Chapter 2
Experimental Creative Practices

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1 Introduction

From the earliest human creative expressions there has been a relationship between art, technology and science. In Western history this relationship is often seen as drawing from the advances in both art and science that occurred during the Renaissance, and as captured in the polymath figure of da Vinci. The twentieth century development of computer technology, and the more recent emergence of creative practice-led research as a recognized methodology, has lead to a renewed appreciation of the relationship between art, science and technology.

This chapter focuses on transdisciplinary practices that bring together arts, science and technology in imaginative ways. Showing how such combinations have led to changes in both practice and forms of creative expression for artists and their partners across disciplines. The aim of this chapter is to sketch an outline of the types of transdisiplinary creative research projects that currently signify best practice in the field, which is done in reference to key literature and exemplars drawn from the Australian context.

2 Art + Science

In his work *Behind appearance: a study of the relations between painting and the natural sciences in this century* Waddington, a biologist writing about painting and natural sciences, suggests that "science is not merely a one-eyed Cyclops" but instead, humans have "innumerable eyes, all yielding their overlapping insights to his one being, that struggles to accept them in all their variety and richness" (1969). It is in this spirit that we set out to addresses the subject of *Digital da Vinci*—that is to say this chapter discusses creative practices that transcend traditional disciplinary boundaries in the same manner as Leonardo da Vinci—working across art, science and technology. To approach this subject we turn to the field of art-science, and consider this field from the perspective of literature on the philosophy of science,

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experimental art, and interdisciplinarity. In this vein there is a focus on practices that do not replicate existing disciplinary forms, divisions of labor, or hierarchies of knowledge, but instead seek new synthesis and negotiate what Barry et. al. describe as “forms of agonism and antagonism that often characterize relations between disciplinary and interdisciplinary research” (2008).

Guattari describes such artistic cartographies as having “always been an essential element of the framework of every society” (Guattari 1995, p. 130). This is no different in science to any other domain of society, and from this perspective contemporary art-science projects that provide one of the more compelling responses to the question posed by *Digital da Vinci*—how can we encourage and empower a new generation of “well-rounded” scholars and students, through unconventional and creative application of computer science? This question will be addressed through an examination of several key Australian examples of art-science projects. The art-science community in Australia is particularly vibrant—considering the size of the country—and actively supported by the Australia Council for the Art, through the Experimental and Emerging Arts program.

Studies of inter and trans disciplinarity provide one way of approaching art-science. In this chapter we will reference two key bodies of work, that of Nowotny (2001) and that of Born and Barry (2010) who extend Nowotny’s work in a way that allows a more nuanced evaluation of art-science projects. The chapter then turns to ask what makes experimental art experimental, and considers this question not from an art historical perspective, but through the lens of the philosophy of science, and specifically in relationship to the history of scientific experiement(ation). Thus reframing the concerns of artists about the intrumentalisation of art when undertaken within scientific paradigm, by articulating this in relationship to the contested relationship between experimenter, instrument/experimental apparatus, and theory see within the broader literature.

Despite questions about the nature of creative experimentation and whether it constitutes research[1], has been an increased recognition of Artistic Research[2] within Australia over the last 5 years. This has been a result of changes in Government research policy[3] that lead to the recognition of artistic and creative outputs as research outputs. When combined with the discussions on inter/trans disciplinarity, and experimentation, we see that experimental art-science projects engage in a what Willis (2006) describes as ontological design, This we suggest points toward a significant methodological development for Artistic Research more broadly. Similarly such

[1] This debate can be seen in the broader literature on Artistic Research, creative practice-led research, for example Working papers in Art and Design Research, Art&Research: A Journal of Ideas, Contexts and Methods. This concern is also echoed in literature focused on innovation and research & development. For example NESTA reports by Bakhshi and Throsby (2010), Bakhshi et al. (2011).

[2] In this chapter the term Artistic Research will be used to refer to creative practices undertaken in the context of research, which is drawn from the work of Coessesn et al. (2009).

[3] For example the Australian Excellence in Research policy that recognizes creative works as research output.

an ontological perspective suggests art-science projects may be exemplars of what Bakshi et al. (2010; 2011) describe as innovation through experiment. As a result this chapter aims to present one way of approaching of the epistemic tensions and transformative potentials of the larger *da Vinci* agenda.

3 Art and Science—Genealogy of Sorts

Art-Science, and Experimental Art, are not new areas of practice—and both can be positioned in respect to a range of historical threads (genealogies of practice). For the purposes of this chapter, and in line with the focus of *Digital da Vinci* on computer science, we will begin with the movements of computer art, cybernetic art and experimental art—which emerged in the 1960s as a result of the convergence of art and the nascent fields of Information and Communication Technology. These movements are relatively marginal; either being cited in respect to other named movements, or regarded simply as technological experimentation. Yet in the context of this chapter we consider artists working with new technologies mid last century, such as early computers, and exploring the implications of emerging scientific theories as precursors of today's art-science practice.

Over the last decade there has been a renewed interest in these movements, and a range of publications that map this terrain, for example Art of the Electronic Art (Popper 1993), Digital Arts (Paul 2003), New Media in Art (Rush and Rush 2005), Art in the Digital Age (Wands 2006), and Art and Electronic Media (Shanken 2009) to name but a few. Similarly there are a number of voices, such as Manovich (2001); Bourriaud (2002) and Quaranta (2010), who have examined the distinctions between contemporary art and New Media Art, and the emergence of a "post-media aesthetic" (Manovich 2001). More recently Bridles's (2011, 2012) *New Aesthetic*[4] has emerged as a "catch-all" for almost all forms of art and design that involve digital technologies and computation reshaping the aesthetic experience of everyday life—and increasingly life itself. While there has been substantial interest in the ways technology (and science) are changing creative practices and art, new artistic forms and practices related to science and technology have continually struggled to find a place within domains of science or art. This is not so much a result of some form of resistance from the any so called conservative establishment, but is really due to the difficulty in appreciating (valuing) new practices that cross over disciplinary boundaries, or result in new synthesis of disciplines.

Art science is one of those areas that poses such problems. For Born and Barry (2010) the practices and outcomes need to be understood, and valued, in respect to a broader context that encompasses multiple disciplinary perspective and histories. This they suggest includes: conceptual and post conceptual art; historical movement of art and technology; and the broader development of computation,

[4] As documented by Bridle at the following URL: http://new-aesthetic.tumblr.com/.

biological sciences and technologies, with an origin in theories of cybernetics. The challenge of understanding such practices is that they do not comfortably fit within a disciplinary framework, and are commonly found outside the normal sites for disciplinary practice. For example the computer artists of the 60s and 70s often found themselves working in newly formed interdisciplinary departments, which had begun to explore the use of computers within an art setting. However, these groups often found themselves outside the normal practices of existing disciplines. Brown (2008) describes one such interdisciplinary group, the Experimental and Computing Department within the Slade School of Fine Art, and the difficulty of artists working in this area in the early 70s to gain recognition within exiting disciplines. However, the work coming from these early interdisciplinary groups was instrumental in the development of the broader field of computer graphics[5], and has been recognized in retrospective exhibitions[6]. Today this type of practice is described as "blurring the boundaries between genres and disciplines, [as well as] redefining the contexts of use and modes of distribution" (Freyer et al. 2008, p. 10). This is often seen as a result of a continual focus on the "new"—as is suggested in names like New Media Art.

Artists working with new technologies have often been criticized for a form of technological fetishism (Manovich 2003), where the focus on new technology is in part viewed as over-determining artistic practices and outcomes. However, to engage in a constructive reading of such practices requires, as Paul (2008, p. 5) argues, more than a "strictly art-historical perspective." Understanding the significance of such practices requires an appreciation of the multiple disciplinary trajectories that converse within a specific instance of practice, which draws together fields of science, technology and media theory. This is not to disregard an art-historical perspective, for example authors such as Gere (2008); Popper (1993) and Shanken (2009) trace the linage of New Media Art practices to the Futurist, Surrealist, Dadist, Fluxus, Systems Art and Cybernetic Art movements of the last century, and note the influence of figures such as Dechamp, Nam June Paik, Cage and Sol LeWit. What emerges from the literature is an appreciation of the diversity of art-science. Art-science spans the full spectrum of both scientific endeavor and art practices—from critical engineering practices of Jerimijenko to the radical posthumanist work of Stelarc and the bio-arts of Kac, Zurr & Catts. These practices are all unique combinations of science and art, which in each configuration draw upon different histories of science and art.

[5] Computer Graphics is an examples of a field that has been the result of interdisciplinary research—from the early computer artists and researchers working together to develop the potential for new visual technology, to the contemporary animation studios working across Film, TV and Computer games pushing boundaries of the field through creative application.

[6] For example the computer art collection at the Victoria and Albert Museum London, see Beddard (2009).

Much of what is named art-science takes place within a research setting, as is seen in Wilson (2002) survey of what he calls *Information Arts*, in which he outlines several differing artistic approaches to engaging with techo-scientific research. This survey spans scientific disciplines, and concludes that artistic research within art-science takes of different forms, including: exploration of new possibilities opened up by science and technology; critical engagement and questioning of the cultural implications of specific lines of research; the use/application of new capabilities to address themes not directly related to specific science of technology; to the incidental use of technology within practices. (Wilson 2002, pp. 8–9) In the context of this chapter we are most interested in practices which do not simply "use" new technology, but have a critical or applied role in a specific line of scientific or technical research—rather than being a "distant commentator" or consumers of the outcomes of research without taking part in the processes of knowledge creation.

4 From Inter to Trans Disciplinary

These types of art-science project exhibit transdisciplinary characteristics, and to develop an appreciation for art-science requires an understanding of the movement from discipline to inter disciplinary to trans disciplinary. As Ox and Lowenberg point out "art-science, refers to worldviews, conceptual systems and research based on equal contribution from differently trained minds." (2013) In the first issue of *Leonardo*, a journal dedicated to writings about art science and technology inaugurated in 1968, Waddington writes that it would be a "mistake to see the traffic between art and science as one-way" (1968). Yet in outlining this interaction, art and science remained within fixed disciplinary boundaries influencing each other through their expressions. Around the same time C. P. Snow presented his two cultures argument, which marks a moment in recent history cited in much of the literature on interdisciplinarity.

> the clashing point of two subjects, two disciplines, two cultures—of two galaxies, so far as that goes—ought to produce creative chances. In the history of mental activity that has been where some of the breakthroughs came. (Snow 1964, p. 6)

Since C. P. Snow's 1964 two cultures argument, there has also been an increasing focus upon of interdisciplinary. More recently Csikszentmihalyi (1999, p. 314) argues that it is only within interdisciplinary settings where "individuals, domains and fields intersect" that the process of creativity can be observed, is particularly poignant. Carter (2004) suggests that this process of creativity is a form of *poiesis*, or place-making. This he describes as "collaborators plunge[ing] into the realm of Becoming" (Carter 2004, p. 11). The resulting tensions and exchanges bring into question the assumed "natural places of ideas, images and materials" (Carter 2004, p. 11). The outcomes of art-science collaborations are expressions of this negotiation, as ideas and materials as they are reorganized into creative forms and experiences. This is a shared creative act of placing things back together, a process that Carter argues, produces knowledge through the way collaborators combat the ideological character of their respective disciplinary discourses and myths by inventing artificial myths.[7] This suggests the importance of the arts and creative practice-led research within interdisciplinary collaborations, which Bennett describes as follows.

> What is clearer today than in previous generations of research is that the aesthetic (in the fullest sense, encompassing the practical study of affect, sensation, perception, behavior, imagination) is fundamental to any understanding of the connections between lifeworlds, disciplinary procedures and given problems: the arts, in other words, are at the core of the transdisciplinary experiment. (Bennett 2012)

The urgency of the so called "trans disciplinary experiment" is driven by the realization that the problems humanity faces, for example complex health issues or global climate change, are highly complex—even wicked (Horst 1973)—and require the combined efforts of multiple disciplines. As a result most of the work on interdisciplinarity has been focused on knowledge production, aka research, and can be seen across a range of disciplinary areas spanning art, design, social science, engineering, to medical sciences. Much of this writing reflects what Nowotny et al. (2001) describe as the movement from Mode-1 to Mode-2 knowledge production. Where Mode-1 knowledge production focuses on highly specialized disciplinary research, Mode 2 is carried out in respect to application, and involves heterogeneous teams of researchers and partners from multiple disciplines. Nowotny et. al use the prefix trans for Mode 2 knowledge. This form of knowledge production is described as "inherently transgressive" in that it "transcends disciplinary boundaries […] reaching beyond interdisciplinary to trans disciplinary" (Nowotny et al. 2001, p 89)."

Within the literature there is a clear distinction made between multi, inter and trans. Multi and inter disciplinary services the "mutual needs of two disciplines", while transdisciplinary work "is impelled by external conditions or problems, but also by the conviction that disciplines do not have proprietary rights over their domains" (Bennett 2012). Across the literature there is a shared focus on complex, multi dimensional, highly relational, interdependent problems, which necessitate a methodological approach that transcends the singular foci of existent disciplines. Combined with the general view that the resulting synthesis cannot be reduced or evaluated from singular disciplinary perspectives; a "theoretical, conceptual, and methodological reorientation with respect to core concepts of the participating disciplines" (McMichael 2000)

Art-science is one of the key examples of this type of trandisciplinarity, and to develop an appreciation for the different types and forms of art-science we will employ the framework outlined in the *Logics of Interdisciplinarity* Barry et al. (2008).

[7] Here Carter is referencing Barthes' *Mythologies* (1973).

They describe the several logics and three modes that frame and organize practices. The most commonly described mode of practice encountered is referred to as the *integrative/synthesis mode* that is "conceived in terms of the integration of two or more 'antecedent disciplines' in relatively symmetrical form" (Barry et al. 2008). The second mode is referred to as the *subordinate/service mode*, where one discipline is in service to another. For example, a technology partner provides a service to an artist, filling a gap based on disciplinary expertise, or an artist is "employed" to visualize scientific data in order to present findings to the public. In both of these instances the partners effort (work) remains within their respective disciplines.

However, not all interdisciplinary collaborations fall into these two modes, a third modes involves a "commitment to contest or transcend the given epistemological and ontological assumptions of historical disciplines" (Barry et al. 2008). This is referred to as the *agonistic/antagonistic* mode, and the mode which most closely reflects descriptions of transdiciplinarity. Many art-science projects exhibit characteristics of this mode, especially where the artistic practices involves a critique, or questioning, of science, or where the working methods of science infect artistic processes and outcomes. Such projects are not easily reduced to the 'antecedent disciplines'. In other words, something new is born which requires a new frame of reference before it can be fully appreciated and evaluated. These three modes are not mutually exclusive, and many projects display characteristics of more than one—especially the third mode, as this type of critical questioning that is part of the artistic method—as seen in contemporary practices within the fields of conceptual and experimental art.

Similarly, interdisciplinary projects follow a series of different logics, which are often invoked when establishing the rationale and justifications for a project. Barry's study of interdisciplinary projects, including art-science, shows that many projects follow what they describe as the logics of accountability and innovation. For example there are numerous examples in the literature which position artists and creativity within innovation life cycles[8], similarly artists work is often seen as providing a form of public account of science (include citations). In many instances these logics become performative[9] and as a result structure practice—from criteria for funding schemes to evaluation methods. Thus despite the range of activity in art-science there remains a predominance of projects that are justified in relationship to either; their role in innovation; or as a way of representing science to a public. In contrast to these two logics, of innovation and accountability, there are some examples of art-science projects that follow a logic which Barry and Born name as the "logic of ontology".

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[8] This is the basis of much of the work on Creative Industries and Innovation, see Bakhshi et al. (2010; 2011).

[9] Performative is used here in respect to concepts of performativity and practice, with origins in the work of Austin (1962). Similarly Pickering (2010) describes science as performative.

> certain art-science initiatives are concerned less with making art or science accountable or innovative than with altering existing ways of thinking about the nature of art and science, as well as with transforming the relations between artists and scientists and their objects and publics. (Barry et al. 2008)

This focus on ontology and change is similar to notions of ontological design (Willis 2006) and Fry's (2009) redirective practice. This is an important concept in respect to art-science, and transdiciplinarity, as transdisciplinary projects very often involve a "redirection of the habitual, a change in the being of the practitioner" (Fry 2009, p. 20). This is a recognition of the ontological nature of transdisciplinary practices, and the ways practice is involved in self and world making. The work of Fry, a design theorist, shows that we are designed by, and design within, the designed world, and that our designs continue to design long after leaving the drawing board, studio or laboratory. In his studies of the practice of science Pickering presents a somewhat similar description of the material agency of the machines of science as a decentered posthumanism. Similarly Winograd and Flores (1986) discuss the ontological nature of design, showing how the design of a "new technology or systemic domain create new ways of being that previously did not exist and a framework for actions that would not have previously made sense" (Winograd and Flores1987, p. 177). Ontological design(ing), Willis (2006) claims, is both a "hermeneutics of design [...] understood as a subject-decentered practice" as well a case for mindful intervention within this circular operation of design, which in the context of the contemporary crisis of crisis is necessarily political. This recognition of the political brings us back to Barry et al. (2008)—who suggests that one mode for interdisciplinary projects has a ground in Mouffe's political theory of agonism (2013), a subject developed in respect to practices in art and design by DiSalvo (2012). Many of the artists and designers discussed by DiSalvo in his work could be described a working broadly within art, science and technology, and as experimental. Here we see artists and creative works engaged in a form of critical dialogue, which is beyond that which is possible within commercial design or purely technically focused research.

5 Art Science and the Experimental?

> What confers [art] with its perennial possibility of eclipse is its function of rupturing with forms and significations circulating trivially in the social field. [...] Art confers a function of sense and alterity to a subset of the perceived world. The consequence of this quasi-animistic speech effect of a work of art is that the subjectivity of the artist and the 'consumer' is reshaped. The work of art, for those who use it, is an activity of unframing, of rupturing sense, of baroque proliferation or extreme impoverishment, which leads to a recreation and a reinvention of the subject itself. (Guattari 1995, p. 130)

In addressing the subject of art and science it is always tempting to provide a handy definition, yet any such definitions are fraught as both art and science are heterogeneous fields of practice, with their own contestations and deliberations about what constitutes art or science. As Wilson notes, the last century of Art history "has left the philosophy of art in turmoil"—making it "difficult to achieve consensus on a definition of art, the nature of the aesthetic experience, the relative place of communication and expression, or criteria for evaluation." Over the same period science as a field has gone through a series of what Kuhn (1970) describes as paradigm shifts. The claims and assumptions of science have been critiqued and questions by numerous authors, including Polyani (1964); Hacking (1983); Feyerabend (1985); Winner (1986)—foregrounding in many instances the social and human dimensions. As a result both within science, and in studies of science, there remains contestation regarding key questions of methodology, epistemology and ontology, which makes it difficult to resolve any shared consensus. More recently authors like Pickering (2010); Haraway (1998) and Lenoir (1998), have argue that scientific research produces highly situated knowledge and can be understood as cultural construct, rather than straight theory or facts. Thus Wilson (2002) comes to the conclusion that both art and science "make questionable truth claims and attempt to create privileged positions, but in reality participate in the system of symbols and narratives that shape the culture" (2002, p. 19).

> 1. Our apprehension of the world is active, not passive, and art displays an emergent apprehension.
> 2. Art is only incidentally and not essentially aesthetic. Art is concerned with every kind of value and not particularly with beauty.
> 3. Art interrogates the status quo; it is essentially, and not incidentally, radical.
> 4. Art is experimental action: it models possible forms of life and makes them available to public criticism. (Brook 1974)

For Brook (2012) experimental art is a form of "memetic innovation," a view that draws our attention to the way experimental art operates within the social field. While Pickering (2010) describes science as an encounter where machines, instruments, facts, theory, human disciplines of practice and social relationships are intertwined." If we are to appreciate art as social relation (Carter 2004), experimental art can be seen as a similar encounter—one that Brooks describes as emergent, radical and interrogating the status quo. Such practices for Guattari (1995, p. 130) involve a "rupturing of forms and significations circulating in the social field … lead[ing] to a recreation and a reinvention of the subject itself" (1995, pp. 130–131). Thus experimental art is not an experiment conducted to produce singular truth, or falsify a hypothesis, as if operating in a world of scientific realism. Instead experimental art questions the assumptions of both art and science—which includes the logics of experimentation—through the way it explores the possible. This occurs in public, becoming part of a complex ecology of relationships—taking the form of a radical experiment.

Both science and art are emergent in nature, Pickering (2010) described science as an emergent practice occurring in "real-time", while Brooks' describes experimental art as involving an "emergent apprehension". So it not surprising that experiment and experience share similar etymological origins—both derived from the Latin 'experiens', meaning to "to try out". The definitional difference here is that experiment is intransitive, while experience is direct. We experience the world first hand, yet experiment upon or on the world. The emergent, 'real-time' nature of science suggests that this distinction is not so clear, and foregrounds the experiential nature of experiment. In a similar way, Feyerabend suggests that when considered from a cultural point of view—we mistake the structures of Being with the way "Being reacts to human interference" (1996). From this perspective we can come to an understanding of experimental art as a form of experiment that is designed to explore the meaning and structures of Being, by creating artistic/ aesthetic social experiences, experiments in which the audience plays a direct role.

A further decomposing of *experiens* reveals the prefix ex, meaning "out of", and the suffix periri', which refers to trial, peril, thus involving risk. It is this notion of risk that draws us to another similarity and difference between art and science. An experiment involves risk, without risk is it an experiment? Both artists and scientists take risks when they make commitments to their creative works, and hypothesis/ theories respectably. Both commit to an uncertainty, and once published, put themselves on the line publically for their work. As will be seen in the examples discussed, the risk of the experiment of art-science, is ever present but is transformed through the movement out of the research lab and into the public.

Art and science are full of contradictory theories, it is however easier to reconcile ambiguities within the arts, than science. Artists trade in metaphors, analogies, poetics, signs and symbols, all of which have no singular or fixed meanings, and in many instances the significance of a work lies in its ambiguity, or the complexity of multiple readings. Within science the most significant contradictions emerge from the view that science constructs the reality it studies. This is either through the very act of observation, for example in high-energy physics where particles of interest are created, as opposed to being found, within monumental experimental apparatus. Yet, as authors like Pickering, Freyebend and Ascot show, we do not need to turn to quantum mechanics to see these contradictions and tensions within science. Such philosophical debates may prove concerns within science, yet Ascot suggests it is artists who are "particularly responsive to the idea that nature is constructed" (2006, p. 9)—due to the fact they primarily deal with metaphor and other forms of ambiguity and uncertainty.

In science the experiment plays a pivotal role in theory generation (or falsification). Questions about the epistemological and ontological implications of experiments, and experimental apparatus, have been motivation for paradigm shifts over the history of modern science. Yet there prevails a view that theory is more important and separate from the messy embodied material real world in which experiments take place, and the tacit and practical knowledge that is integral to the success of any experiment. As such experiment is caught within a dichotomy—between theory (*theoria*) and practical skill (*techne*). This Feyerabend describes as a "conflict between a real but hidden world and a sham world that is accessible to humans" a conflict that he argues can be "found in all areas of human endeavor."

(1996) However, readings of the history of science—from primarily observational origins of Aristotle to Galileo, to the classical macroscopic experiments of Bacon to the modern microscopic experiments—have shown that the assumed relationship between *theoria* and *techne* are highly contestable. Sennett (2008) presents an analogous argument in his work the *Craftsman*, when he sets out to liberate the "practical man or woman at work" from the stereo type of *Animal laborans.* This divide between technical skills and imagination or higher-level activities attributed to *Homo Faber*, is for Sennett an artificial one. Central to both arguments is a complex interplay between *techne* and *theoria*—which revolves around the practice of making "artefacts."

> My basic image of science is a performative one, in which the performances—the doings—of human and material agency come to the fore. Scientists are human agents in a field of material agency which they struggle to capture in machines. Further, human and material agency are reciprocally and emergently intertwined in this struggle. Their contours emerge in the temporality of practice and are definitional and sustain one another. Existing culture constitutes the surface of emergence for the intentional structure of scientific practice, and such practice consists in the reciprocal tuning of human and material agency, tuning that can itself reconfigure human intentions. The upshot of this process is the construction and interactive stabilization of new machines and the disciplined performances and relations that accompany them. (Pickering 2010, p. 21)

It is the assumed position of the instrument within this performative doing that is science, specifically the experiment, which forms a focal point for critiques of artistic methods within a scientific paradigm. The concern expressed by many artists is that within a scientific paradigm there is the risk of art becoming instrumentalised. To be instrumentalised, Lelas says, is to "be eliminated, or at least transparent, something that leaves no trace." (1993) Thus for artists the issue is that when art is viewed as a research instrument, an experimental apparatus, employed as a method of data collection, to either generate theory or falsify hypothesis, it becomes subordinate to science and loses its value as art, as memetic innovation. Worst of all it becomes transparent, and can be eliminated.[10] Carter argues that "to conceive of the work of art as a detached datum is to internalize a scientific paradigm of knowledge production", which is "wrong for science" and fails to understand art as a social relation (2004, p. 10). The suggestion that this is "wrong for science" takes on multiple meanings when read in light of the previous discussions regarding the philosophy of science. On one hand the suggestion is that the methods of art are not suitable instruments for scientific research, and on the other hand the view that any instrument provides transparent access to nature is highly contested.

As we have seen in even a brief outline of the contestations in and about science, the (experimental) instrument cannot be eliminated so easily. The instrument is both the lens through which we discover the universe, and the machines within which we

[10] A similar argument is made in relation to art within industry innovation pathways, where creativity and artistic practices become an input which is easily instrumentalised in the logics of innovation, and as a result rendered invisible, or "eliminated".

create the universe. It has been brought into the world through the human hand. This temporal, emergent and performative process of making, and experiencing, leads to new ideas, new theories, that in turn cycle back influencing what we make. The things we make are both the result of theory, and deeply involved in the production of theory. This is a form of ontological designing; a material thinking; a performative materializing practice (Bolt 2001, 2004), a performative "doing" involving human and material agencies akin to Pickering's (2010) description of science. This observation reveals the importance of both the artifact, and the practices of making, within processes of knowledge creation, which is a required movement if we are to develop an appreciation of experimental art-science projects; and artistic research, as a recognized research methodology that can be described in respect to science.

There is one aspect of experiment, which marks normal science and art as different, which has not been addressed directly and is important to appreciate the methodological implications of experimental art-science. In science, experiments do not take place in "public"[11] and are not an end in themselves. Experiments are part of a larger process aimed to generate new knowledge that is presented to the world in other forms—research publications, theoretical constructs, patents and so forth. In contrast, the experiment of experimental art directly involves a social relationship rendered in public. The artwork, a performative experiment, is in itself an expression of knowledge. It is not simply about aesthetics or beauty, but is valued by the way it generates new meanings—memetic innovation. In this respect the experiments of art and science vary in a significant way.

This difference is in some countries recognized in research policy. In the Australian context, creative outputs can be recorded as research outputs in themselves, and universities across the country count creative outputs as part of their research collections. If this were to be the case for science—the artifacts created by and through science could in themselves be counted as research outputs—an experimental instrument or disease resistant crop for example could be presented as expressions of new knowledge. However, this would undermine the methodological significance of the scientific paradigm. That is, the ability to repeat, prove or disprove theory, and the associated processes of dissemination and critique—which in science takes the form of peer review and publication. In other words, it is in this way we come to a central difference between the two domains—that is the way knowledge is expressed, and value ascribed to works of art and science.

Art-science projects however find themselves in an unusual place within this landscape—and it is the projects that take on the form of public experiment—or experimental art—that "reconfigure the objects both of art and of scientific research" (Barry et al. 2008). Such works are not about only communicating scientific theory to a public, or visualizing data, but are instead closer to forms of scientific experiment. However, they take place in public, and often directly involve the public. Born and Barry use the example of de Costa's *Pigeonblog*[12] – a work which involves

[11] This is with the exception of some forms of citizen science, and the current movement towards "removing the walls" of the science lab that can be seen in many institutions.

[12] See the project web site: http://beatrizdacosta.net/Pigeonblog/statement.php.

gathering data about air pollution, and as an example is hard to easily describe as either art or science. The work makes pointed political and social commentary, questions the nature of scientific measurement, and is also cited in the early literature on the internet of things.[13] De Costa's work, like many art-science projects, is neither art nor science as commonly understood, it is instead "a social public experiment between humans and non-humans" (de Costa 2006). Such experiments Barry et al. see as "forge[ing] relations between new knowledge, things, locations and [people] that did not exist before" (2008).

6 Australian Context

In the late 90's Shaw suggested that there is limited evidence of "artistic work directly influencing science" (Shaw 1998, p. 165), and this concern remains current today as it was in the 1990s[14], with artists commonly finding it difficult to creating meaningful art science collaborations (Ox and Lowenberg 2013). Despite this, there is a small but surprising range of examples from which to draw inspiration. It is the drive of practitioners, described as "creative interdisciplinarians" (Wilson 2002), that has lead to the growth and development of Art Science as a field of practice. As a result there has developed an increasingly sophisticated and diverse species of art-science project, and an associated body of theory/ knowledge about such projects. In this final section of the chapter we will look at two examples from Australia, which are both recognized nationally and internationally as leaders in development of art-science projects and collaborations, and advancing transdisciplinary work. These two examples are *SymbioticA*, a bio-art research center at the University of Western Australia, and the Synapse program run by the Australian Network for Artists and Technology (ANAT), based in Adelaide.

6.1 SymbioticA—Experimental Bio-Art Practices

Many of the collaborations through the 1990s focused on "new media" and computational forms. Today art-science projects span the full spectrum of scientific research. One of the more challenging art-science fields of practices is that known as bio-art, which brings together artists and the biological sciences, as seen in the transgenic and living works Eduardo Kac. In Australia the leading site for this bio-art of work is *SymbioticA*[15]. While there are other pockets of work being conducted

[13] For example Julian Bleeker's "A Manifesto for Networked Objects—Cohabiting with Pigeons, Arphids and Aibos in the Internet of Things" (2006) See http://dm.ncl.ac.uk/courseblog/files/2010/04/whythingsmatter.pdf.

[14] See for example Ox (2013) paper "What Is the Challenge of Art/Science Today and How Do We Address It?".

[15] See the SymbioticA web site: http://www.symbiotica.uwa.edu.au/.

across the country[16], *SymbioticA* is by far the most concentrated and internationally recognized center, with a stated focus on “enabling artists and researchers to engage in wet biological practices” (UWA n.d.) within a science department. The center has since its inception supported numerous artists and projects through a program of residencies, education and research.

In this setting the tools and technologies of science are not simply used as a resource within a creative practice, nor do they form some distance object of commentary. The proposition that the tools and technologies of biological sciences could be raw materials, or resources, within a creative process is deeply problematic. This problem is not limited to artists working in biological materials in an experimental setting, but is the ethical territory all researchers in biotechnology operate within, and *SymbioticA* does not shy away from directly engaging in the related debates. They advocate that it is only through “experiential practice” within a scientific setting, that it is possible to develop an “understanding and articulation of cultural ideas around scientific knowledge.” (UWA, n.d.) This is seen as being important for “informed critique of the ethical and cultural issues of life manipulation.” On the surface this suggests the work follows a logic of accountability, where artists are engaged in work that in some form is aimed at holding science to account, and representing this to a boarder public. However, upon close inspection there is also an ontological logic, which is *“less with making art or science accountable or innovative than with altering existing ways of thinking about the nature of art and science”* (Barry et al. 2008) *This* can be seen in both sustained commitment to biological arts within a wet lab, and the programs of education, research, public presentation and scholarly publication. Similarly this program of activity suggests a mode of operation that cannot be easily reduced to antecedent disciplines. Instead it appears focused on developing the emergent field of bio-art, through a contestation of the assumptions implicit in the respective domains of art and science.

To provide an example we will draw a case study from one of the projects from *SymbioticA*—The Tissue Culture and Art Project[17] (TC&A) lead by Oron Catts and Ionat Zurr, which is described as “exploring the use of tissue technologies as a medium for artistic expression.” (Catts and Zurr, n.d.) The project is however not simply focused on formal exploration of a particular artistic material, but instead is interested in “new discourses and new ethics/epistemologies” of the semi-living and “the contestable future scenarios they present”. This is seen in the range of artworks that are part of the TC&A, one of the more poignant of which is *Victimless Leather*[18], which will be discussed below. *Victimless leather* is an excellent example of the ways in which Art-science operates – and provides an illustration of how concepts of instrumentation and experimentation play out within a creative work, and in an exhibition setting. *Victimless leather* is a small stitch-less jacket grown from immortalized cell, cultured and grown over a biodegradable polymer matrix,

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[16] For example Dr Svenya Kratz who completed her practice-led PhD working at the Institute for Health and Biotechnology Innovation at the Queensland University of Technology.

[17] See the *Tissue Culture Art Project* web site: http://tcaproject.org/.

[18] See the *Victimless Leather* web site: http://www.tca.uwa.edu.au/vl/vl.html.

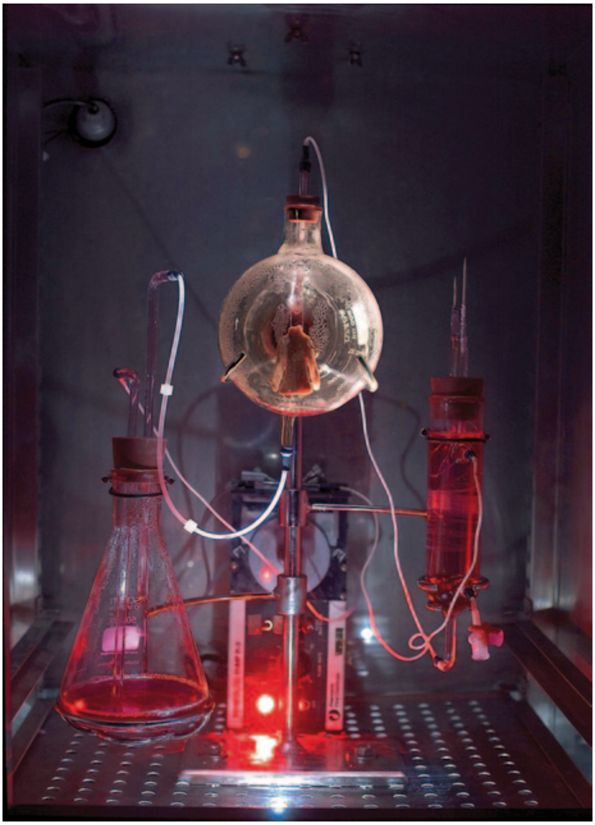

Fig. 2.1 *Victimless leather*. (Oron Catts and Ionat Zur 2004)

described as problematizing the garment by making it semi-living (Zurr and Catts 2003). When exhibited, the semi-living jacket is presented along with a bioreactor, required to keep it "alive", and with each exhibition there is the associated performances of care—"feeding" during the exhibition, and ultimately killing of the work at the end (Zurr and Catts 2003). In this way the work not only employs the aesthetics of science, but is a functional example of the technology and practices of a tissue culture laboratory, and directly embodies the associated ethical dilemmas (Fig 2.1).

Victimless Leather appears to have come straight out of the "wet lab" into the gallery; with the small jacket grown from living cells only part of a whole. Its presence, and "semi-living" status, is only possible by way of the experimental setup designed to keep it alive. In this respect the work takes on the form of a public experiment, not an experiment the public partake directly in, but an experiment that unfolds in the public as opposed to behind closed doors. Like any experiment it involves risk, the risk of the experiment failing, the semi-living work "dying" prematurely through contamination, or through a lack of "care" in the practices required to sustain its living status. This risk, and the precarious and fragile existence of the living jacket, draws our attention to questions of care and responsibility. The care required to sustain an artwork made from living cells, and responsibility for its continued life. At the same time the work critically questions our existing relationship to clothing made from the skin of animals by suggesting a possible "victimless" future. But do such issues require an art-science response, or rephrased, why is an art-science project the most potent approach for addressing these issues? What is most important in addressing this question is that the artists are working with specific material technologies, which would otherwise be rendered as experimental apparatus—for data collection and writing about—but not ever published or circulated in themselves.

While the aesthetics of the biology experience, transparent glass, fluids, messy growths of cells, are present, it is only by way of an appreciation of the science and the associated ethical debates that the significance of the work becomes apparent. It is far more than an artifact for the polite, yet squeamish viewing, of gallery audiences. It is both a bringing into the world a creation, and a bringing forth a semi-living form created from cells—it is far from "natural"—yet we are squeamish because it is made from living cells, and presented with the apparatus that life support. Thus the material technologies of the biology wet lab are presented as art object within a gallery setting—constructed as an experience in order to generate thought and discussion. It is both an art object, an exploration of the formal properties of a "semi-living" material, as well as a real time experiment using contemporary scientific techniques. It thus questions the status quo and unsettle the normative assumptions of science and art and in the process become part of an emerging new field of bio-art.

Here we see a cue to the transdisciplinary nature of the project—in that what is presented as an artwork, is the result of the combined artistic and scientific disciplines thus transforming the "relations between artists and scientists and their objects and publics." (Barry et al. 2008) Through the practice of making the work, its exhibition, and writing about the works, the artists engage in a critical dialogue about the intellectual, ethical and political limits of biotechnology as a science, as well as existing normalized practices within society. This echoes the approaches of critical design[19], which challenge the normative practices of design and instead employ speculative design fictions to engage in a critical dialogue about topical issues. Yet were critical designers create non-functional fictional designs in order to critique issues related to science or new technologies—the work of TC&A goes one step further in that it employs the very science it is critiquing. It is both experimental art, and science experiment—yet cannot be comfortably understood as either. It is this inability for the work to be evaluated, or understood, from the perspective of existing disciplines that makes it of interest. To apprehend its value requires a reading of not only the respective disciplines of art and science, but the emerging field of bio-art.

Victimless leather is just one of over a dozen projects, each of which explore tissue cultures as artistic material, and at the same time engage in a similar critical dialogue. For example *Semi-living Steak* (2000) and *Disembodied Cuisine* (2003)

[19] Critical Design is best captured in the practice of Dunne and Raby (1999; 2001).

both of which explore the growing of meat for human consumption, research which is today, in 2013, only just reaching pre-commercial stages (Post 2013). Beyond the work of Catts and Zurr, *SymbioticA* runs an artist residency program, which since 2000 has supported over 60 artists from around the world.[20] As such *SymbioticA* is an important international example of transdisiplinary art-science, which is advanced through a combined program of education[21], workshops, symposium, exhibitions, research and artist residencies. When read in combination this provides one possible model for fostering, encouraging and empowering a new generation of "well-rounded" artists, scholars and students, through unconventional and creative application of science.

6.2 Synapse

> Collaboration between the arts and sciences has the potential to create new knowledge, ideas and processes beneficial to both fields. Artists and scientists approach creativity, exploration and research in different ways and from different perspectives; when working together they open up new ways of seeing, experiencing and interpreting the world around us. (ANAT n.d.)

The second example is the ANAT synapse program, which is aims to support collaborations between scientists and artists through the combination of a residency program, an online database of art-science practice (http://synapse.org.au) and an Australian Research Council (ARC) Linkage program that provides support for longer term projects that are developed through the initial residency.[22] Over the last 10 years the residency program has placed artists in close to 20 different research centers across the country, and internationally, in a disciplines ranging from Astrophysics to Synthetic Biology. A few examples of residencies supported through Synapse highlight the diversity of art-science partnerships: Chris Henschke at the Australian Synchrotron in Melbourne, Erica Seccombe in the Department for Applied Mathematics at the Australian National University, Robin Fox at the Bionic Ear Institute and George Pookhin Khut at The Children's Hospital Westmead. While each artist supported employs different tactics for engaging with science, there is a requirement for a joint application where there is a commitment to the collaboration from both artist and scientists. The program also has an explicit research focus, and is designed to allow for artists to immerse themselves within the science setting, and for the partners to develop an understanding of each other's respective practices. From this perspective Synapse is framed to foster transdisciplinary practices within

[20] For a list of Artists see http://www.symbiotica.uwa.edu.au/residents.

[21] *SymbioticA* run undergraduate and postgraduate courses on bio-art and Art Science practices, which are detailed at the following URL: http://www.symbiotica.uwa.edu.au/courses.

[22] This run through the Australian Research Council (ARC) Linkage grant scheme, which involve research conducted with an industry partner. For the Synapse Linkage scheme the industry partner is the Australia Council for the Arts. http://www.australiacouncil.gov.au/artforms/experimental-arts/opinion_piece._synapse_sharing_partnerships.

the context of science facilities—and in many instances artists engage in scientific research work as part of their residency, a strategy aimed at supporting longer term projects, which extend beyond the initial residency. Not all supported Synapse projects have gone beyond the initial residency; however there are several very notable ongoing projects that have emerged from Synapse residencies. Below we will mention two of note.

The first example, which will be discussed very briefly, is George Pookhin Khut's work with Dr Angie Morrow on the *BrightHearts* project[23]. The project is a synthesis of Angie's clinical knowledge and experience in medical research, and George's focus on the body combined with a background in research and "human-centered design methods and values", which has led to a relatively novel approach to the problem of "managing pain and procedure-related anxiety experienced by children" (Khut et al. 2011) Beyond being simply a medical research project, the resulting iPad application developed through *BrightHearts* research has been exhibited within gallery settings in exhibitions which span Art[24] and Design[25]. The work has produced several research publications, and has been recognized with an Australian Business Art Foundation (ABAF) award[26], and the Queensland New Media Art Award[27]. This range of outcomes demonstrates the value of the project across art, design and medical research and shows how such projects can lead to multiple outcomes without being subsumed by, or in service of the logics of either partner discipline (Fig 2.2).

The second example, which will be discussed in more detail, is the collaboration between Mari Velonaki, and roboticists David Rye, Steve Scheding and Stefan Williams at the Australian Centre for Field Robotics at the University of Sydney[28]. This collaboration developed from an initial residency, which to a 3-year Synapse Australian Research Council (ARC) Linkage grant to develop the *Fish Bird* project. The work *Fish-Bird: Circle B—Movement C*[29], which is one of a series of works, involves two autonomous robots in the form of wheel chairs, Fish and Bird, who are in love but cannot communicate directly. Instead they communicate with each other and an audience via movement and text (Velonaki 2008b).

Presented publically—in gallery settings—*Fish-Bird: Circle B—Movement C* is a unique artistic work, and experiment in robotics, one which has allowed Velonaki and collaborators to explore the central problems of the Center for Social Robotics,

[23] See the *Brighthearts* web site: http://georgekhut.com/brighthearts/.

[24] For example *Brighthearts* was included in, and won, the 2012 New Media Art Awards at Gallery of Modern Art in Brisbane Queensland. See http://www.qagoma.qld.gov.au/exhibitions/past/2012/national_new_media_art_award_2012.

[25] The work has also been included in *CUSP; Designing the Next Decade* curated by the Australian Center for Design. Similarly the work of Mari Vilonaki discussed in this paper is also included in the same exhibition. See http://www.cusp-design.com/.

[26] See the Arts and Health Foundation Award 2012 http://www.creativepartnershipsaustralia.org.au/arts/awards/2012-abaf-award-winners.html.

[27] Ibid. 25.

[28] See the Australian Center for Field Robotics web site: http://www.acfr.usyd.edu.au/.

[29] See the artists web site: http://mvstudio.org/work/fish-bird-cicle-b-movement-b/.

Fig. 2.2 *Brighthearts*. (By George Poookhin Khut. Photograph by Julia CharlesVelonaki 2012, 2004, 2011)

which formed in 2006 within the Australian Centre for Field Robotics. Specifically the aim was to "study human-robot interaction in social environments"—which they describe as requiring "a multidisciplinary understanding of the science, technological sociological and cultural dimensions of human robot interactions" (CSR, n.d.). In this way *Fish-Bird: Circle B—Movement C* becomes an experiment played out in public, having been show around the world and encountered by tens of thousands of people, a field trial of a scale that would be difficult without the artistic setting. However, the experimental approach goes a step further than *Victimeless Leather*, in that it directly involves the audience within the dynamics of the experiment, through their interaction with the work in a direct manner. The audience becomes part of an experiment, both as participants in a study of human-robot interactions, and as actors within an unfolding robotic love story (Fig 2.3).

Since forming as a group in 2006 Velonaki and her collaborators have won research and arts funding to support a number of similar projects, which have been exhibited internationally, and also resulted in publications across art and science. Of note are developments that come out of this body of research including two PhD theses. One studying artificial skin and the interpretation of touch in human-robot

Fig. 2.3 *Fish-Bird: Circle B*—Movement C. By Mari Velonaki 2004

interaction (Silvera Tawil 2012); and a second focusing on the psychophysiological correlates of emotive and cognitive variables in computer-based tasks (Brown 2012). Similarly, through the work of the center, Velonaki and collaborators have refined a methodological approach to support their research. This focuses on multi-objective evaluation (Velonaki 2012), which is framed from a multi disciplinary perspective, as opposed to inter or trans. This appears a strategic choice; to design projects to produce outputs that have meaning within respective disciplinary contexts, yet work together as a whole. This approach may in part be driven by an environment that is structured along the lay lines of disciplines, both the university and funding bodies. For example both arts funding and research funding is commonly structured around disciplines—with reviewers for applications selected based on disciplinary expertise. The one exception to this is the Experimental Art program run by the Australia Council for the Arts.

In the paper *Shared Spaces: Media Art, Computing, and Robotics*, Velonaki, Scheding, Rye and Durrant-Whyte, note that they came together around a shared interest in "the creation of human-machine interfaces" Velonaki 2008a, b. This is of specific note in the context of interdisciplinary fields, as the field of Human-Computer Interaction (HCI) has undergone several transformations as a result of interdisciplinary encounters; from cybernetics and man-machine interaction, to HCI and Interaction design, to the contemporary formulation of experience design, which has a curious echo of experimental. So while their methodological approach articulated as multi, we see in this example the emergence of an approach which involves a "synthesis of research at the stages of conceptualization, design, analysis, and interpretation by integrated team approaches" (Hadorn 2008. Cited in Ertas 2010)

In Falk's 2011 case study Rye described the significance of the work of the CSR as the way it "declares the importance of an area, which is really the non-technological, non-scientific, non-engineering influences on robotics". In this way the CSR and its approach prefigure the movement of robotics and robots, out of the lab and into the world. This can be seen as analogous to the transformations of HCI and Computer Science as computers became ubiquitous through the 1990s to the 2000s. As a result there is a demand robotics (and robots) become a focus for study and research, where "psychologists, anthropologists and cultural theorists who can interpret relational dynamics and data" (Falk 2011) come with scientists and engineers to address the challenges and problems resulting from the increasing use of a new technology within society.

In this example art gallery becomes an experimental space where the human audience plays a role in a multi objective evaluation framework. This renders any close reading of the particulars of the project difficult, as one needs to be appraised of the significance the knowledge outcomes across different disciplines. What is of specific interest in this example and in the context of this chapter is the way Mari's creative practice and robotic works, *Fish-Bird* and more recently works like *Diamandini*, provide a point of focus for a sustained research agenda, and a unique opportunity to study such human interactions with robots outside the lab. As an example of art-science we see the artwork become instrument, experiment, creative expression and experience, without becoming invisible through this process. It is the complex interrelations that form around the creative work, which provide the potential for new knowledge far beyond technical innovation alone (Fig. 2.4).

Falk presents the value in terms of the logic of innovation: "This story captures a recurring theme in creative innovation: collaborations foster interpersonal relationships that can kick-start long-term innovation paths and engagement across industry lines." (Falk 2011) This highlights the importance of such collaborations and mechanisms for fostering relationships and sustaining long-term projects. However these projects cannot be viewed through the logics of innovation alone—for it is the "logic of ontology" which is key to transformation, as is seen in the evolution of HCI as a field of research and the resulting ways this has transformed our relationships with, and understandings of technology. Similarly, there is a two way movement between art and science which is seen in Velonaki's recent move to the University of New South Wales to lead the Creative Robotics Laboratory[30] with the National Institute for Experimental Arts.[31] Here research begun within a more traditional robotics research center, conducted within a multi-disciplinary frame, has evolve into a program within a research center that like *SymbioticA* has been established with a focus on transdisciplinary experimental arts practices.

[30] See the Creative Robotics Lab web site: http://www.niea.unsw.edu.au/about/niea-groups/creative-robotics-lab.

[31] See the National Institute for Experimental Arts web site: http://www.niea.unsw.edu.au/.

Fig. 2.4 *Diamontini*. (By Mari Velonaki 2011)

From even this short investigation of just two of the art-science partnerships supported through Synapse there emerges a picture of the potential for such transdisciplinary experimental practices. However, Synapse as a program stands in the face of a system of funding and reporting which remains polarized along disciplinary lay lines, and often driven by the demands for immediate outcomes. This second point on immediate outcomes, with projects framed in periods of typically 12 months to 3 years, undervalues the importance of time in the development of transdiscplinary practices. Successful Synapse projects, like those discussed above, are only possible through extended work, where there is time for the partners to develop a "theoretical, conceptual, and methodological reorientation" (McMichael 2000) seen in mature transdisciplinary practices. Upon close inspection Synapse may prove to be an international benchmark in this respect.

7 Conclusions

To conclude we return to da Vinci, and a view of his work as a polymath which questions the contribution he made to scientific knowledge. Of Leonardo Carrier says "[his] art is great, but his studies of science and technology are of interest only to intellectual historians." (2008) For Carrier it is not da Vinci's contributions to science that are significant, but instead his "fascination for the relationship of art and science" (2008), as expressed not just though his artworks, but through his journals and sketches. It is this interest in the relationship between art and science that we suggest is more important than dreams of a contemporary "Renaissance man". What this suggests is a trans disciplinary approach—one that Bennett describes as engaging with, and motivated by, "external conditions or problems [and a] conviction that disciplines [should] not have proprietary rights over their domains" (Bennett 2012). For it is from the places where disciplines come together and interact, that new meaning emerges.

As we have seen such forms of practice do exist, however the question remains as to how these practices—often grounded in collaborations—are formed, fostered and supported. And more specifically how such an appreciation for Art **and** Science is realized in curriculum. With the exception of a few exemplars, the mainstream body of university education remains polarized around disciplinary "silos". The structures and logics of institutional organization, funding and reporting, form an inertia pull towards disciplines that needs to be questioned, and resisted—not just by faculty; but by students themselves. In the face of looming change in the university sector internationally—driven by developments in information and communications technology that are transforming the way education is produced and delivered—there is no more potent moment for the radical rethinking of disciplinary based programs.

In response to the question posed by *Digital da Vinci* we suggest a subtle reformulation—how can we encourage the same type of interest, or fascination in our scholars and students for both art and science as we see in Leonardo da Vinci? From surveying the state of art/science practice over the last 50 years what is clear is that this is not necessarily a problem of the arts. What is more urgently required is for the science, technology, engineering and mathematics disciplines to genuinely see the substantial value art and creative practices bring to their respective fields. Here a new formulation has emerged which includes art which is gaining traction in internationally.[32] It is this recognition of the value of art, beyond a subordinate mode of operation framed by the logics of pre-existing disciplines, which is central to addressing the challenges posed by this text—*Digital da Vinci.*

[32] See for example Roger Malin's work Chair of Arts and Technology at the University of Texas http://www.utdallas.edu/atec/malina/ and the Science Engineering Art and Design (SEAD) developments http://www.utdallas.edu/atec/cdash/ and http://seadnetwork.wordpress.com/, the Leonardo Education and Art forum http://www.leonardo.info/isast/LEAF.html, the liberal arts and engineering programs at California Polytechnic State University http://laes.calpoly.edu/, and the Rhode Island School of Design's STEM to STEAM program http://stemtosteam.org/.

References

Ascott, Roy. 2006. *Engineering Nature: Art & Consciousness in the Post-biological Era*. Bristol UK: Intellect Books.

Australian Network for Art and Technology (ANAT). 2008. Synapse – Art Science Collaborations. http://www.synapse.net.au/. Accessed September 10, 2013.

Austin, J. L. 1962. *How to Do Things With Words*. London: Oxford University Press.

Bakhshi, Hasan, and Throsby, David. 2010. *Culture of Innovation*, London: National Endowment for Science, Technology and Arts (NESTA).

Bakhshi, Hasan, Freeman, Alan and Potts, Jason. 2011. *State of Uncertainty*, London: National Endowment for Science, Technology and Arts (NESTA).

Barry, Andrew. Born, Georgina, and Weszkalnys, Gisa. 2008. Logics of Interdisciplinarity. *Economy and Society* Vol. 37, No. 1: 20–49. doi:10.1080/03085140701760841.

Barthes, Roland. 1973. *Mythologies*. St Albans, Herts.: Paladin.

Beddard, Honor. 2009. Computer Art at the V&A. *V&A Online Journal* no. 2. http://www.vam.ac.uk/content/journals/research-journal/issue-02/computer-art-at-the-v-and-a/. Accessed September 10 2013.

Bennett, Jill. 2012. What is Experimental Art. *Studies in Material Thinking*, Vol. 8. http://www.materialthinking.org/papers/88. Accessed 8 September 2013.

Bleecker, Julian. 2006. A Manifesto for Networked Objects—Cohabiting with Pigeons, Arphids and Aibos in the Internet of Things. http://dm.ncl.ac.uk/courseblog/files/2010/04/whythings-matter.pdf. Accessed 8 September 2013.

Bolt, Barbara. 2001. Materialising Practices: The Work of Art as Productive Materiality. PhD thesis, Murdoch University.

Bolt, Barbara. 2004. *Art Beyond Representation: The Performative Power of The Image*. London: I.B Tauris & Co Ltd.

Born, Georgina, and Barry, Andrew. 2010. Art-Science. *Journal of Cultural Economy* Vol. 3 No. 1: 103–119. doi:10.1080/17530351003617610.

Bourriaud, Nicolas. 2002. *Relational Aesthetics*. France: Les presses du réel.

Bridle, James. 2011. Waving at the Machines. http://www.webdirections.org/resources/james-bridle-waving-at-the-machines. Accessed 6 September 2013.

Bridle, James. 2012. "#sxaesthetic report". http://booktwo.org/notebook/sxaesthetic/. Accessed 6 September 2013.

Brook, Donald. 1974. About the Australian Experiemental Art Foundation. http://aeaf.org.au/about/aboutaeaf.html. Accessed 7 September 2013

Brook, Donald. 2012. Experimental Art. *Studies in Material Thinking*, Vol. 8. https://www.materialthinking.org/papers/101 Accessed 8 September 2013.

Brown, Paul. 2008. From Systems Art to Artificial Life Early Generative Art at the Slade School of Fine Art. In *White Heat Cold Logic: British Computer Art 1960–1980*, ed. Gere, C., Brown, P., Lambert, N. and Mason, C. Cambridge, Massachusetts: MIT Press.

Brown, I. 2012. *Cognitive context: exploring psychophysiological correlates of emotive and cognitive variables in computer based tasks*. PhD thesis, Australian Centre for Field Robotics, The University of Sydney.

Carrier, David. 2008. Introduction: 'Leonardo' and Leonardo Da Vinci. *Leonardo* Vol. 41, No. 1: 36–38. doi:10.2307/20206514.

Carter, Paul. 2004. *Material thinking: the theory and practice of creative research*. Melbourne, Australia: Melbourne University Publishing.

Catts, Oran, and Ionat Zurr. n.d. The Tissue Culture and Art Project. http://tcaproject.org/. Accessed September 10, 2013.

Catts, Oran, and Ionat Zurr. 2000. Semi-Living Steak. http://tcaproject.org/projects/victimless/steak. Accessed September 10, 2013.

Catts, Oran, and Ionat Zurr. 2003. Disembodied Cusine. http://tcaproject.org/projects/victimless/cuisine Accessed September 10, 2013.

Catts, Oran, and Ionat Zurr. 2004. Victimless Leather. http://tcaproject.org/projects/victimless/leather. Accessed September 10, 2013.

Centre for Social Robotics (CSR). n.d. About Us. http://www.csr.acfr.usyd.edu.au/about.htm. Accessed September 11, 2013.

Coessens, Kathleen, Darla Crispin, and Anne Douglas. 2009. *The Artistic Turn: a Manifesto*. Brussel: Leuven University Press, 2009.

Csikszentmihalyi, M. 1999. Implications of a Systems Perspective for the Study of Creativity. In *Handbook of Creativity*, ed. R. J. Sternberg. Cambridge: Cambridge University Press.

Da Costa, Beatriz. 2006. PigeonBlog. http://beatrizdacosta.net/Pigeonblog/index.php. Accessed September 10, 2013.

DiSalvo, Carl. 2012. *Adversarial Design*. Cambridge, Massachusetts: MIT Press.

Dunne, Anthony. 1999. *Hertzian Tales. Electronic Products, Aesthetic Experience, and Critical Design*. Cambridge, Massachusetts: MIT Press.

Dunne, Anthony, and Fiona Raby. 2001. *Design Noir: the Secret Life of Electronic Objects*. London: August Media Birkhäuser.

Ertas, Atila. 2010. Understanding of Transdiscipline and Transdisciplinary Process. *Transdisciplinary Journal of Engineering & Science* Vol. 1, No. 1:54–73.

Falk, Michael. 2011. Assembling Social Futures: The Centre for Social Robotics. *Creative Industries Innovation Centre*. http://www.creativeinnovation.net.au/Media/docs/CSR-4f2e1256-8ae5-4491-9680-5e04f3d69fe0-0.pdf. Accessed September 10, 2013.

Freyer, Conny, and Troika (Firm). 2008. *Digital by Design: Crafting Technology for Products and Environments*. London: Thames & Hudson.

Feyerabend, Paul. 1985. *Problems of Empiricism: Volume 2: Philosophical Papers*. Cambridge: Cambridge University Press.

Feyerabend, Paul. 1985. *Realism, Rationalism and Scientific Method: Volume 1: Philosophical Papers*. Cambridge: Cambridge University Press.

Feyerabend, Paul. 1996. "Theoreticians, Artists and Artisans." *Leonardo* Vol. 29, No. 1: 23–28. doi:10.2307/1576272.

Fry, Tony. 2009. *Design Futuring: Sustainability, Ethics and New Practice*. Sydney: University of New South Wales Press.

Gere, Charlie. 2008. New Media Art and the Gallery in the Digital Age. In *New Media in the White Cube and Beyond Curatorial Models for Digital Art*, ed. by Christiane Paul. Berkeley: University of California Press.

Guattari, Felix. 1995. *Chaosmosis: an Ethico-aesthetic Paradigm*. Bloomington, Indiana: Indiana University Press.

Hacking, Ian. 1983. *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge: Cambridge University Press.

Hadorn, H. G., Susette Biber-Klemm, Walter Grossenbacher-Mansuy, Gertrude Hirsch Hadorn, Dominique Joye, Christian Pohl, Urs Wiesmann and Elisabeth Zemp. 2008. Handbook of Transdisciplinary Research, Enhancing Transdisciplinary Research: A Synthesis in Fifteen Propositions. Chapter 29, p. 435.

Haraway, D. 1988. Situated knowledges: The science question in feminism and the privilege of partial perspective. *Feminist Studies* Vol. 14, No. 3:575–599.

Khut, George Poonkhin, Angie Morrow, and Melissa Yogui Watanabe. 2011. The BrightHearts Project: a New Approach to the Management of Procedure-Related Paediatric Anxiety. OZCHI Workshops Program, Canberra.

Kuhn, Thomas S. 1970. *The Structure of Scientific Revolutions*. 2nd ed. Chicago: University of Chicago Press.

Lelas, Srdjan. 1993. Science as Technology. *The British Journal for the Philosophy of Science* Vol. 44, No. 3: 423–442. doi:10.2307/688014.

Lenoir, Timothy. Ed. 1998. *Inscribing Science: Scientific Texts and the Materiality of Communication*. California, US: Stanford University Press.

Manovich, Lev. 2001. *Post-media Aesthetics*. DisLocations. Karlsruhe: ZKM / Zentrum für Kunst und Medientechnologie.

Manovich, Lev. 2003. Introduction. in *The New Media Reader*, ed. Wardrip-Fruin, Noah, and Montfort, Nick. Cambridge, 13–25. Cambridge, Massachusetts: MIT Press.

McMichael A.J. 2000. What makes transdisciplinarity succeed or fail? First Report. In *Transdisciplinarity: recreating integrated knowledge* ed. Somerville MA, Rapport DJ. Oxford, UK: EOLSS Publishers Ltd.

Mouffe, Chantelle, *Agonistics: Thinking The World Politically*. London – New York: Verso, 2013.

Nowotny, H., Scott, P., & Gibbons, M. 2001. *Re-thinking science: Knowledge and the public in an age of uncertainty*. Cambridge: Polity.

Ox, Jack, and Richard Lowenberg. 2013. What Is the Challenge of Art/Science Today and How Do We Address It? *Leonardo* Vol. 46, No. 1: 2–2.

Paul, Christiane. 2003. *Digital Art*. London: Thames & Hudson.

Paul, C. 2008. *New media in the white cube and beyond: curatorial models for digital art,* University of California Press, Berkeley

Pickering, Andrew. 2010. *The Mangle of Practice: Time, Agency, and Science*. Chicago: University of Chicago Press.

Popper, Frank. 1993. *Art of the Electronic Age*. London: Thames & Hudson.

Post, Mark. 2013 *Cultured Beef Project* Maastricht University. http://www.maastrichtuniversity.nl/web/show/id=6866536/langid=42 Accessed September 20, 2013.

Quaranta, Domenico. 2010. *Media, New Media, Postmedia*. Milan: Postmedia Books.

Rittel, Horst WJ, and Melvin M Webber. 1973. Dilemmas in a General Theory of Planning. *Policy Sciences* Vol. 4, No. 2: 155–169.

Rush, Michael, and Michael Rush. 2005. *New Media in Art*. 2nd ed. World of Art. London: Thames & Hudson.

Silvera Tawil, D. 2012. *Artificial skin and the interpretation of touch in human-robot interaction*. PhD thesis, Australian Centre for Field Robotics, The University of Sydney.

Sennett, Richard. 2008. *The Craftsman*. New Haven: Yale University Press.

Shanken, Edward. 2009. *Art and Electronic Media*. London: Phaidon Press.

Shaw, Jeffery. 1998. Convergence of Art, Science and Technology. In *Art @ Science*, ed. Editors Sommerer, Christa, and Laurent Mignonneau, 162–166. Springer.

Snow, C. P. 1964. *The Two Cultures*. London: Cambridge University Press.

The University of Western Australia (UWA). SymbioticA. http://www.symbiotica.uwa.edu.au/. Accessed September 10, 2013.

Waddington, C. H. 1968. New Visions of the World. *Leonardo* Vol. 1, No. 1: 69–75. doi:10.2307/1571907.

Waddington, C. H. 1969. *Behind Appearance: a Study of the Relations Between Painting and the Natural Sciences in This Century*. Edinburgh: Edinburgh University Press.

Wands, Bruce. 2006. *Art of the Digital Age*. London: Thames & Hudson.

Willis, Anne-Marie. 2006. Ontological Designing. *Design Philosophy Papers* no. 2.

Wilson, Stephen. 2002. *Information Arts: Intersections of Art, Science, and Technology*. Cambridge, Massachusetts: MIT Press.

Winner, Langdon. 1986. *The Whale and the Reactor: a Search for Limits in an Age of High Technology*. Chicago: University Chicago Press.

Winograd, Terry, and Carlos F. Flores. 1986. *Understanding Computers and Cognition: a New Foundation for Design*. Norwood, N.J.: Ablex Publishing.

Velonaki, Mari. 2012. Multi-Objective Evaluation of Cross-Disciplinary Experimental Research. *Studies in Material Thinking*, Vol. 8. https://www.materialthinking.org/papers/100. Accessed 8 September 2013.

Velonaki, M., Scheding, S., Rye, D. & Durrant-Whyte, H. 2008a. Shared spaces: media art, computing and robotics. *ACM Computers in Entertainment*. Vol. 6, No. 4: 51:1–51:12.

Velonaki, M., Rye, D., Scheding, S. & Williams, S. 2008b. *Fish-Bird: A perspective on cross- disciplinary collaboration IEEE MultiMedia*, January–March:10–12.