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Chapter

Transdisciplinary Art-Science Identities and the Artification of Learning

Kathryn Grushka

Abstract

Transdisciplinary art-science learning is linked to semiosis and the performative nature of learning. At the core of contemporary learning is sensemaking through images. We learn through how we perceive, remember, and imagine the world. An ethics-approved inquiry looked at the artmaking practices of gifted secondary school students between the ages of 15 and 17 years (n = 108) with a focus on their art-science performative learning. The study applies Deleuzoguattarian thinking and other post-structural perspectives on contemporary representational practices for learning and communication in art-science spaces. One of the research key findings is that artified visual pedagogies can both transverse and/or facilitate meaning-making across art-science spaces and brings forth the creation of science-linked identities. Educators must now engage with the idea that visual reasoning as performative action is now the connecting pedagogy in all epistemic fields.

Keywords: science-linked identities, visual borderlands, transdisciplinary learning, art-science, semiosis, artification, visual learning, science communication

1. Introduction

There is an emerging watershed moment that is set to challenge the relationship between dominant text-based instrumentalist imperatives of the last century and visual art and science education in transdisciplinary learning spaces. With the ideas of contemporary post-structural philosophers such as Deleuze and Guattari entering educational discourse, visual performative thinking and semiosis are forging a rethink about knowledge and communicative connections between disciplines [1]. As our artefactual world now centres on the image, what we come to know as experience and learning are being redefined by how we perceive, remember, and imagine the world as images and signs. Educators must now engage with the idea that visual reasoning, as performative action is now the connecting pedagogy in all epistemic fields with the capacities to visualise, transform, and communicate information.

The chapter argues that the concept of visual borderlands has the potential to unmake current constructs of both traditional art and science curriculum and their related pedagogies by exploring the liminal, embodied, and artified knowledge spaces

emergent in their borderlands. This has significant resonance as neoliberal ideology, promotes certain student/teacher behaviours in the name of creativity [2], and has become intricately connected to making a scientific workforce and presenting a dogmatic image of thought about scientific knowledge [3]. This chapter seeks to loosen such ways of knowing in science education in the consideration of the role artification plays in contemporary science learning. I write this at a time when pedagogical rhetoric across secondary and higher education is shifting to a focus on the importance of transdisciplinary knowing yet remaining anchored in positivist text-based assessment and teacher-centred content. Ironically, policy and debate on pedagogical futures which speaks to student-centred inquiry and knowledge connections continue to have the side effect of the neglect of the arts generally, and specifically visual contemporary arts practice which accesses all signs and epistemological contributions as artfied ways of knowing and being when inquiring and when communicating to audiences.

Current pedagogical challenges are heightened by everyday digital imaged technologies and their semiotic complexities. These imaged technologies provide agency and fluid learning opportunities for all youth. The next education frontier must look to the significance of the visual, its visual learning processes, and its semiotic contribution which grounds personal experience, aesthetic, affective, and performative learning. By drawing on the Deleuzoguattarian method as one of intuition, it is argued that visual boundary learning goes beyond the actual and our limited, or fixed forms of representing life, to recognising that we are always seeing [4] with affective and imaginative potential. Drawing on gifted secondary school visualisers enrolled in a commencing introductory first-year university fine art 2D course, it seeks to provoke accepted constructs of traditional visual art and its more contemporary contribution to learning. Within this course, students were asked to explore a scientific concept of choice and straddle subject borderlands. The inquiry examines the extent to which scientific and arts-based learning has the capacity to de-territorise knowledge. In so doing, it brings to the surface the concept of an artfied pedagogical perspective. Artfied learning is linked to adaption and aesthetics and, in the spirit of transdisciplinary learning, presents insights into new ways of seeing or imagining future pedagogical connections and possibilities.

2. The watershed moment: neo-liberal education and the fluid performative realities of being a digital visual learner and communicator

There is a coalescing of current educational commentators critical of the current instrumentalist and positivist knowledge perspectives on pedagogical design which will have ripple effects on society into the future. Four key ideas are presented and will be foregrounded in this chapter: (i) scientific commentators who challenge the hegemonic dominance of the contemporary positivist idea of fixed scientific representations and teacher-centred pedagogies; (ii) the performative nature of learning which links percepts and affect, becoming and the multiple ways we make meaning; (iii) the digitisation of social media, dominated by the visual, its fluid processes, unstable meanings, and artful semiotic practices; and (iv) the concept of visual borderlands [1] at the heart of transdisciplinary learning where the learning is affectively driven, relational, and connected. A pedagogy offering imaging as a valued liminal space sees visual borderlands as being able to connect knowledge, identities and employ metaphor across epistemological boundaries for new understandings.

In the first watershed moment, a rupture now exists between our understanding of the need for transdisciplinary knowledge diversity and associated learning assets and a perceived excessive focus on dis-imagination in quest of vocational and science, technology, engineering, and mathematics (STEM) education [5, 6]. Commentators like Yong Zhao [7, 8] speak to the unintended side effects of such economic education policy narrowing society's skills and talents/interests as non-STEM skills are undervalued. He argues against a focus that educates uselessness to one with a focus on creativity, resilience, and talent diversity. Zhao emphasises specifically the ways of knowing offered in the arts. Ways of knowing that refine interpersonal, intrapersonal ways of knowing, and their intrinsic, aesthetic, critical, and communicative skill sets are central to contemporary subject-objective reality. Lovat [9] further draws attention to the pedagogical challenges of dominant positivist/instrumentalist pedagogies and their learning limitations emphasising that knowledge is never generated in isolation but is dependent on how the learner effectively receives and understands the knowing. Indeed, there is resistance to the assumption that education is just about producing a scientific workforce. Commentators on art-science, creativity, process pedagogy, and learning continue to argue against the marginalisation of some students towards a consideration of the idea of 'science-linked identities' [10]. They argue for the removal of subject borders [11, 12]. Given the agency of digital culture, and the way young learners both effectively [13] and cognitively access visual reasoning visual representations are now considered a significant cognitive tool both effectively [13] and cognitively access visual reasoning is now considered a significant cognitive learning tool [14]. The siloed nature of the curriculum and the de-imagination of learning occurring in neoliberal education simply performs the task of using education to train workers for service sector jobs and to be cultural consumers with the rhetoric of being able to straddle the development of self-knowledge and citizenship.

The second current arises from a philosophical and research shift that acknowledges the performative nature of learning that links subjectivity and autopoiesis to machinic ecology [15, 16]. Deleuze and Guattari [17, 18] speak to subjectivities and the multiplicity of ways in which we continuously connect our past and present in future orientations. These ways of knowing are always shifting in a process of learning and becoming. They reference autopoiesis which presents sensemaking or meaning-making in nature as a living machine, continuously replaced in pursuit of a self-referentially organised ecology for adaption [19]. For Guattari [20] autopoiesis operates within a machinic ecology which is greater than our biological being. It is an ensemble of conditions or a machinic assemblage where all the components are relationally and transversely connected. A machinic ecology is defined by Guattari [20] in his book 'The Three Ecologies' which speaks to 'a machinism that has technological, social, semiotic and axiological avatars' (p. 34). Contemporary communication, education, and culture are also identified in this dynamic ecology and rest on a relational ontology [21–23] that has no clear boundaries. Furthermore, it has shifted the emphasis in which language and communicative action have typically played a central role towards a performative approach that holds that truths, realities, knowledges, relationships, literacies, agency, and identities as performed in and through material-discursive practices [24]. Milovanovic and Medic-Simic [25] extend these ideas drawing on self-organisation in complex systems physics in their study of neuroaesthetics and artmaking, stating that contemporary art practices, with their postmodern aesthetics, consolidate both art and science. Commentators on Deleuze and art research present contemporary art as a practice that dwells in the transcategorical and transdisciplinary, or liminal spaces between historical and contemporary representational practices [26].

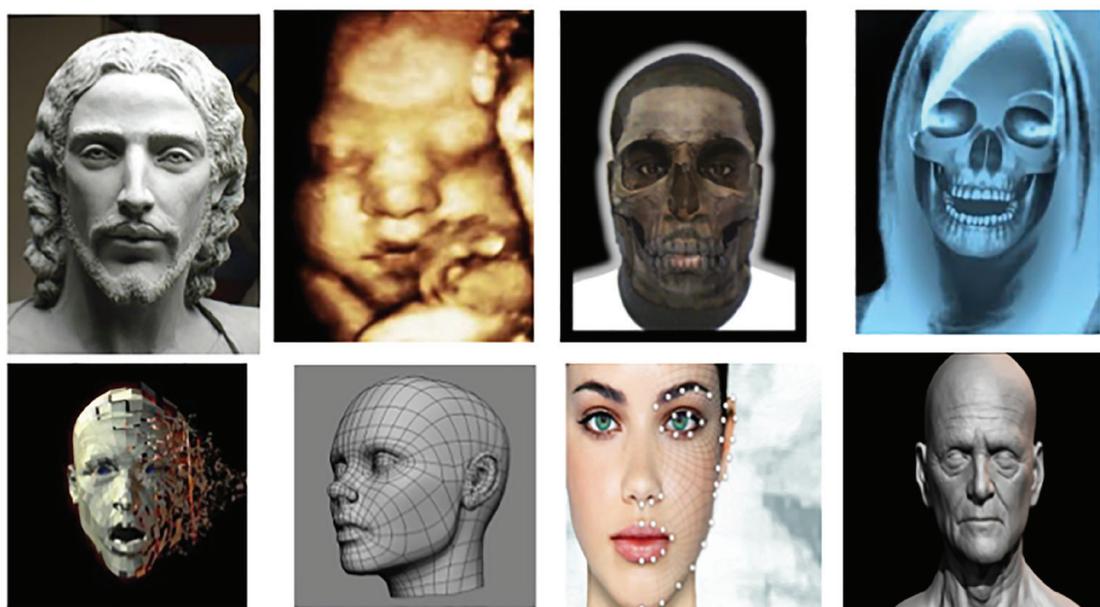
Acceptance of the cognitive and affective work images as meaning-making tools do in both the arts and sciences is required if we are to extend our current limited ideas on transdisciplinary learning. Images are used for visual observation as perceptual and experiential knowledge bridges and include representations, both material and virtual. Both art and science carry multiple common semiotic structures, such as diagrammatical and metaphorical practices which Root-Bernstein et al. [27], sees extends the correlation of thinking skills across art and science.

Art and science have always been close. The images in show how visual representations, across art and science, are historically, relationally, and transversely connected and codependent on the sociocultural and technological skills of the day. Driven by new media and communication imperatives, the representations of knowledge are increasingly digitally enhanced and open to fluid interpretations and uses. Visual communicative competency as sociocultural learning is now an essential skill across all disciplines and significantly in science [28, 29]. Pauwels [30] commenced the discussion around the unstable or interpretive nature of visual scientific communication, the processes and methods by which they are produced, and how scientific images, through their repeated copying, have been normalised as fixed across learning and communication contexts. She draws attention to the inscription, transcription, invention, and fabrication of scientific images across algorithmic and non-algorithmic representation practices such as the use of the camera or X-ray and the role of scientific illustration ([29], p. 149). These ideas have more recently been extended beyond the science of communication to science communication where writers seek to address questions about ontology, such as what is real or true, and how scientific ways of knowing or epistemological points of view or lenses are used to initially capture reality, and then how they are used by social media or the wider society for the communication of ideas [31].

The third consideration informs the first two considerations and is driven by the benefits of artified digitisation. Communication and learning are increasingly propelled forward by the new image-based economy with new knowledge in the sciences and arts increasingly conscious of the flow of signs and images destabilising knowledge [32]. All images are now aesthetically curated and culturally situated within social media. Dominated by the visual and its semiotic complexity, we are all participants as actors, producers, and consumers of information [33]. Digital online photo-sharing and videoing acts now creatively and intuitively connect all experiences and representational knowledge from all discipline fields. These images effectively trigger and connect content and contexts to individual learners [34].

Science education has traditionally focused on conceptual or factual understandings when using visual representations and less on visual representations as epistemic objects for scientific identity [35]. There is a renewed focus on how visualisation contributes to knowledge formation in science from the learners' perspective. It is acknowledged that epistemic representations as boundary objects are incomplete and precipitate an unfolding [36, 37]. Increasingly science educators seek to disrupt the currently accepted normalisation of scientific images as fixed truths or facts. Pauwels [29] asks the science educator or the observer to question what is revealed, obscured, included, or excluded, in these representations. She also asks that we pay attention to how scientific illustrators now readily adapt their images, reframe them for an increasingly wider audience, that of producers or consumers as represented in **Figures 1 and 2**.

Science educator-researchers have begun to respond to the shifting demands of new digital communicative and multimodal semiotic realities of the classroom



THE MATERIALITY OF THINGS: TAKES US BEYOND WORDS

Figure 1.
The materiality of things: Takes us beyond words (Grushka, 2019).

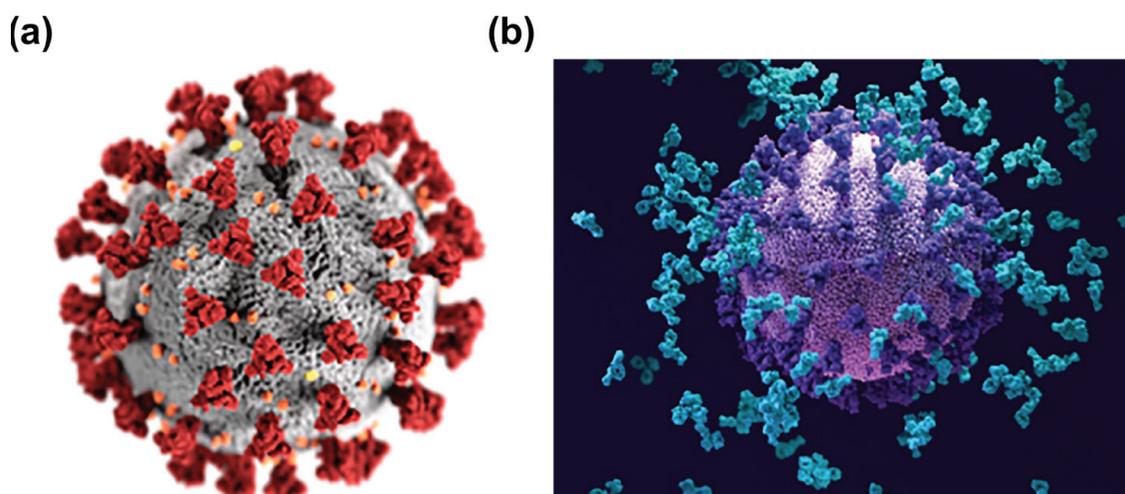


Figure 2.
Depictions of the COVID-19 virus.

learner. In doing so, they are identifying the limited visual literacy and visual communicative skills of their pre-service teachers [38]. Leßmöllmann and Gloning [39], arguing that there are indeed diverse communicative responses required when seeking to connect multiple relationships between scientific knowledge, audiences, and work. Scientific contemporary communication to the public can inform, influence, and even negotiate the science via new social media platforms. It is inevitable that the social and cultural realities of the world of work and the WWW will collide as the vast world of images and their performative and semiotic intersections cross all subject fields.

Transdisciplinary learning for knowledge production and as a communication enterprise is a process of semiosis. Semiosis is a sign or meaning-making process with a choice to select [40]. It is the continuous production, translation, and interpretation

across all societies of everyday signs. Human communication thus engages in dynamic relations formed by the human mind and its cultural artefacts [41, 42]. Semiosis is presented as an assemblage or bricolage of different semiotic codes used to build communicative coherence in the contemporary learning culture. It is increasingly identified as affective as we invest in the world via our intentionality, habits, and prejudices [43].

Scientific representations have entered mainstream media with normalising social and cultural traction, such as the COVID-19 virus.

The media-driven scientific culture acknowledges that the algorithmic image of COVID-19 is aesthetically enhanced through artful acts. In **Figure 2**, the SARS-CoV2 image describes the antibodies and is enhanced as light blue. It also acknowledges it as an artist's impression [44]. These images have intentional affective traction as contemporary scientific image makers use artful intuiting representations, such as colour to help in the communication of concepts, abstractions, aesthetic insights, and design orientations that seek to immediately bring forth 'effects' from the audience. These 'effects' can be passive or active and are dependent on an individual's 'seeing' within their personal, social, and cultural context. This seeing is shaped in part by epistemic insights and multiple learning contexts [45]. Such a shift in thinking about the work of scientific images in learning and understanding their knowledge complexity, their performative nature, and interpretive possibilities, is currently a pedagogical challenge as re-imagining transdisciplinary pedagogies and its assessment continues to prove difficult [38].

The concept of artification, as adaption is an important concept when considering the rapid speed with which images are created, modified, and communicated. Artification, emerged from the work of Dissanayake [46] which was deeply grounded in evolutionary anthropology and psychology. It presents art as behaviour and its verb is to artify. It has been subsequently re-set or redefined in contemporary discourse as a sociocultural process located in time and space [47, 48]. The processes of artification, as defined by Shapiro, within a post-positivist paradigm, carries the attributes of meaning which may include displacement, renaming, the shifting of categories, organisational and institutional change, functional differentiation, redefining time, legal consolidation, patronage, aesthetic formalisation and intellectualisation ([48], p. 267). These processes are not the limit of possibilities and Saito [47] argues that artification must maintain a critical stance if it is to promote new ways of thinking and doing. Ways of thinking and doing that promote creativity, imagination, spontaneity, passion, and innovation towards a re-imagining of learning that can break away from the use of normalised images, goal-centred planning, and text-dominated assessment in curriculum.

The concept of visual borderlands is the fourth and final concept and is presented as a new way of thinking as experimenting about relational and connective concepts in transdisciplinary learning. This has been a key finding of the art-science research previously reported and extended in this chapter. The concept foregrounds the productive and performative role of imaged learning identified by the researchers. Visual borderlands in learning are the liminal spaces that are ever-present when students work with images to represent their knowledge. By their very nature, images dwell between the borderlines of art and science and carry a relational aesthetic. Visual borderlands are fluid spaces where the historical representation practices, all now virtually accessible, can hold past knowledge that can all co-exist with new imaging acts. To give meaning and form to emergent concepts, artists and scientists alike draw heavily on metaphor because metaphor can support this indeterminacy when confronting new ideas. It is in these visual borderlands that the generation and communication of ideas in transdisciplinary learning are shared between students and with teachers.

Indeed, visual borderlands extend the earlier sociocultural claims by Mirzoeff [49] that vision and visuality would shape how we choose to see ourselves and others in the production of subjectivity. Visual borderlands and the skill of visuality, or critical visual literacy, have now spilled over to an educators' understanding of the way all young learners, 'capture' experiences, select images and concepts to be explored and communicated. These imaging acts are performative. In the processes of communicating their lives via mobile and digital devices they continuously engage in a process of image juxtaposition to explore 'the existence of the encompassed possible' ([50], p. 347). This student-centred learning is the core of visual art studio classrooms.

Visual borderlands identified in the research to date embed arts-based inquiry pedagogies with the affordances of a fusion of ideas and concepts from many knowledge areas, across the sciences, culture, and society. The skills developed in arts-based learning tolerate and are driven by the conceptual and visual communicative learning process. As identified, they operate at visual borderlands between arts and science, access other semiotic systems, and offer creative and personalised approaches to learning [51].

3. The inquiry into visual borderlands

The ethics-approved longitudinal inquiry looked at the artmaking practices of gifted secondary school students between the ages of 15 and 17 years ($n = 108$). The students were selected to participate in a first-year 2-D fine art course at an Australian regional university. The course focuses on visual reasoning, arts-based inquiry as a research [52–54]. Students were selected across a range of regional secondary schools.

Year	Regional secondary schools	Participating students
2015	4	20
2016	6	23
2017	5	21
2018	6	22
2019	7	22

Students were given the opportunity to do an individual arts-based research project where they take a personal problem-centred approach to their inquiry. Broadly, this inquiry focuses on the transdisciplinary meaning-making processes of young visual art students and how they approach and explore a scientific concept or phenomenon of choice, through arts-based research. Students have been selected by their art teachers, interviewed, and subsequently invited to enrol in the university course while concurrently doing their school studies. Students keenly accepted the challenge of the additional workload because generally, they saw learning through imaging acts as a preferred way to learn. The inquiry into the art-science learning in the gifted education program has run at the university from 2015 to 2019. The students draw on their school-based science learning and personal scientific interests, but drive their inquiry through individual troubling about self, art, the world, and their own expressive meaning-making processes. This chapter draws on the work previously done on visual borderlands [1] and considers how performative artification operates in the works of two students, Charlotte and Aynsley. They are two of the gifted visualisers.

The inquiry *applies a* Deleuzoguattarian lens and draws on arts-informed qualitative inquiry research methods [55, 56]. It presents the learning as material, non-linear, non-hierarchical, unstable, shifting, mobile, and multiple forms of knowledge [57–59]. The data sources informing the inquiry include the student artworks, their visual diaries as performative sites, student surveys as reflective insights, student focus group interviews, and audience survey feedback collected at each final exhibition. In this chapter, consideration is given to how students engage at subject borders between self, art, science, and their broader sociocultural world. In particular, it will consider how the students traverse the boundaries between arts and science, how they draw on different artistic and scientific representations and apply visual semiotic and artfied pedagogies.

3.1 Visual borderlands as artfied assemblages: Charlotte and Ansley

This section explores the intersections between the student artefacts from the arts-informed interpretive inquiry and embeds the concepts from the literature in seeking to extend the definition of visual borderlands as a liminal art-science trans-disciplinary meaning-making space. This lens brings to bear the shifts in thinking about what constitutes a learner's scientific identity amplifying the voices around the semiotic work that folds across learning assemblages in both visual education and science learning. The analysis looks at Aynsley and Charlotte's personal inquiry into their selected scientific phenomenon. It considers their unique problem-centred learning processes identified in the artefact analysis. These artefacts provide glimpses into the students' ideation and incorporeal thinking which Deleuze describes as the process which is indivisible, and ideation brings forth effects transferred into their artmaking. It will look at connections to past and present semiotic meanings with consideration of their future-oriented subjectivities at the boundaries between arts and science.

3.1.1 Aynsley

The work of Ansley connects us immediately to the world of entomology. A study of her final drawing below pulls an audience into considering the connections and relationships between humans and insects. Is the question she wishes the audience to ask or to consider, the evolutionary, ecological, and biodiversity issues that face humanity? Where does this question sit, in science or sociocultural inquiry? Will the evidence offer opportunities to consider what a contemporary learning culture of the science classroom might look like?

Aynsley's artist statement below sees her dwell on issues of vulnerability for humanity, the world of living things, and the environment.

My study demonstrates the relationship of art verses science through the study of entomology...combining butterflies and the human form. As an artist my goal was to express the unique nature and vulnerability of each and everyone of us...these artworks symbolise beauty and how it defines us. We are all equal... it shows how people can interpret beauty in different ways.... For some, the wings could be the focus point and others would believe the eyes capture the viewers opinion on appearance (Aynsley: Artist Statement, 2018).

For Aynsley, there appears to be no separation between humanity and nature, no species hierarchy, all be this is not clearly articulated in her artist statement, but

possibly implied by their juxtaposition. She states clearly that human and butterflies are equally vulnerable. Her intertwining of the butterfly and the human eye is bound by the aesthetic materiality and affective rendering of the wings and eye towards an aesthetic likeness, or possible oneness (**Figure 3**). The observer can see in her diary entries, displayed as an assemblage created by the researcher (**Figure 4**), that she follows some of the fundamental non-algorithmic scientific observational and experimental methods, such as species identification and classification of insects called lepidoptera, butterflies and moths and drawing as illustration. The processes of artification displayed could be seen as a re-classification, or shifting of classification [48] as she experiments and adapts her drawings. She does demonstrate a strong perceptual bias towards established historical drawing techniques and formal design attributes in her representation of the butterfly and the eye, but it is accompanied by a process of visual editing and manipulation as she worked towards her goal 'to express the unique nature and vulnerability of each and everyone of us'.



Figure 3.
Aynsley artwork, butterfly eyes (2017), drawing.

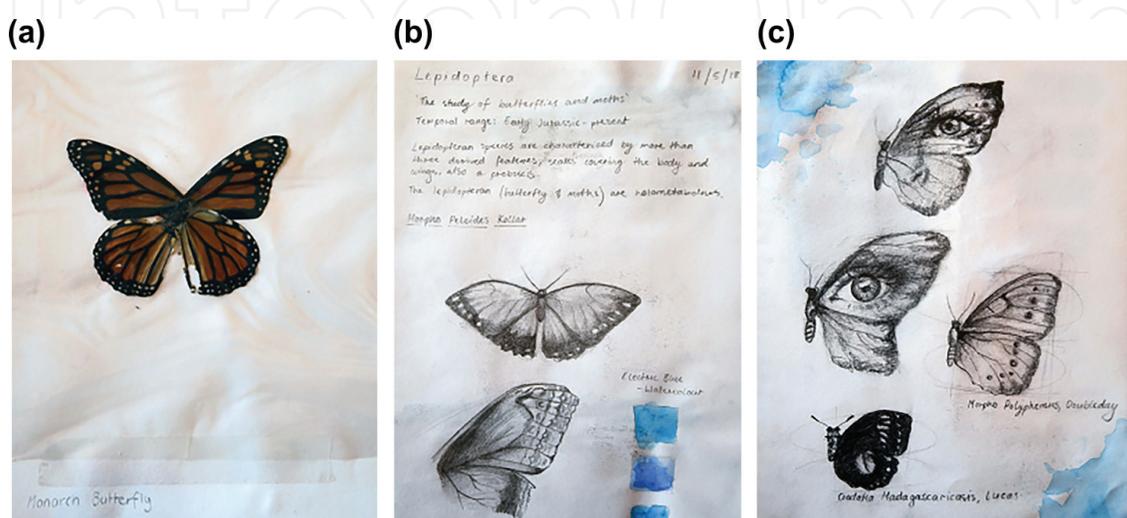


Figure 4.
Visual process learning An assemblage.

Her artfied behaviours find her commencing her inquiry with a real photographic representation of the butterfly (a) she has selected to draw (b). Page 2 of **Figure 4** sees her create a descriptive illustration of the species following the formal humanist art traditions and using the scientific process of labelling or categorising. However, there is an emergent new space, a liminal space where there is the possibility of a re-classification as seen in the image on the right (c) of **Figure 4** or a re-grounding of her subjectivity [57]. Aynsley speaks to the possible interpretive lenses of the viewers, some seeing an insect, others seeing a human. Aynsley, however, has created a new resemblance of difference, a possible de-centering of the traditional humanist-centred world. It speaks to a new generation of youth who are aware of the planet and species vulnerabilities and as such Aynsley's transdisciplinary study may speak to the 'disidentification from established patterns of thought (which) is crucial for an ethics and politics of inquiry that demands respect for the complexities of the real-life world we are living in' ([57], p. 16).

3.1.2 Charlotte

Charlotte, like Aynsley, embeds artfied visual representation behaviours that could be seen as informed by both algorithmic representations, brain scans, and mixed media conceptualisations in her installation. Reading from left to right of her installation in **Figure 5** we see the set of three painted artworks that illustrate stages of imbalance or disease states in the human brain. The inquiry is related to psychological and emotional well-being from a healthy brain towards a brain in an imbalance, the result of neglect. In front of her paintings are three plinths with a plant pot on top. Each pot carries a resemblance of brain neglect through the analogy of plant growth. Charlotte literally speaks to her performance of neglect in her artist statement.

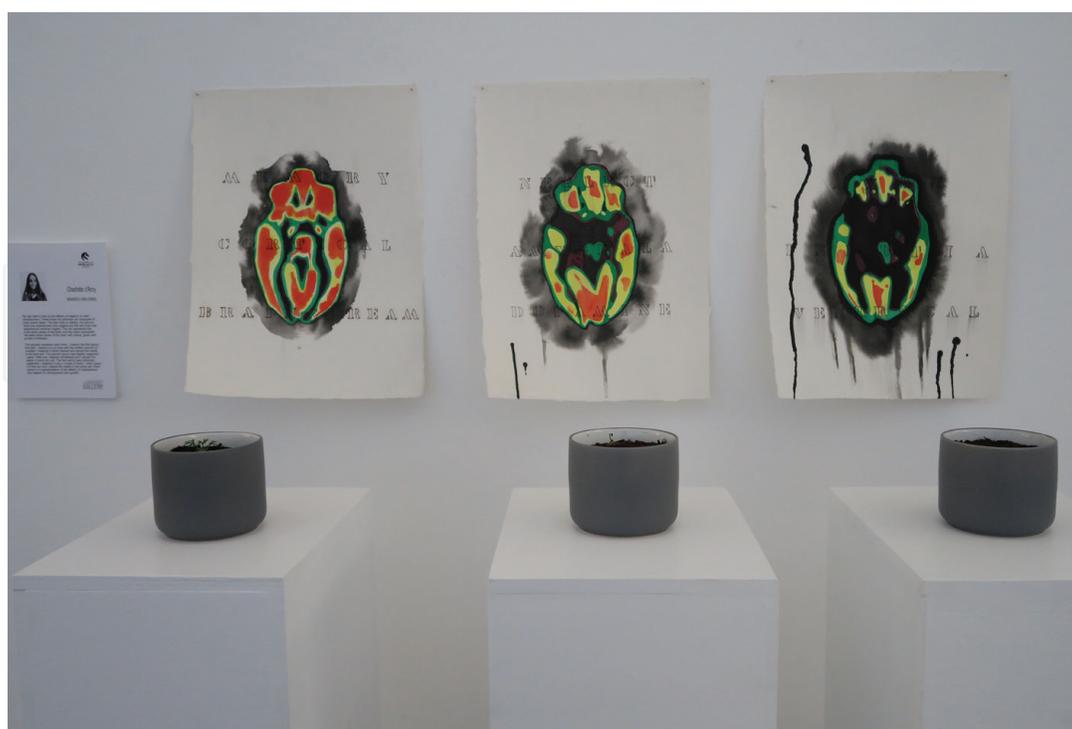


Figure 5. *Memory, Cortical, Brain.* Art installation comprising three mixed media ink and printed drawings accompanied by three plants in pots (Charlotte, 2017).

My aim was to look at the effects of neglect on brain development... examples of brain scans... The first brain is healthy, the second brain has experienced mild neglect and the last brain has experienced extreme neglect. The red represents the most active areas of the brain and the black represents the least active areas of the brain with yellow, green and purple in-between.

The sprouts represent each brain. I treated the first sprout the best. I placed it in an area with the perfect amount of sunlight, I watered it when needed and placed the seeds in the best soil.... The last sprout was extremely neglected. I watered it only a couple of times, I didn't place it in the sun, and I placed the seeds in the worst soil. (Artist's Statement, 2018)

In **Figure 6**, two pages from Charlotte's visual diary are displayed. She draws heavily from the scientific epistemic insights and the comparative study of each brain state.

It contains a strong observational focus with an effective and personalised perspective as she considers the implications of neglect on the individual and society. In addition, you can see her actively bringing together scientific emergent evidence, concepts, and visual communicative ideas. At the interview Charlotte revealed that loved ones surrounding her worked as mental health professionals, so she was both aware of mental health issues and the social consequences of neglect.

Being a critical self-reflective visual art student requires that one writes about one's artmaking in process, critically reflects on both one's intentionality and the emergent artwork. This is a continuous process as concepts emerge in progress and must be constantly re-assessed for their potential interpretive outcomes such as those formulated in an artist statement that is specifically for an audience. In the fine art course studied by both Aynsley and Charlotte these material artefacts are measures of the summative assessment course components. So, it was gratifying to be able to see audience statements that confirmed the scientific, social, conceptual, and communicative goals of Charlotte:

The effects of neglect on the brain – Charlotte: I like the contrast between the paintings themselves and the paintings and sprouts to illustrate the impact of neglect on the brain. I think the artwork very successfully conveys its theme and purpose (Audience survey, 2018).

Making artworks, describing processes and practices, engaging in critical self-reflective acts through performative subject/object engagements are core in visual art education pedagogies.

There are similarities and differences between both Aynsley and Charlotte's artworks. Both appear to have started from the position of a school taught deductive scientific investigative approach, gathering facts and visual evidence surrounding their inquiry towards a reasoned and logical conclusion. In Charlotte's research, she goes directly to algorithmic digital evidence and uses accessible scans of the brain as her starting point as she seeks evidence of brain deterioration related to psychological states in humans. Of course, there are limitations or conditions to the validity of her accessed images [60], given that they may have already gone through an artification process prior to accessibility via the web. However, the images are sufficient to allow Charlotte to commence her thinking as an experiment. Aynsley commences her

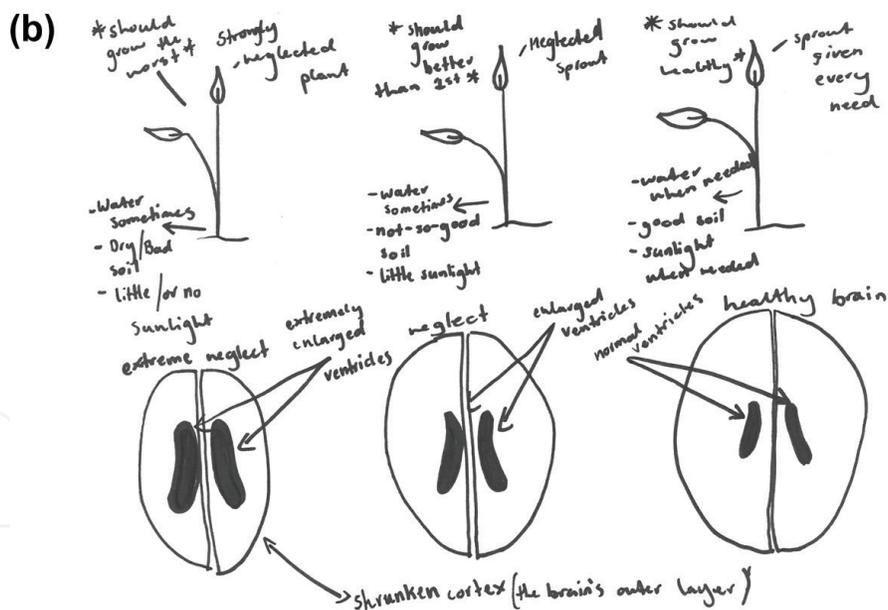
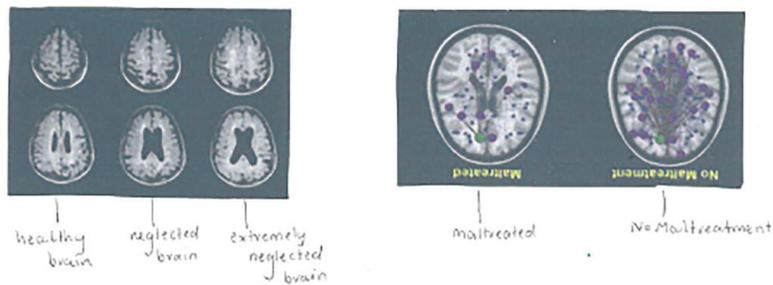
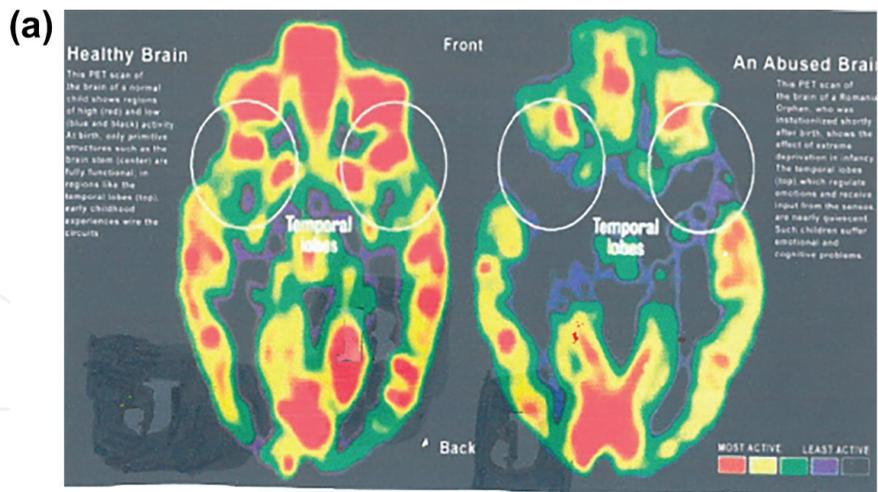


Figure 6.
Visual process learning diary page entries.

investigation through the processes of image development and refinement in line with non-algorithmic methods, such as scientific illustration. Aynsley performs her own perceptual and sensory artification when drawing her butterfly. From the outset, her research is a process of knowing-in-being [24]. Both the investigative processual approaches of Charlotte and Aynsley bring into play the need to understand that a more nuanced conceptualisation and empirical operationalisation of materiality in communication, learning, and education needs to be considered.

4. Discussion: transdisciplinary artification in visual borderlands

This section is a discussion about the students learning gathered from 2015 to 2019. All student learning was seen to embody a crossing of the borders between their scientific and artful inquiry lenses. Their artworks can be described as, being visual borderlands, occupied by signs from across our socio-semiotic world. In these spaces, the signs from different epistemologies intersect or intertwine as the students make links from their different lifeworlds. From informal learning to their school formal learning, they draw on personal experiences and the vast world of digital media. This has been a key finding of the longitudinal inquiry and audience responses to each exhibition, all spoke to being able to see both art and science learning. In this chapter, one of the key research findings is that artified visual pedagogies can both transverse and/or facilitate meaning-making across art-science spaces. Visual borderlands are the spaces occupied by the adaptive process of artification. Artification enables the students to embed the traditional humanist world of perception, observation, and illustration with the contemporary algorithmic world of curated digital scientific images. Both can be combined via different pedagogical practices from different subject fields, and as they combine, new ways of thinking and doing emerge to answer real-world inquiry questions.

These key findings are exemplified through the artefactual evidence of both Aynsley and Charlotte. It presents the concept of transdisciplinary visual borderlands learning, and it is argued that the examples presented in this chapter are evidence of how artification processes fit within a transdisciplinary learning construct. A construct where students apply two or more knowledge and skill areas to support their inquiry. The learning experiences have been interpreted by the researcher as being spaces that extend the experience to an encounter with being as becoming, to self as 'different social formations through very different assemblages, both artistic and scientific. This can be understood as knowing-in-being when learning in a transdisciplinary space. All learning carries transformational potential that is deeply embedded in the personal and 'consists in genuine learning from signs in the folding experience' ([61], p. 116). It entails folding acts that for Aynsley commence from the inside as embodied or dependent of percepts and affects [17] which are then folded with scientific understandings from the outside. Charlotte commenced from events in the personal, but her learning as an experiment commenced through the gathering of outward or scientific evidence which she subsequently folded on the inside in the formation of her own concepts grounded in her unique lifeworld experiences. The learning journeys of both are made up of expressive and shifting knowledge relationships. It is possible to see how both Charlotte and Aynsley take on ideas about the world and humanity and fold them deeply into their own sense of self; beyond being a visual art student to the consideration of a science-linked identity [10].

The learning artefacts of Aynsley and Charlotte are entwined with both traditional dichotomies of art/science, nature/culture, natural/artificial, incorporeality/materiality, subjectivity/objectivity, sense/effect, or body/thought and all collide in the performing of their unique learning. Importantly, all of these dichotomies can potentially disassemble and realign, as they intersect and intertwine as a new learning assemblage. Within an arts-based research paradigm, Aynsley and Charlotte were permitted to re-imagine how to learn, to de-territorise the art-science dichotomy. It is not as a crossing over from art to science or vice versa, but an opening up of liminal border assemblages full of possibilities. Indeed, no

science was taught at all by the fine art lecturer with an assessment brief to consider only the development of visual artmaking skills and the clarity of the student conceptual visual communication. This left any scientific inquiry to be driven by the student's past learning about reasoning in and through scientific imaging acts and they were free to imagine any assemblage of a combination of sign systems that best communicated their learning and ideas to an audience. Indeed, some students who had traditionally rejected the sciences were surprised by how much science they had actually learnt.

Beyond the key finding, that contemporary transdisciplinary art-science learning occurs at visual borderlands that facilitate the adaptive process of artification was the identification within the research that:

Science communication is now a significant field of research for science educators and that the artistic visual skills it embeds need to be considered by teachers when requiring students to represent their learning in the digital age.

Ways of knowing in science education must address the communicative goals of scientific images and teach students that all images are created for a particular audience. In so doing they teach students that the world of scientific images is indeed open to interpretation.

Learning emergent in visual borderlands is made up of different assemblages with a range of concepts and forms, dependent on the life world and perceptual focus of the student. The world of signs occupies these spaces and all images within this space are fluid. Each observer (student or teacher) will find new and unique connections or interpretations when they encounter the signs generated in learning.

Artification occurs in-knowledge generation and transversely operates across the visual borderlands of transdisciplinary knowledge. This is true for both visual socio-cultural communication as it is for scientific communication.

Transdisciplinary learning is a place where the semiotic and cognitive work of image construction is now centred. Transdisciplinary learning disassembles epistemic boundaries or de-territorises knowledge and allows the imagination to enter all reasoning as science education is increasingly transformed by artified scientific media communication. This argument does not diminish the significant fundamental knowledge learnt within visual art education. Visual art education is a unique form of material knowing and communication. Its contemporary pedagogies reside within a post-structural understanding of knowledge construction offering insights into how the imagination and material knowing are active in personal meaning-making.

Science educators must now engage with the idea that visual reasoning as performative action is now the connecting pedagogy in all epistemic fields. The phenomena of fluid and online visual media communicative practices in youth today should be triggering for educationalists in these COVID times that the new consumption rituals for learning are being re-shaped by multiple manipulations and applications of imaged technologies. The visual habits of knowledge acquisition and production for concepts and communication increasingly contain unique perceptions, affectively, aesthetically, and spontaneously communicated as imaging actions. Art is now being presented as not subject to epistemological boundaries but requiring an expanded ontology [25]. The challenge that now faces teachers wishing to pursue transdisciplinary learning in their schools is that the world of assessment still essentially resides in an outcomes-driven curriculum, which embeds goal-centred planning, normalized images, and text-dominated assessment in the curriculum. This is a focus of future research with teachers.

5. Final considerations

This chapter argues that visual reasoning (both material and digital) as performative action is now the connecting pedagogy in all epistemic fields. Its artfied visual pedagogies can both transverse and/or facilitate meaning-making across art-science visual material and media borderlands in the creation of transdisciplinary 'science-linked identities' [10]. Science educators must now engage with the idea that current education dogma and policy gives significant value to vocational and science, technology, engineering, and mathematics (STEM) education over the significant contribution of the arts and all their expressive and communicative forms. Its policy rhetoric speaks to creativity and transdisciplinary futures without acknowledging the non-linear, non-hierarchical, unstable, shifting, and mobile ways knowledge emerges today within both contemporary visual communication and science education.

There is a new science communication project being driven out by a recognition of the multiple lenses through which scientific images are created, interpreted, and communicated across expanding audiences and into popular digital media. Science learning requires a shift away from the objectivist learning position to a space that reconnects the world of signs beyond disciplinary boundaries [61]. This is also true of discipline boundaries within science education. It is images that infiltrate all epistemic fields of knowledge, and the work of images is capable of making the connections across and towards new knowledge constructs. The art-science inquiry on how gifted visualisers encountered and communicated their learning cross semiotic epistemological boundaries in this chapter demonstrates student capacities to use the world of images and be imaginative knowledge generators. Awareness of the complexity of images and their role in learning, assessment, and communication in science now speaks to the skill of visual performative competency where students are scientific, critical, and imaginative thinkers and communicators.

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