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New Visuality in Art/Science: A Pedagogy of Connection for Cognitive Growth and Creativity

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ABSTRACT

New visuality in art/science pedagogies challenges teachers to rethink their curriculum and the role of digital new media in facilitating conceptual thinking and the role of the creative representation of knowledge. Recent neuroscientific research on cognition, perception, memory, and emotion inform and provoke implications for 21st-century learning. Analysis of student artwork uncovers pedagogical challenges for teachers. Teachers use visual learning and its forms of higher process thinking to allow students to make cognitive connections with images, giving them the capacity to integrate concepts for the communication of art/science learning. Examples of student learning from years 3–5 and 15–17 illustrate these ideas.

Introduction

Digital new media has reshaped how we communicate knowledge of the social, cultural, and natural world and occupies one of the strongest voices in pedagogy today. Learning is now enhanced by multimodal, interactive, technology-mediated platforms. Simultaneously, visual cultures central to new media and visual cognition in learning continue to be a marginalized pedagogy for teachers, yet they increasingly occupy the interdisciplinary learning spaces students prefer and access. This paper seeks to provoke new ideas about the contribution of visual learning and its forms of communication at the intersection of the sciences and visual arts. Digital visual pedagogies and research emerging from neuroscience challenge educators to engage with the cognitive work of images as they provoke new understandings about perception, cognition, memory, and emotion, and engage with the implications this has for treating students as unique, embodied, and enactive learners. The research presents findings from two projects: a study of early childhood visual digital learners in the UK, and an Australian study on fine art studio learning for high-performing 15- to 17-year-old students who engage with art and science visual cultures through material and digital ways of knowing in a university context. The findings challenge assumptions about art/science visual learning and invite discussion about the opportunities to engage with new visuality in curriculum spaces.

New visuality and interdisciplinary border crossing

New visuality embeds material and digital visuality and has appeared largely as a result of the digital revolution. It encompasses all visual epistemologies, their historical antecedents, and our imaged contemporary world. The new visuality is understood to refer to the diverse means of visual representation.

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The definition encompasses the cognitive and physical aspects that have common ground in relation to the representation and interpretation of visual artifacts across disciplines such as art, science, literature, and politics (Grushka, 2010). It acknowledges that images are integral, not only to the dissemination of scientific knowledge but also to cognitive learning processes that are used to build that knowledge (Kolijn, 2013; Pauwels, 2005; Tversky, 2015), and as such, it is a skill to develop in all students (Grushka & Donnelly, 2010).

New visuality, argued in this paper, foregrounds the inadequacy of dominant linguistic semiotics in learning and the significant contribution of visual semiotic forms (Jappy, 2013; Jay, 1996; Nöth, 2011). Visual semiotics is not an extension of linguistic semiotics. Visual expression reflects underlying brain structures that will be represented in the image, and therefore understanding the image and the functioning of the brain are complementary pursuits (Stafford, 2007, 2011; Zeki, 1999, 2001). This is supported by neuroscientific investigation, that higher order cognitive functioning is not linguistically dependent nor, for that matter, is it visually dependent (Knauff, 2013; Stafford, 2007, 2011), drawing meaning from all modalities. Both scientists and artists prove capable of extended abstract thought albeit in accord with the symbol systems with which they are familiar (Kozhevnikov, 2015). With the increasing preference for video and digital imagery as the representational choice of mobile device users, there appears to be an increasingly pressing need for a critical evaluation, or redefinition, of literacy as embracing the visual (imagery and movement) as well as the semantic-linguistic (Cope & Kalantzis, 2000; Grushka, Donnelly, & Clement, 2014; Tversky, 2015). Interest in the image extends across disciplines with each discipline interpreting the epistemic function of the image within its own disciplinary assumptions (Barbousas, 2014; Jay, 1996). Art-science interest in visuality noted by Jay and Barbousas suggests that the spaces occupied by images provide a unique opportunity for learning at interdisciplinary boundaries. Dillon (2006, 2008) and Akkerman and Bakker (Akkerman, 2011; Akkerman & Bakker, 2011) argue that boundaries indeed present creative opportunities for learning by employing the new visuality as a pedagogy of connection.

The emergence of the scientific digital visuality skill is shifting traditional ideas about "right depiction" or truth in scientific illustration to accommodate ideas of presentation as an aesthetic fusion between artifacts and natural phenomenon. The representation of DNA strands using nanotechnology employs aesthetic design elements as "enhancements to clarify, persuade, please—and sometimes, sell" (Daston & Gailson, 2007, p. 412). This shift in our understanding of the role of scientific imagery has direct implications for student learning both within the learning process and the representation of their meaning making. Students too can now manipulate visual images and new forms of creativity, expression, and representation in communication and so influence the way that meaning is made and expressed, challenging the dominance of linguistic representations and adding weight to the function of visuality in knowledge creation (Dinham et al., 2007; Grushka, 2010).

Contemporary learning ecologies

Contemporary learning ecologies shift us from an understanding of closed classrooms to environments that offer multiple learning spaces where students express ideas and make meaning through complex relationships and experiences (Muscovitz, 2013). Learning ecologies are heavily situated, relational, and increasingly reliant on multimedia digital devices opening informal learning opportunities, the capacities and proliferation of which offer new possibilities for learning (Grushka et al., 2014). With learning ecologies undergoing continual adaptation, we need to be reminded that human learning is a consequence of and dependent upon context. It is also dependent on the sensory biological nature of the species because learning is modified by interaction with the environment (Diamond, 2007, 2009), albeit increasingly via new media technologies.

Figure 1, the work of five-year-old Mahmud (pseudonym), shows a sophisticated use of the camera as a tool to capture a concrete visual representation from his perspective. This reveals his relationship with the environment, with self at the center, and offers us insight into how the digital camera allows for visuo-spatial interaction, seen as provoking an emotion of anticipation through the acute representation of the slide's angle.

Figure 1 A five-year old's digital interpretation of a playground experience.

In Figure 2, "Inter Connection," Harley, a student in the High-Performing Student Program, describes his work as a connection between different human anatomies, from small microscopic anatomies to large bone structures. He is interested in how to represent and express the phenomena of networked body flows as he combines his digital imaging with his drawing. In Harley's published artist statement, he talks about how his artwork draws on graphic design, how X-rays of human structures and stenciling techniques are layered, and how over time different "satisfying" experiences saw his concepts "altered and changed" in his quest to represent the "perfect flow."

Reflecting on both images, we find support for the idea that the accumulation of education experiences sculpts the brain (Suzcs & Goswami, 2007) and what we pay attention to drives cognition, affect, and memory (Dolcos, Katsumi, Denkova, & Dolcos, 2017, Phelps, 2006), with the arts building creative reasoning through its higher process thinking (Willis, 2013). Teachers hold the capacity to expand or limit learning according to the presence of new visuality as a valid pedagogy. Too often students are required to learn through the dominant text-based literacy and numeracy and value facts and data over the creative integration of ideas (Diaz & McKenna, 2017). Such an approach can lead to a failure to acknowledge personal learning styles, the aesthetic, and the affective when encountering new learning moments with students. Though we all have similar brains, we carry unique experiences along with individual perceptual, learning, and representational preferences. Zeki (2014), drawing on neuroscience and

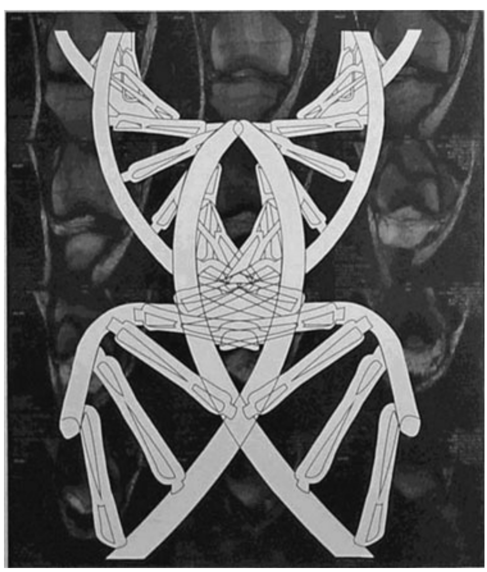

Figure 2 *Inter Connection* (Digital Photography).

learning theory, identifies the primacy of subjective learning truths present in the sciences, philosophy, and the humanities. The failure to give relational attention to scientific reasoning and the embodied selves underpins Iain McGilchrist's book *The Master and the Emissary* (2009). He argues that this failure gives emphasis to scientific materialism (p. 299) and systematic conformity. This position is evidenced in education through the rise of curriculum models that silo knowledge, educational standards, global testing, and the demise of arts courses across all educational sectors.

Simultaneously, the rise and ubiquity of handheld digital devices such as the mobile phone and tablets now profoundly impact learning. Handheld devices, as our cyborg memory, free us from our previous dependency on remembered facts and numbers and we can easily link to associated conceptual relationships via the web (Grushka et al., 2014). Digital images produced with our handheld mobile devices can now be described as a personal meaning-making and communication tool. Digital images are now a global, historical, cultural, and material phenomenon and an increasingly preferred way of communication. Extended text is falling aside, replaced by the selfie or short video images on Facebook or Instagram.

Reasoning with art/science pedagogies

Underpinning this research project are two fields of endeavor, philosophy and neuroscience, and their ideas on cognition and learning affecting how students represent art/science concepts. This project focuses on the philosophical work of Gilles Deleuze and Felix Guattari and their educational commentators that posit the idea that artistic and aesthetic insight resides in all experience and informs all learning through affect, percepts, and concepts (Deleuze & Guattari, 1987). Therefore, learning is generated as a dynamic inquiry that is "experimental and embedded in experience" (Semetsky, 2009, p. 443). The evaluation of experience and making and remaking of concepts brings forth creative insights as learning. Learning requires positive and active forces that bring forth facts and expressive processes. Facts and expressive processes are required when seeking ways to imagine and image epistemic representations. Both art and science engage in the re-imagining and representation of concepts, and both learning cultures draw on the visual to both reason and represent their phenomena of inquiry (Pauwels, 2006).

In addition, neuroscience posits that all brains are biologically similar, each requiring attention, perceptual focus, and affective response to trigger cognition, memory, and learning. Zeki (2014) argues that artistic and scientific questions are similar and evolve from experience, memory, and learning. Both are subjective in nature but are approached or reasoned differently according to a preferred epistemological preference. Concepts evolve in unique ways according to an individual's experiences, as well as perceptual and observational orientations. The uniqueness of individual experiences and perceptual orientations makes any claim that there are fixed ways to represent the knowledge of both art and science an impossible proposition. However, there may well be cognitive and learning benefits to be had if teachers are sympathetic to the historical representational cultures of the arts and sciences. The "sameness and continuity" in the historical cultures of reasoning and representation suggested by Akkerman and Bakker (2011, p. 133) could be argued as an entrée for visuality as a significant means of imagining and imaging new concepts in student learning. The literature underpinning this paper offers educational researchers interested in studying how knowledge crosses art/science curriculum boundaries four areas to consider: visual observation, visual representation, image as metaphor, and aesthetics.

Visual observation

Kolijn (2013) pinpoints observation as a bridge to cognitive recall, which together with text, has been instrumental in the communication of scientific information (Pauwels, 2005a, 2005b). Kolijn suggests that the arts and sciences branch according to how they approach the phenomenon being observed. He claims the sciences "reveal and explain our reality" (p. 597) and are subject to representational protocols, with the arts being more expressive with less rigorous reasoning protocols. This differentiation of apparent reasoning styles has been challenged by Daston (2008). He argues that notions of the positivist quest for neutrality of observation or objective inquiry are no longer sustainable in scientific communities. It is therefore more appropriate to inquire "into the *ontology* of scientific observation: how expert observation discerns and stabilizes scientific objects for a community of researchers" (p. 98).

Artistic observation also seeks to stabilize an object, but artistic representations have an interpretive cultural practice that is subjected to critical interrogation. Meanings represented in artworks are therefore interpretive, less bound by epistemic representational norms, with artists free to adapt representations or symbolic forms to support their inquiry. Daston (2008) also claims that many of the selected representations of both artists and scientists in contemporary society draw on the expanding range of digital imaging tools, from X-ray to nanotechnology, and one that students increasingly use to reason about their art/science phenomena.

Visual representation

Visual representation is essential to scientific discourse and goes beyond the replication of nature, harnessing the full range of visual semiotic practices accessible to the visual arts (Ambrosio, 2014; Prain & Tytler, 2013). Scientific visual representations may include visual or nonvisual phenomena, including graphs, diagrams, or models. Visual semiotic forms are not an extension of linguistic systems (Jappy, 2013; Jay, 1996; Nöth, 2011). Scientific representations employ visuo-spatial modeling together with aesthetic decisions when determining which image best communicates an idea or concept. Representation will always involve the negotiation of both epistemic and ontological dimensions (Daston, 2014). Cognition is visually dependent, complementing all other modalities. Visual cognition is applied when students opt to boundary cross between an expressive, technological, or graphic form of generated image.

Visual metaphor

Visual metaphor provides a non-figural mode of representation, used in both the arts and sciences for representing, interpreting, and explaining phenomena in the world (Wilson, 2014; Wilson, Hawkins, & Sim, 2015). Metaphors "help scientists, artists and other practitioners to link experience, intuition and imagination when erecting conceptual scaffolding" when literal language proves inadequate (Wilson et al., 2015, p. 155). Metaphors are core agents in developing new conceptual models and used when bridging creative ideas and new concepts (Dillon, 2006; Jones & Galison, 2014; Koenig, 2015; Leach, 2012; Wilson, 2014; Wilson et al., 2015). It is metaphor that takes us back out of the system of science to primary experience, embodied experience, and links the self through symbolic reasoning (Deakin-Crick & Grushka, 2009).

Aesthetics

Questions of aesthetics are relevant in relation to science as well as the arts (Daston & Galison, 2007; Wilson et al., 2015). Chatterjee and Vartanian (2014) identify that aesthetic experiences, whether of emotion-valuation or sensory motor in nature, are widely distributed across the brain and co-opted to support individuals' knowledge-meaning system. Root-Bernstein, Siler, Brown, and Snelson (2011) note that the arts don't just make science pretty or technology more aesthetic, they often make both possible because the arts provide innovations through analogies, models, skills, structures, techniques, methods, and knowledge that support other disciplines' ways of representing phenomenon. Both the arts and sciences require divergent thinking for innovation, and both require aesthetic and metaphoric tools for their cognitive endeavors although they function within the framework of each discipline.

Digital imaging technologies for learning: Two studies illustrated

To illustrate the importance of digital imaging to contemporary learning ecologies and reasoning, two studies have been selected that reveal how the digital camera, and the images it processes, can be used as cognitive tools in the investigation of holistic real-world phenomena for learning.

Study one: How children aged 3–6 use a digital camera to make meaning in their world

The first study is an innovative UK research project that reveals how personal visual and aesthetic perception informs the emergence of conceptual knowledge in an early childhood setting. The research was based in a public school in Tower Hamlets, London. The school had three quarters of pupils with

Figure 3 Umar's set of photographs.

English as an additional language, two thirds eligible for pupil premium (financial support), and most were from minority ethnic groups. The study examined the decision-making of 3- to 6-year-olds when using a digital camera without any instruction or guidance from a teacher. No instructions were provided to the students by the researcher. They were given complete freedom to use the camera for as long as they wanted and to capture images that fascinated them.

Four-year-old Umar (pseudonym) only took five photographs in total, in the space of about three minutes (see Figure 3). The photographs were all centered on circles in his set of images, yet when asked about his photographs he was drawn to the one of "mud with water" as his favorite, pointing out, "it's all dark." This image still captures an element of "roundness" and in some ways is the most abstract one he took.

The choice to describe the phenomena of focus using aesthetic descriptors "it's all dark" reminds us of how important multi-sensorial experiences are for children. In this case, Umar was able to tell us this by rendering the experience important enough for a picture. In fact, his photographs as a complete chronological set fulfill this purpose. Umar used the camera as a tool to communicate something personally significant and also as a record of his learning in that moment. The digital camera allows the student to engage autonomously and spontaneously with the environment and actively make decisions about what to represent to others.

All experience constitutes learning and all representations are a combination of modalities and media. Digital technologies translate the material and sensory experiences into virtual images and, when employed, mirror neural processes, as stimulus captured by our multiple sensory modes is internalized via perception, emotion, cognition, and memory work. In turn, these trigger a reaction or action with the external world. Learning employs the interplay between our observations and experience of our natural and mediated world with our sensory reactions to produce new external representations. Learning and communicating through images reflects these underlying brain structures, and therefore, understanding the image and the functioning of the brain are complementary pursuits (Stafford, 2007, 2011; Zeki, 2001, 2014).

Umar's active decision-making about what to select and what to reject in his images speaks to the communicative power of images. He showed little concern for capturing people, or anything that represented his relationships, but used the camera to aesthetically explore his environment and did so with great sophistication. He quickly developed a "theme" for his images, deciding what he was drawn to and then continuing his search for images that fit this visual concept. Umar's photographs not only offer us insight into his perspective on the world or his interests; more important, they inform us that children, even at the age of four, are capable of refining their own concepts (in this case, using digital photography) when pursuing a chosen phenomena (in this case, circles) without adult direction.

Allowing children to realize this through their own experience is essential; Umar would not have had this learning experience if an adult had instructed him in how to use the camera, or guided him in what to take photographs of. Essentially, the camera gave him a voice because he was able to make this discovery himself. Umar's set of photographs demonstrates the incredible level of creative representation that can take place when children are given an empowering tool that enables them to directly engage with the world, especially at an age where writing or speech is less able to fulfill this role. The findings of this study act as a successful example of phenomena-based, self-directed, and personal learning with the student commencing their investigation through aesthetic visual cues.

Study two: The high achievers art/science learning project

The High-Performing Students Program has provided exceptional academic high school students with the opportunity to study at their regional university while still in high school. A first-year fine art course is delivered at a local high school where they have access to world-class lecturers and online learning technologies. The learning outcomes are exhibited in the University Gallery. In 2014, twelve ($n = 12$) students from eight regional high schools participated. The students were identified by their teachers for their talent in visual arts and were interviewed by representatives of the School of Creative Arts and the organizing local school. The students studied this course on Friday afternoons for 13 weeks. The course introduced them to fine art core skills required to develop and explore the expressive potential of contemporary drawing, painting, or printmaking practices. They explored basic material, technical, historical, theoretical, and conceptual dimensions of these media in an art studio environment. Studio learning develops a unique set of thinking skills or dispositions identified as supportive of adaptive or creative thinking. It emphasizes the importance of perception and observation, combined with reflection and exploration strategies, that expand ideas through play, intuition, and finding opportunity in mistakes or accidents (Hetland, Winner, Veenema, & Sheridan, 2007). At the conclusion of their studies, students were invited to exhibit their final artwork in the University Gallery, welcoming the local community to view their work. The graduating exhibition elements were all designed by the students. The students named the exhibition and provided the graphics and artwork for the invitation, and each student wrote their individual artist statements. In 2014, the students were asked to focus their studies on a personal interest in a phenomena that can be inquired through both the sciences and the visual arts. The study investigated how the students reasoned about the phenomena they selected and also asked how they chose to investigate and represent what they learned.

Inquiry and analysis of the project

This study applied the method of interpretive phenomenology (Smith, Flowers & Larkin, 2009) to examine how the high-achieving students reasoned about their selected phenomenon through making art. The researchers—artists, visual art educators, and education academics—collected and applied a range of data including short student surveys; audience surveys; image elicitation interviews with the tutor; summative student focus group conversations; and image analysis of artworks, art diaries, and artist statements. The results will be presented through a case study of one student, Max. The case study applies the art-science reasoning pedagogy lenses of visual observation, visual representation, integrative arts-science research, the metaphor, and aesthetics to reveal Max's unique thinking. In so doing, it aims to shift from the particular to the shared, and from the descriptive to the interpretive. The researchers act as "interpretive bricoleurs" (Denzin & Lincoln, 2005, p. 189) and overlay their expert and collective interpretations of the data with independent feedback from the audience survey. It seeks to reveal how the artistic and aesthetic insight of Max resides in his personal experiences and how his learning is generated as a dynamic "experiment … embedded in experience" (Semetsky, 2009, p. 443).

The image of Max beside his works (Figure 4) provides a window into the art/science inquiry approach he took. His decision to display the digital photographs of his selected phenomenon on field clipboards, the kind used in both scientific fieldwork or for outdoor sketching, signals the investigation's orientation

Figure 4 *Nature: Waves, Lightning, Fire, and Water*, digital photography.

as notations or incomplete investigations. His artist statement described his intention to "show complicated connections between the energy we see as perfection in the world around us and less envisioned scientific factors that drive them" (Max, Artist Statement). He selected the key phenomenon of waves, lightning, fire, and water to drive his inquiry and to "challenge the audience to think why things happen the way they do."

He is a surfer who spends many hours on the waves, experiencing the constant shifts in the weather and the sea. Figure 5 demonstrates his orientation to his experiences as both aesthetic and physical. His tutor describes his approach to his inquiry: "Surfers have a different relationship with the waves than artists [who] admire wave's visual qualities. …Big waves are a good thing for surfers, but Max scientifically presented them as a warning about changes to the nature of the earth" (Andy, tutor). His visual journal shows how his concepts evolved from his immediate experiences of waves, the scientific questions they generated, to broader questions about scientific concepts and how to represent them. He talks about his concept generation in the following way, " … drawing can be a real mix of ideas, but you can always get the concept when you look at it" (Max, focus interview). This demonstrates his capacity to recognize relationships occurring between symbolic conceptualizations (Willis, 2013). He sought to present the natural world as abstracted aesthetic photographs and the science, "the forces driving the energy as formulas," as a visceral comprehension. His reasoning moved beyond an objective, abstract,

Figure 5 Max: *Waves*, digital photography.

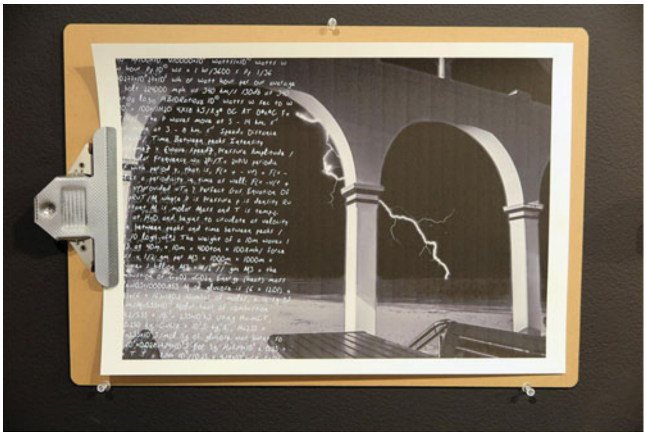

Figure 6 *Lightning*, digital photography.

and/or symbolic comprehension of energy to an artistic composition of waves and lightning revealing, through visuo-spatial and metaphoric reasoning, his high-process thinking as the acts of making art.

Discussion

At the heart of cognitive growth is the importance of observation and experience. In both studies, when the students were given a choice concerning what they wished to study, their unique experiences, perceptual, and aesthetic foci drove their concept development. The learning examples presented strengthen studies that give weight to the importance of attention, perception, cognition, affect, and memory in driving learning (Phelps, 2009) and the evaluation of choice (Willis, 2013). It is education that sculpts the brain (Suzcs & Goswami), and learning is shaped and modified by a student's interaction with their environment (Diamond, 2007, 2009). Increasingly, cognitive growth, creativity, and digital media underpin contemporary learning pedagogies. Virtual and real experiences interact, and more and more we see students working with different forms of visual technologies and new media to inform, record, and represent their experiences. Along with the traditional observation and representation tools of sketching, sculpting, or modeling, new media tools, such as video, animation, and digital photography further extend access to concept generation and therefore, meaningful learning.

Visual metaphor is a mode of representation present in both art and science (Wilson et al., 2015). Metaphors are used to link experience, intuition, and imagination, and they bridge creative ideas and concepts that are difficult to enunciate. Figure 5 demonstrates Max's sophisticated representational knowledge as he aesthetically merged "the science we see" (his digital images) with the "science we cannot see" (the representation of force and energy as scientific formulas and symbolic codes). He did not seek to abstract the seen and unseen understandings of the world, but rather to overlay the artistic and scientific epistemic representation tools, leaving the interpretive integration to the viewer.

Max was very clear that he considered his most successful artwork his image *Lightning* (Figure 6). It "combines science and art better than the others." He was not interested in abstracting the phenomenon of lightning, but rather capturing it as a virtual image of the real event. This image also required artistic and technical research, and Max himself identified the image as requiring the "most research" into "electric equations" which were overlaid as personal script across the constructed scene at a local beach site. This work may have resonated as the best for Max because it had the strongest metaphoric link with successful resolution of its symbolic conceptualizations. The composition of the artwork can be read as lightning being a metaphor of the power of nature (electricity) and its force or unpredictability juxtaposed with the man-made structures of the beach house, and the viewers are left to make their own associations. Is this image about our human capacity to harness this force as energy or is it about the latent and potential forces of nature to respond in unpredictable ways for humanity? What is striking in this series of artwork is the capacity of both scientists and artists to draw on visual reasoning to extend abstract and metaphoric thought.

Max's artwork carried his phenomena of focus, the energy found in waves, fire, lightning, and flowing water. Creating images and constructing the digital montaged photographs saw him reflect scientifically on the intentions he wanted to show. This was an example of "the complicated connections between the energy we see as perfection in the world and the less envisioned scientific factors that drive them." His artwork explored the relationship between the science we see (waves and fire, for example) and the science we cannot see, force as energy, represented in scientific symbolic formulas as personally notated script. The image, being of a well-known surfing spot, carried iconic resonance for community members because it is an image of powerful and personal resonance for the local audience. From a critical, artistic perspective its aesthetics and image composition are strong and dynamic. The curated "clipboard" grouping (Figure 4) engaged the audience in the scientific observational pursuit with each scene, capturing a significant event for the artist and transferring as images that connect in deeply personal interpretive ways for an audience. From Max's perspective and from an audience's perspective, the success of the images lies in their ability to convey clearly the artist intentions—for others to consider "what they cannot see" (Max).

Conclusion/implications

Although the two studies focus strongly on visual technologies for learning, they clearly demonstrate the power of developing the skill of visuality in the generation of concepts and the dissemination of scientific and artistic knowledge. Both forms of knowledge harness the aesthetic, abstract, symbolic, and metaphoric to render knowledge (Kolijn, 2013; Pauwels, 2005a, 2005b; Spector, 2015), albeit often in different epistemic or cultural frames. Both studies strengthen the importance of providing students with learning ecologies that capitalize on a wide range of personal learning opportunities. Particularly, learning encounters are shaped by opportunities for individual affective and aesthetic responses, which require conceptual thinking, critical analysis, judgement, and the ability to recognize connections across symbolic structural systems. The findings strengthen existing research about the role of the arts in learning (Root-Bernstein et al., 2011; Willis, 2013, Wilson, 2014; Wilson et al., 2015) and invite discussion about existing assumptions regarding visual representations in art-science. Educators are forced to consider such opportunities to engage with the possibilities afforded by new visual pedagogical spaces. Key ideas that require consideration by educators are how:

- new concepts emerge in learning when we nurture personal experience as observation and experimentation as representation;
- the brain responds to new information through physical, emotional, and social encounters;
- imaging as learning carries the toolbox of cognitive reasoning domains: abstract, visuo-spatial, and metaphoric reasoning;
- images engage creativity and integration of ideas as they connect concepts through symbolic representations
- artistic thinking supports critical judgments and regulates choice when reasoning.

Most important, the learning encounters we have described are rendered worthless unless teachers maximize explicit links between different ways of knowing such as scientific and artistic observational orientations, different ways of thinking about and representing knowledge, and the excitement and engagement of these learning moments, and offer a range of opportunities for their expression. The study reminds us that the human brain was not designed for curriculum structures and that it carries the unique creative potential to generate experimental ways to render and represent experience. New visuality through access and application of digital/visual technologies is the current personal toolkit of each student, used extensively to capture their environments, to refine concepts, and to evolve imaging processes that build their reasoning capacities, build knowledge, and later represent their learning. Assumptions about students' inability to represent complex concepts through imaging is challenged by these two case studies. Teachers are now charged with acknowledging the sophistication of aesthetic visual representations made possible for all students through visual digital media and how they can embed imaging pedagogies in their students' learning.

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