act of perception of a similarity. They emphasize the role of communication and art in creativity, citing the example of Helen Keller who, through communication with her mentor Anne Sullivan, was led to understanding of a similarity between the sensation of water and the symbolic gesture pressed into her palms which represented it.

Similar insights characterize the creative work of famous figures such as Leonardo da Vinci. For example, da Vinci's celebrated drawing of 'Water Falling Upon Water' (Figure 1/Snaplog 1) is not a realistic snapshot of a jet of water but an attempt to "elaborate on several types of turbulence caused by the impact of the jet" (Capra, 2007, p. 195). It is the form of water – its changeable, dynamic shape – and the shifting boundaries of perception that provide the focus of da Vinci's drawings. These are, in fact, never realistic renderings of a single instance, but a synthesis of repeated observations through which he attempted to craft a theoretical model.



[Figure 1/Snaplog 1] Images for Leonardo da Vinci's Drawing 'Water Falling Upon Water'

The blurring of boundaries, not only as in da Vinci's multiple drawings featuring spiral patterning, but also in his effective use of the technique of sfumato, challenges the view of early modern philosophers of aesthetics, which favoured 'disinterested observation' as a means of making sense of perceptual encounters with the world. Da Vinci's focus on representing what something "may appear like to the human eye" (Capra, 2005, p. 196) goes in the opposite direction, as it recognizes how closely connected sensing and acting are.

As mentioned earlier, perception, in art as well as in science, is different from simple 'reception' (as in the process of registering stimuli from an external reality). Perception is very much an active shifting of our own attention to the world, as in the original Latin 'ab-tension': that is, to draw something or somebody towards. The role of human creativity is thus central for putting forth new sensory orders and structures that form new perceptions, and for this reason, the awakening of creative intelligence is what enables science to understand both the world and the human nature from which that science was first generated. An aesth-ethic engagement, in this regard, is the act of making sense of the sensorial relationship that is being established with and in the world (Bergmann, 2019).

Artistic creativity, because it is not subject to purposive, language-bound rationality, can give access to aesthetic experience and to much of the systemic wisdom re-linking us with our context. Similarly, scientists' work is rooted in the individual's own sensorial experience of the world, and such embodied experience is at the heart of the ideas, imagery and conceptions formulating their thinking (Gosetti-Ferencei, 2018). Hence, visual and aural images, kinaesthetic sensibility and sensorial elements play into the repertoire of both scientific and artistic creativities (Gosetti-Ferencei, 2018) to constitute a complete 'feel' for and a 'becoming' part of the systems under study. Unlike conventional views which equate creativity to the linear and analytic thinking that feeds conscious purpose, thinking and knowing in the arts and sciences embraces the unconscious and recursive processes upon which all scientific and artistic creativities, from simple appreciation to the actual process, are embedded in the natural world (Bateson, 2000/1972, p. 478).

The study of nature's patterns, such as spirals (Figure 2/Snaplog 2), offers a clear example of how forms in the natural world may stimulate and respond to diverse and complementary creativities. Spirals are a recurrent and naturally occurring shape in natural systems, found in the arrangement of leaves and petals, plants, shells, bones and the weather. They have been studied in mathematics through the well-known Fibonacci sequence, but they also offer a means of tracing the continuity of life forms through evolution, and they speak about how matter is organized and distributed across living and non-living forms. Illustrating the concept of system thinking, characterized by interrelations at multiple scales and levels, spirals are patterns that connect (Bateson, 2000/1972).



[Figure 2/Snaplog 2] Connecting scientific and artistic creativities to naturecultures
 A reformulation of scientific and artistic creativities as synergistic processes for the creation

of symbols, as well as knowledge and understanding of one's own self as embedded in and communicating with the natural world, is fundamental to reformulating conceptions of STEAM education. STEAM brings artistic and scientific creativities together in a reformulated contract between science, arts, the environment and society, to work towards potentially competing aims. On the one hand, the mass production associated with the manufacturing and disposal of technological products contributes to driving economic growth, with the emergence of linear patterns cutting off the redundancy of nature's creativities (Capra, 2002). But another way of understanding STEAM is one that is rooted in the nexus between the material reproduction of daily life, cultural beliefs and nature, and thus can potentially act as a critical mediator. In this sense, our attention is less on the design of products as marketable 'inventions', and more on the recursive insights between nature and culture that form part of the creative process. Pursuing this line of thinking calls for a renovated understanding of knowledge as being embedded in transdisciplinary practices, which take into account contextual, ontological and ethical dimensions, as we will outline in the section that follows.

III. Why 'Seeing' Transdisciplinarity Matters

Challenging the established demarcations that come with knowledge and subject hierarchies, and bringing forth a renovated understanding of creativity as embedded in sensory experience of the natural world, resonates strongly with the essence of transdisciplinarity.

The notion of transdisciplinarity exemplifies one of the historically important driving forces in the area of interdisciplinarity, namely, the idea of the desirability of the integration of knowledge into some meaningful whole. (Petrie, H. G., 1992, p: 300)

Transdisciplinary thinking has been described as a practice that seems to have the most potential to respond to new demands and imperatives. Its characteristic features are a focus on 'real-world' problems, and a methodology that incorporates reflective processes that are responsive to the particular questions, settings, and research groupings involved (Russell, 2008). Another definition of transdisciplinarity, as outlined by Stella Sandford (2015, pp. 160-161) is one in which theory and concepts "are not necessarily identifiable with any specific disciplinary fields, either in their origin or their application".

Sandford suggests that a number of factors are needed for something to be considered ‘transdisciplinary’. The first is the transformation of conceptual thinking into ‘historically based [and] materialist’ critique’. The second is a focus on, not a neutral philosophical critique, but a politically inflected act of theoretical and practical criticism (p.171), and the third is the use of methods that transgress disciplinary boundaries to offer a productive means of both unsettling disciplines and developing a space to think and work within transdisciplinary modes. If a disciplinary mode of thinking is defined inwardly and aimed at setting clear distinctions and boundaries of specialist language, focuses of inquiry, and levels and unit of analysis, a transdisciplinary mode of thinking is concerned with the “potential of divergent elements to coexist, communicate, create entanglements; also through friction, dissonance, and disharmony” (Marenko, 2021, p. 167).

Yet methodologically, it is not sufficient to assemble an assorted group of people working together in the hope that transdisciplinarity will happen. Rather, the inquiry is still very much at the political level, with questions concerned with “What does it take to imagine, design, and inhabit spaces of experimentation, collaboration, and reflection together? How can situations of this kind be crafted? How do we – design educators, practitioners, change-makers – come in close proximity with each other to create togetherness?” (Marenko, 2021, p. 166). In reporting their own experiences of transdisciplinary working, authors illustrate dispositions and qualities that transcend their disciplines, such as empathy, openness to new ideas and experiences, ‘bravery’ in their openness to failure, and trust (Smith & Henriksen, 2016).

So, from an epistemological point of view, transdisciplinarity is rooted in a system view of reality, which acknowledges the need for multi-levelled and multi-perspectival inquiry (Marshall, 2014). In this realm, we locate not only experiences of collaboration between disciplinary researchers, but also those of posthumanist approaches advocating for dialogue amongst an extended peer community – one which includes both human and non-human, and each one bringing a set of legitimate testimonies. As part of this epistemological view, science, rather than being exclusively the source of rigor and objectivity, is also socially constructed, “woven of social relations” (Haraway, 2004, p. 187): it has a class, gender, culture, species and biological context, as well as a methodological context. In taking this more extended and inclusive stance to knowledge creation in transdisciplinary inquires, posthumanist and feminist theorizing advanced by key authors such as Braidotti (2013) Haraway (2004) and Barad (2007) can help us illustrate how transdisciplinary processes enacted through STEAM can extend and transform curricula beyond disciplinary traditions to articulate multiple creativities and

multi-sensorial transdisciplinary connections for sustainable futures.

In the words of the American posthumanist theorist and quantum physicist Karen Barad, relational knowing is illustrated through the concept of diffraction, meaning: “to break apart in different directions” (2007, p. 168). Diffraction patterns can be observed in water waves, as well as sound waves and light waves. Where the waves interfere or overlap they create an interference pattern or “superposition” (Barad, 2007, p. 76). Such entanglements are ‘highly specific configurations’ that require precise apparatuses to study them, as they alter with every ‘intra-action’. The phenomenon that is captured by ‘intra-action’ is transdisciplinarity. Whether it is in a scientific context or an artistic one, intra-action emerges from the assemblage and enmeshment of viewer, phenomenon and apparatus (amongst others). As Barad (2007) explains, “it is not so much that they change from one moment to the next or from one place to another, but that space, time, and matter do not exist prior to the intra-actions that reconstitute entanglements” (p. 74). Whether we are exploring science concepts or mathematics or arts concepts, these are all material-discursive practices that involve ways that can provide different ways of thinking about how students might engage with their learning and then, of course, connect learning to the world.

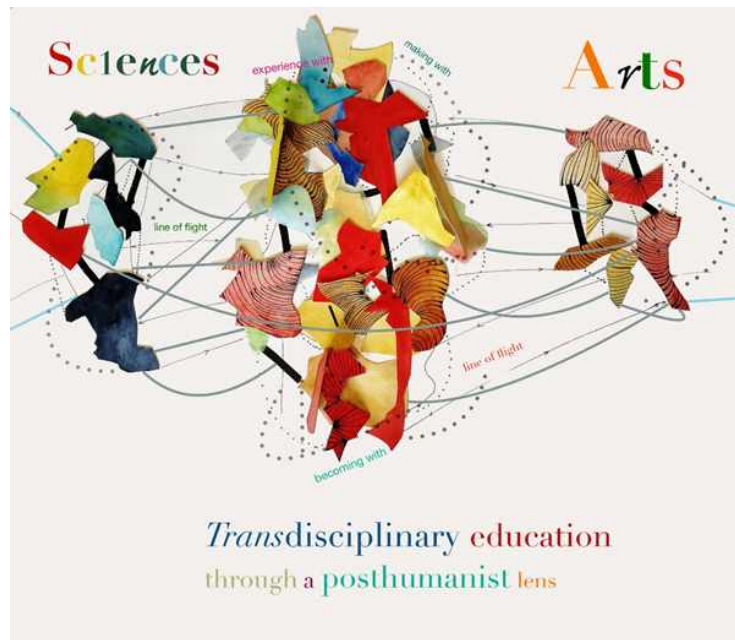
That is, diffraction understands phenomena as both inherently different and differing in terms of time, space and matter, and as deeply relational. Murriss and Bozalek (2019), who observe that diffraction is not only a methodological but also a pedagogical tool, caution that “diffraction troubles humans’ epistemic arrogance of locating knowledge intelligence and meaning-making in the subject and only in the human subject” (p. 4). Drawing on Rosi Braidotti (2013), we argue that the posthuman helps us to combine/reinstate subject disciplines as inseparable transdisciplinary configurations that are embedded within the real world. In this effort, we do not depart from a position of radical divergence, which sees arts and sciences operating as opposites. This position limits the value of the arts to at worst, handmaidens to science, and at best, the tools for emancipation in a dystopian society (Hodgson, Vlieghe, & Zamojski, 2017). Both scenarios reinforce instrumentalist ideas of both creativity and education by focusing on what they should do (e.g., raise interest, deliver outcomes) without regard for their nature – what they actually are in their own right.

Rather we seek to embrace the ‘spaces-in-between’ the disciplines – a pedagogy of co-existence – as this ‘in-betweenness’ exists thanks to our own very nature of being enmeshed within multiple levels of relationality, both in society and within the natural world. Such a position does not deny the need to be critical of economic discourses in education that drive

schools towards performativity. But what it does is recognize that schools may in fact provide a unique space for reflection on and reconfiguration of relationships amongst humans and more-than-human subjects – a space to enact possibilities that may not be visible, or as yet available, in the present order.

In a similar fashion, Deleuze and Guattari (1987) proposed there is no beginning or end to the process or phenomenon of thinking: that is, that knowledge-making is not static and separable from the living and non-living world, but instead occurs in the form of assemblages made up of groups, ideas, elements, or systems that are continually intertwining to do something, to produce something. Inquiry as the process of dialogue with nature/culture therefore does not follow a linear path made of consequential steps, but is rather more like the shape of a rhizome (or tuber, such as, say, ginger), which spreads out in an unruly fashion. As it ruptures in its unpredictable directions, it throws us off onto another path, allowing us to break with old habits and form new ones, making the familiar unfamiliar and offering the space to make the unfamiliar familiar. Accordingly, we conceive of knowledge as rhizomatic, organizing laterally without hierarchies and constantly open to renovated formulations of the norms and processes that narrowly define disciplines, phenomena, and activities. This enables a more fluid exploration of the multiplicities in thinking about and doing arts, sciences, mathematics and other disciplines as ‘ways of being’ and ‘ways of doing’ located within learners’ sociocultural, economic and political conditions.

The examples that follow are thus presented as ‘research assemblages’ that illustrate different ways of drawing together the affective, discursive, historical, sociocultural and material conditions of education. Assemblages are made of and give rise to ‘lines of flight’ that is, bolts of pent up energy, trajectories of possibility which exceed the disciplinary ‘gaze’ to attend to the ongoing folding-unfolding of the self and the world (Figure 3).

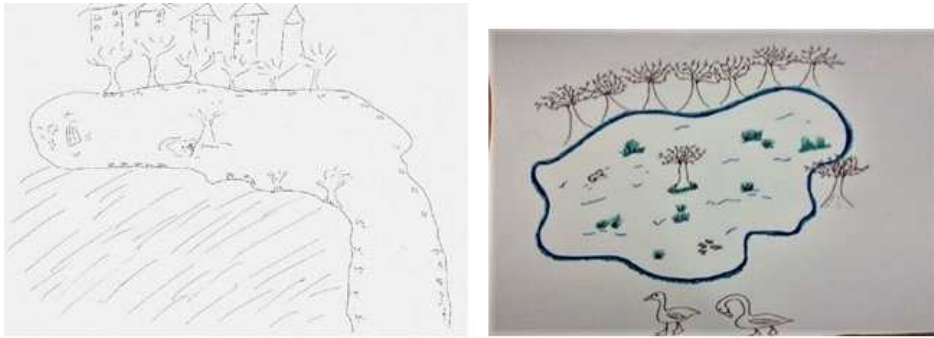


[Figure 3] 'Lines of flight' that break away from given formats of teaching, curriculum and knowledge to create new paths and new possibilities.

IV. Diffracting Posthumanist Transdisciplinary Meetings: A Research Assemblage

What is a pond?

If, in landscape architecture, a pond may be a fabricated structure whereby the emphasis is placed on its volume and shape, in biology a pond is an ecosystem which changes over the course of the seasons, bringing with it a particular community of flora and fauna that is adapted to its changing phases. However, in poetry and language, a pond is also a powerful metaphor for deep thinking – ‘pondering’ over oneself or a course of action. In Colucci-Gray (2020), drawing as the process of mark-making, of shifting perception on paper, supported a multi-level inquiry into a newly found shape in a rather familiar landscape (Figure 4/Snaplog 4). As in da Vinci’s drawings, the same form was traced several times, not with the intention of representing and describing it, but each time seeking to find its ‘truth’: that is, how it came to be and to exist in its ecology.



[Figure 4/Snaplog 4] Selected students' drawings to illustrate shifting perspectives of the same form

A diffractive analysis of the pond-like figure scatters the observers' attention in the same way as the light hitting the surface of the water is scattered and diffracted in different directions to raise new questions – to generate difference in perception. Should a pond be contained? Or should it be confined? What are the boundaries between the pond and the grass? What is the changing color of the water telling us about the nature of its nature? Temporary or seasonal? Created or emergent? A significant consequence of the newly found form was an ethical question: If this was not a 'man-made' pond, how should we negotiate access with other non-humans (the swans)?

Across all levels in education, STEAM practices appear to develop in liminal spaces such as informal learning environments, or as part of programmes devoted to promoting science outreach. In formal school curricula, however, teaching through a combination of subjects, usually as part of integrated inquiry-based projects, is often viewed as problematic by teachers, who are working within the linear model of outcomes-based education where the curriculum and assessment structure appear to be narrowing in terms of both subject choices and scope. Reconfiguring STEM and positioning arts at the core of the STEAM acronym is thus a powerful way to bridge the gap between traditional scientific teaching (as the acquisition of abstract knowledge) and the desire to engage in real-world experiential learning, take account of real issues and problems and work together to find a solution. This stance calls for shifting away from notions of materials as inert and waiting to be manipulated by human skills and control, towards notions of materials as active “ontological heterogeneous partners” (Haraway, 2016, p. 17), engaging with us in ‘material-discursive’ practices of becoming-with and experiencing-with (Harris, 2021).

1. Putting transdisciplinary ‘mattering’ to work

In a speculative feminist musing, Carol A. Taylor and Jasmine B. Ulmer (2020) pursue a specific line of transdisciplinary thinking as a conceptual assemblage, a practical methodological conjunction and a hybrid theoretical politics of location. Knowledge is not a separate component within a self-contained ‘body’; instead, we come to live and think through assemblages in the flesh, emerging from the material and energetic assemblages of the Earth. Going beyond the knowledge offered by the specific disciplines, Affifi (2020) produced a series of lessons in which “art is often explicitly engaged in attempting to integrate the human desire for purposive order with the fact that humans are always engaged in a more-than-human field of actors and processes that exceeds our grasp” (p. 81).

For example, starting from the experience of a watercolor drawing of an apple (Figure 5/Snaplog 5), both the phenomenon under study and the science-artist engaged in the drawing are at the mercy of the whim of water. But it is the diffraction of light through the medium of the water and the crystalline lens of the eye that is integral to visual perception. As Affifi (2020) set out to demonstrate, the similarities and differences between the two apples cannot be determined by criteria that are external to the observing subject. The point here is the use of drawing and emphasis on color as evidence of the diffractive work of light hitting pigments and our own visual and manual perceptive abilities.



[Figure 5/Snaplog 5] “Pink Lady” and “Gala” apples painted by Affifi, 2020

In this sense, transdisciplinary practice is not the result of the addition of disciplines but the search for different ways of structuring the experience of knowing: in this case, the integration between the will and the wildness of human and more-than-human nature. Both dimensions are involved in knowing not only nature – as it may be common in the scientific

attempt to classify and put order over phenomena – but also the nature of nature. As Bateson (2002/1979) suggested, what is known is integral to the process of knowing itself. This is what the ‘pattern that connects’ meant for Bateson (2002/1979), and it is a radical epistemological turn that is crucial because “it indicates that human knowing are living processes in relational continuity with the Biosphere” (Affifi, 2020, p. 86). It is in this manner that incorporating artistic practices into science education can sensitize students to multiple creativities and a form of relational knowing that is crucial for cultivating sustainable science curricula.

2. Identifying transdisciplinary ‘intra-actions’ in STEAM gardens

According to Deleuze and Guattari (1987), relinquishing the power of the ‘sign’ which crystallizes the experience of reality into a given word is the equivalent of a de-territorialization, which enables new points of conjunction to be found, as happens in dialogue when two different ideas are compared and shared. As illustrated through the examples provided so far, this process involves ‘dialogue’ amongst disciplines as ways of knowing: that is, ways of structuring and making sense of a relational experience.

The topic of the fertility of soil represents an ideal domain for experimenting with transdisciplinary and multi-perspective dialogue, and thus it formed the basis for another example of STEAM practice supporting children growing food in their school gardens. The word ‘soil’ is generally used to refer to the ground upon which we walk, build technical infrastructures and grow food. However, due to the long time span needed for its formation, soil is a non-renewable resource, and 95% of the production of food and over 90% of the planet’s biodiversity depend on the quality and the quantity of soil (UN, 2017a). Despite decades of focused scientific research and social concern, soil degradation is on the rise, with soil governance remaining one of the most significant impediments to its prevention (UN, 2017b).

Soil troubles linear conceptions of knowledge because knowing soil is indeed a relational and material experience of being and doing in different places and at different times. For example, while many scientific measures and indicators of soil erosion are available, the impacts of that erosion monitored and recorded by science experts often occur off-site (i.e., at the margins of large cities), whereby they may be at odds with people’s everyday experiences. From a sociological and educational point of view, soil fertility can also stimulate philosophical

speculation regarding the status of the living, the co-existence of living beings, inequities amongst different groups of people, and interactions with the non-human and with the realm of the non-living.

Engaging the transdisciplinary power of STEAM practice, another experimental project involved children in re-designing their school grounds into growing spaces (Gray, Colucci-Gray, & Robertson, in press). This apparently simple idea highlighted the “real, perhaps underlying and hidden, problem to solve rather than the one that was visible and obvious at the start” (Culen & Gasparini, 2019, p. 94), for what mattered was not the content knowledge to be first acquired and then applied as the outcome-based model of education normally prescribes, but rather the experience of tending the plants and attending to their needs, “physically feeling (··) the world of the potato, whose long stem is so fragile to handle that ‘you need to water it gently, from the top or it will snap ··· and the plant will die’ (girl, aged 11)” (Burnard, Colucci-Gray, & Sinha, 2021).

A diffractive analysis invites different sets of questions and (re)configurings that lead to alternative ways of ‘seeing’, ‘knowing’ and ‘doing’ education and research. How does a posthuman transdisciplinary approach challenge who is asking the questions about ‘quality’ of learning environment? How is the children’s touch diffracted across the multiple textures, colors, patterns and shapes that make up the creativities of the plants in the garden? And how do we assess the process of learning? What evidence of learning counts? Whose learning counts? How far is the learning of the children enabled/supported/co-created with the learning of the plants themselves? Diffraction produces a ‘cutting-together apart’ driven by affect, and by the practices, place and people involved in the phenomenon or activity. This is the essence of a STEAM garden: a place where the intra-actions of bodies and materials create new material-discursive practices (Figure 6/Snaplog 6).



[Figure 6/Snaplog 6] ‘Cutting-together-apart’ in the STEAM garden

2. Identifying transdisciplinary ‘intra-actions’ between mathematics and visual art

What follows is a diffractive analysis of a ‘mathartwork’ created by several young South African secondary school students to highlight the differences that disciplinary matter, materiality and mattering¹⁾ make for research, teaching and learning. We employ the example to emphasize the significant contribution that can be made when transdisciplinary creativity shakes up the school curriculum and schools adopt transdisciplinary approaches to engage young people with real-world problems in a manner rooted in their lived experiences. It also presents evidence in which pupils appear to have benefited significantly from this blurring of subject boundaries. One invited South African teenagers to create ‘mathartworks’ (see Figure 7/Snaplog 7 for a sample), employing a dialogue across disciplines – in this case mathematical and artistic knowledges – to advance their knowledge-making practices (some have called this the enactment of da Vinci thinking and seeing differently).

The material realities of “‘being-of-the-world’, not ‘being-in-the-world’” (Barad, 2007, p. 160) are reducible neither to one or the multiple. As Barad writes, “Beyond the issue of how the body is positioned and situated in the world is the matter of how bodies are constituted along with the world, or rather as ‘part’ of the world” (2007, p. 160).

In Figure 7/Snaplog 7, we see where material enactments of mathematics and art meet as a (re)configuring of and dialogue between disciplines.

1) The distinctions between matter, materiality and mattering are significant to building a rhizomatic inquiry and analysing data diffractively. Foregrounded by Barad, here matter refers to disciplinary theories, concepts or curricula, while materiality relates to the materials, apparatus or symbols that facilitate an activity or disciplinary process. Mattering, on the other hand, relates to what matter means, what it means to matter or what comes to matter and what does not. Barad (2007) defines it as the “entanglement of matters of being, knowing, and doing, of ontology, epistemology, and ethics, of fact and value, so tangible, so poignant” (p. 3).



[Figure 7/Snaplog 7] A sample of drawings (MathArtWorks) by South African young people aged 11-16 from non-privileged backgrounds and socioeconomically challenging environments

Many of the pictures focus on hair, hands and bodies. Many suggest a shifting of attention, from judging themselves to being judged in relation to their own mathematical development and progression, and their status as mathematicians and artists. There are often strong cultural references. The differences that come to matter, with cultural associations of anxiety, emotions and bodily reactions which connect and take action with/in the body, communicate stress, solemnness and seriousness. Does this decenter both learner and discipline, troubling human exceptionalism – the idea that intelligences and creativities are situated in

human consciousness and exclusively in the human – to produce a view that doesn't normalize young people in accordance with dominant views on mathematical and artistic development, but focuses on learning that is not linear, fixed or bounded by subjects, but diffracting together in dialogue?

These young people do not separate mathematics from art. They seem to be thinking with and through the relational nature of mathematical concepts, expression and form. We also see that they see or experience the human body as the seat of mathematical knowledge. Making-with mathematics and art is an intra-active conversation. We see a type of transdisciplinary creativity that moves away from the capitalist-consumerist value upon novelty and final products, authoring a different purpose to education through performative knowledges of being and becoming.

What do we hear in the commentary about the learners questioning and experiencing feelings, ideas, shifts in consciousness and an imagining of different realities? Could they be trying to suspend disbelief and work in fictional contexts using a range of mathematics devices, dilemmas and demands? Could this be an expression of deep understandings about the need to enact and embody mathematics learning, and about making the familiar strange inside the art 'work'? These signify a break from the assumption of subject/object dualism, with new patterns of thought (superimpositions) deconstructing power-producing binaries (mind-body, mathematics-art), and showing how mathematics and visual art overlap and change in themselves as an intra-action of what they do and how they connect and co-constitute.

The critical issues here are that there are no inherent and clear borders between matter and discourse, being and knowing, and being and doing. This makes knowing of mathematics and art just as much a matter of the body and the material as it is a matter of the mind and the intellectual, none of which can be separated. Barad (2007) states that the point is not that knowing has material consequences, but that "practices of knowing are specific material engagements that participate in (re)configuring the world" (p. 91).



[Figure 8/Snaplog 8] An entangled assemblage of material and human actors, where agency is enacted 'intra-actively'

Showing how these material-dialogic practices are enactments of transdisciplinary creativity 'propels ideas forward' in time, with 'new discoveries' that, whilst unknown, continue to intra-act with the community in which they originated or in which they might operate, thus operating in a creative and responsive orientation to an unknown future (Hetherington et al., 2020).

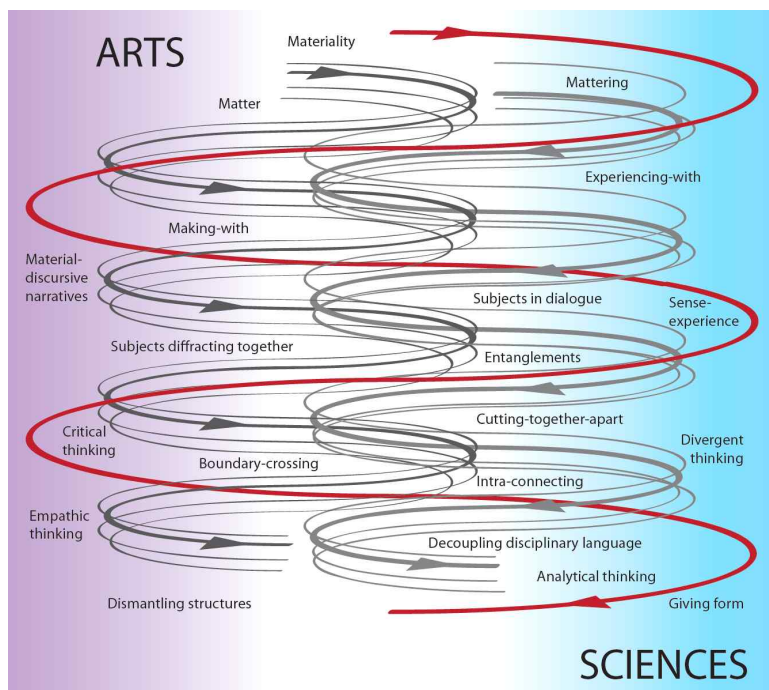
This snaplog (Figure 8/Snaplog 8) comprises data assemblages that illustrate a relational view of people, discourses of environmental protection and discursive materialities. As Hetherington et al. (2020) reported in their chapter, "agency can be understood not simply as an individual, human capacity but as a relational performance within an entangled assemblage of material and human actors, where agency is enacted 'intra-actively'"(p. 289). For others, it might be the intra-actions between ideas, affect and gestures that matter differently and produce different phenomena and different learning, as the snaplogs are evocative of children's experiences of artistic and scientific creativities in their class.

Every art should become science, and every science should become art.

Friedrich von Schlegel

V. Why Posthumanizing Transdisciplinary Education Matters?

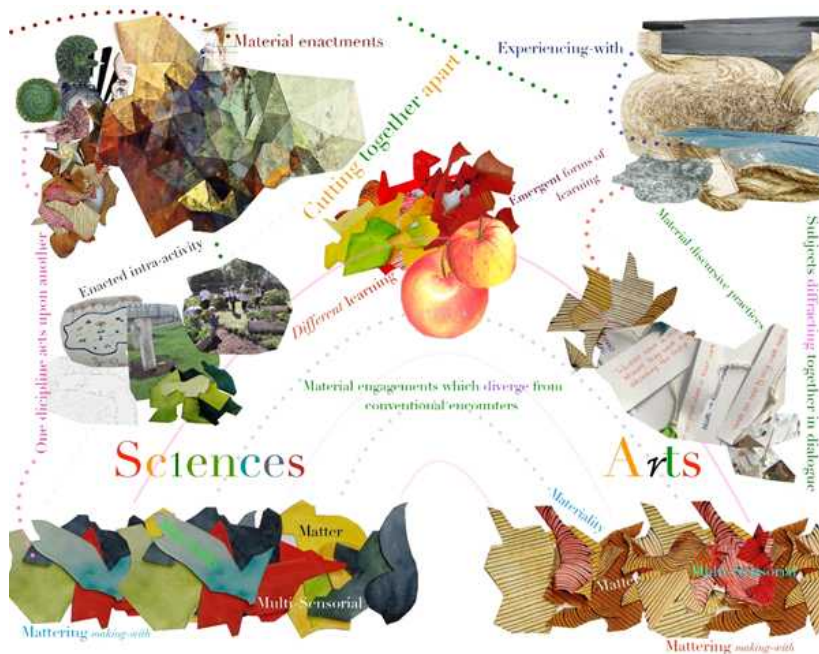
What kinds of thinking and practice are being advanced by these kinds of de-territorializing practices, and how might this posthuman, transdisciplinary way of working de-territorialize subject learning systems? How can the interplay of scientific and artistic creativities generate change and push the boundaries of human-centered thinking towards new territories of transdisciplinary combinations and/or pairings of subject disciplines?



[Figure 9.1] A scientific-artistic mapping of (a non-linear, boundary-crossing constellation of routes into) transdisciplinarity

We offer two ways of (re-)viewing and (re-)framing transdisciplinary education through a posthumanist lens (see Figure 9.1 and Figure 9.2). Understanding how sciences and arts meet and come to matter requires the erasure of subject silos and the activation of new ways of entangling subject disciplines, not simply as spaces for acquisition of knowledges and skills but as transdisciplinary creativities with potential for authoring real impact on the individual's life and community. The aim is not simply to revision and reframe posthumanist transdisciplinary

education, but to develop ways in which areas of the curriculum may be radically redesigned and mobilized through transdisciplinary pedagogies. By reframing intra-acting binaries as transdisciplinary creativities – as math-art, science-geography, mind-body, art-science, material-discursive, discourse-affect, textual-visual, theory-practice, historical-political, geographical-socioeconomic – reveals how boundaries are porous, indeterminate, non-permanent and always changing. This allows us to see differences relationally, to diffract and differentiate, yet does not beget dominance by any one discipline (Fig. 9.2).



[Figure 9.2] An artistic-scientific mapping of (a non-linear, boundary-crossing constellation of routes into) transdisciplinarity.

And so, in place of binaries – siloed disciplines – we argue for the imperative/importance of posthumanizing transdisciplinary education with a much greater understanding of the different logics of knowing in the arts and sciences, and the diverse and multiple creativities they shape and cultivate in practice. As Marenko (2021) has recently argued, “trans-disciplinarity is, first and foremost, trans-gression: of boundaries, of expectations, of received assumptions” (p. 179).

This research assemblage suggests there is scope to reframe our thinking to inquire into not only how arts and sciences purposefully connect, but also how they stimulate different forms of logics, rationality and affect: how they become part of an inquiry that is embedded within posthumanism, which highlights how human beings never act alone and are always entangled with/in their environments (Dernikos et al., 2020), particularly in the new normal of a COVID-19 world.

The integration of arts and sciences into transdisciplinary action will allow education to meet children's fundamental right to a liveable and sustainable environment. The arts offer the unique opportunity for children to develop an understanding of the world that values their affective subjectivities while at the same time enabling their relational capabilities to 'be with' and 'think with' other living things, within a shared 'learning ecology'.

The integration of scientific and artistic perspectives brings forth both analytical and empathetic thinking, offering a range of different modalities for 'dwelling' with objects of attention, and for thinking and being in the world. Re-uniting these two dimensions in multi-modal, transdisciplinary and real-world activities addresses some of the limitations of current curriculum and assessment structures.

For teachers, enacting posthumanist transdisciplinary education requires commitment to understanding how scientific and artistic creativities come to matter for sustainable futures. This stance diverges from not only the outcome-based model of education, but also from the instrumentalist approach of progress towards a sustainable target, as if sustainability were a point fixed in time. Instead, through the experiences illustrated in the research assemblage, we have endeavoured to show sustainability as a path that involves multiple creativities, and as such is allowed to diverge from an original plan in order to remain close to the path of perception and sense-experience. 'Sustainable futures' here are thus futures that are enacted through disruptive practices of making-with and co-relating, as opposed to co-planning. This opens up several new lines of curriculum reform involving a set of negotiated co-authorings with a community of transdisciplinary teachers and learners.

These learning 'ecologies' will produce tacit understandings, inferred practices and theoretical assumptions which can be made explicit as new forms of knowledge that generate and diffract into new transdisciplinary practices and processes. Letting arts and sciences teach together will open up ways of making that require makers to work with and shape new realities. Letting arts and sciences teach together has the potential to cultivate different capacities, which has broader implications for society, politics, the economy and the

environment. Letting arts and sciences teach together offers a potent set of transdisciplinary practices and repertoires of human faculties for thinking and experiencing the world.

It is essential to note that for transdisciplinary learning to become real in the classroom the role of teachers and students involved in practical activities within and outside the classroom is essential. To this aim, ideas for professional learning communities co-authoring whole-school transdisciplinary educating-futures ecology can be facilitated through:

- Working collaboratively to co-author posthumanizing transdisciplinary approaches which recognize the importance of the intra-action amongst disciplines.
- Committing to flattening subject hierarchies by posthumanizing a transdisciplinary-led curriculum that extends and transforms curricula beyond disciplinary traditions and towards sense-experience.
- Attending to the emerging material-discursive narratives of reductionist science in education and think of new stories to tell your stories with (Haraway, 2016).
- Being open to diverse creativities that help to de- and re-territorialize subjects, norms and processes that narrowly define disciplines.
- De-coupling the specific language of a discipline from its original context, opening up new possibilities for viewing and experiencing the same phenomenon, and the materiality of difference (Braidotti, 2019).
- Dismantling structures that deny a turn in future-making education to transgress and transcend disciplinary boundaries, and reposition STEAM education so that arts and sciences are not separate or even separable endeavours, but each discipline acts on the others through a relational materialist approach to transdisciplinary configurations.

Globally, educators are confronting many challenging issues at the forefront of curriculum change agendas. While transdisciplinary practices are new, they do not equate to ‘new teaching approaches’ that needs to be taught to teachers, but they are ways of being in the learning space, fundamentally embedded in the creativity and collaborative ethos of pupils and teachers. To illustrate how this idea works in practice, this paper has offered a number of practical examples illustrating how significant transformation can take place by engaging artistic and scientific creativities that invite learners to question and explore one’s limits and to find opportunities for new meanings. The act of ‘cutting-together-apart’ is not an abstract notion but a concrete action drawing strength from the courage to re-make, re-think and re-configure and

then, to assess together what new skills for listening to oneself and for learning with others have emerged. Taken as a whole, posthumanizing transdisciplinary education reflects the need for a fundamental praxis shift/turn – for educators in all fields to ponder important issues beyond their own speciality and push back the frontiers of their own knowledge and practice. We end with some visionary thinkers on the interrelations between sciences and arts:

To be creative means to connect. It's to abolish the gap between the body, the mind and the soul, between science and art, between fiction and nonfiction.

Nawal El Saadawi

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