



Foundations of ArtScience: Formulating the Problem

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Abstract

While art and science still functioned side-by-side during the Renaissance, their methods and perspectives diverged during the nineteenth century, creating a still enduring separation between the "two cultures". Recently, artists and scientists again collaborate more frequently, as promoted most radically by the ArtScience movement. This approach aims at a true synthesis between the intuitive, imaginative methods of art and the rational, rule-governed methods of science. To prepare the grounds for a theoretical synthesis, this paper surveys the fundamental commonalities and differences between science and art. Science and art are united in their creative investigation, where coherence, pattern or meaning play a vital role in the development of concepts, while relying on concrete representations to experiment with the resulting insights. On the other hand, according to the standard conception, science seeks an understanding that is universal, objective and unambiguous, while art focuses on unique, subjective and open-ended experiences. Both offer prospect and coherence, mystery and complexity, albeit with science preferring the former and art, the latter. The paper concludes with some examples of artscience works that combine all these aspects.

Keywords Art · Science · Artscience · Conceptual metaphor · Metaphorm

1 Introduction

The separation between science and art is not as ancient as it may seem. In Antiquity and the Middle Ages, what we now call "arts" and "sciences" were merely seen as advanced crafts that allowed their practitioners to create impressive results—such as maps, cathedrals, portraits, or elixirs. These bodies of knowledge were based on explorations in domains as varied as geometry, architecture, astronomy, philosophy, poetry and alchemy, albeit without clear distinction between artistic and scientific disciplines (Strosberg 2001). Renaissance figures like Leonardo da Vinci, Albrecht Dürer or Andreas Vesalius combined precise scientific observations (e.g. of anatomy) with beautiful, imaginative renderings of their ideas, sophisticated techniques and novel inventions. Or as Peters explains quoting

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Kittler, “Italian Renaissance, although celebrated for its humanism, ‘was great actually because its artists were engineers.’” (Peters 2015; p.26).

Our modern idea of science as a formal inquiry into the laws of nature only became fully established during the eighteenth century Enlightenment. The famous *Encyclopédie* edited by Diderot and d’Alembert to cover the whole of knowledge available around 1760, still did not make a sharp separation between the fields, as reflected in its subtitle “a Systematic Dictionary of the Sciences, Arts, and Crafts”. However, in part as a reaction against the cold, detached rationality envisaged by Enlightenment thinkers, the nineteenth century movement of Romanticism promoted the artist as a creator driven only by her passion, imagination, and highly personal, subjective experiences. This created a sharp contrast between the archetypes of the intuitive, emotional artist and the dispassionate, rational scientist—a dichotomy that still underlies the view the public has of the differences between art and science, as well as the attitudes of most scientists and artists.

The separation was formalized with the development of academic institutions, in which the different disciplines were relegated to separate departments, institutes, and methods of teaching. This resulted in the still dominant picture of what the scientist/novelist C.P. Snow labeled the “two cultures”: the scientific one, based on hard observations and formal theories, and the artistic/literary one, rooted in soft, subjective feelings (Snow 1993). However, throughout the nineteenth and twentieth centuries artists continued to perform more scientific investigations (e.g. the poet Wolfgang Goethe, the composer John Cage, or the sculptor Alexander Calder), while scientists also expressed their ideas in artistic forms (e.g. the engineer Buckminster Fuller, the mathematician Roger Penrose, or the biochemist/novelist Isaac Asimov).

More recently, the separation between the two cultures is increasingly put into question, both by artists investigating and finding inspiration in new scientific developments, and by scientists presenting a much more creative, uncertain, and subject-centered picture of the world (Brockman 1995; Heylighen 2012; Prigogine and Stengers 1984). Two trends promote this rapprochement. On the one hand, a variety of methods and tools that derive from scientific research, such as algorithms, simulations, robots, sensors, 3-D printers and biotechnology, are becoming available to artists—extending their creativity to new, often science-inspired realms, “bringing forth a diversity of new practices, attitudes, techniques, processes, media, and devices” (Penny 2017). On the other hand, a new science of complexity has arisen, which proposes notions such as self-organization, evolution, non-linearity and chaos to explain the intrinsic creativity of nature, thus cohering with the worldview of the artist (Casti and Karlqvist 2003; Heylighen 2009; Heylighen et al. 2007; Lewin 1999).

This emerging reconciliation between science and art has incited a number of artists and scientists to propose a more radical merger: *ArtScience* (Dominiczak 2015; Siler 2011). *ArtScience* has been defined as a new way of understanding nature and ourselves “through the synthesis of artistic and scientific modes of exploration and expression” (Root-Bernstein et al. 2011). Edwards (2008) describes it as a creative method that “combines the aesthetic and scientific, intuitive and deductive, sensual and analytical, and is comfortable with uncertainty, embracing nature in its complexity”. More generally, we could characterize *ArtScience* as an integrated way to produce new creative insights, which could not be achieved through either art or science alone, or as a new philosophy of research that combines artistic and scientific modes of investigation.

After this first sketch of what *ArtScience* is purported to be, it is worth noting what it is *not*, by distinguishing it from a myriad of possible interactions between science and art that could be easily confused with it. *ArtScience* is not the same as the illustration, visualization

or popularization of scientific results by artists. Here art is merely a support for scientific communication, rather than an integral part of the investigative process. Scientific output that happens to be aesthetic, such as fractal images, or pictures of neurons, bacterial colonies or galaxies, is also not ArtScience, since artistic creativity did not play a role in its generation. Artists who apply advanced technologies, such as computer-generated imagery or sound processing, to produce traditional types of art, such as film, music or installation, are also not working in ArtScience per se, since they use these technologies as tools, without reflecting about the underlying scientific ideas or socio-technological procedures. The same applies to the presently popular “living labs” (Bergvall-Kåreborn et al. 2009; Kiemen and Ballon 2012), “fablabs” (Walter-Herrmann and Büching 2014) and “science shops” (Leydesdorff and Ward 2005), in which people are provided with a variety of tools and technologies, such as 3-D printers, electronic components or chemistry labs, to experiment with and produce creative designs, artifacts and practical solutions. Useful, original and instructive as the resulting products may be, unless they generate truly novel artistic and scientific insights we would not call them “ArtScience”.

All of these are domains in which artistic and scientific approaches come into contact. In that respect they are without doubt valuable, inspiring and educational, extending people’s horizons, creativity, and understanding of science and art. However, we prefer to reserve the term *ArtScience* for a more ambitious enterprise: one that aims at a genuine synthesis between artistic and scientific methods of creation and understanding. Such an attempt at synthesis requires a clear understanding, first, of the common ground between science and art, second, of the actual differences. To achieve this, we will first analyze the creative drive for deeper insight that science and art have always had in common. We will then zoom in on the specific characteristics, such as subjectivity vs. objectivity or rationality vs. intuition, that seem to separate them. This will give us a starting point to understand how these characteristics could be integrated, what problems arise in the attempt to do so and what such a synthetic approach could add to both science and art. We will illustrate these possibilities by briefly reviewing some inspiring examples of ArtScience research. Having thus formulated the problem, in a subsequent paper (Heylighen and Petrovic 2020), we will then try to formulate a theoretical foundation for ArtScience by proposing a model for creative processes and the construction of meaning that encompasses all these characteristics.

2 Assumptions: Concepts vs. Practices

Before we start our investigation, it is necessary to delimit its scope, which is primarily theoretical or foundational. That means that we wish to clarify and make explicit the assumptions that most working scientists, artists and the general public have about what art and science do, and in what way they differ. That will allow us to focus on what precisely ArtScience may contribute to these standard approaches, by proposing new concepts and methods that overcome these differences.

A criticism to be expected is that the conceptual framework for art and science we propose is oversimplified because it ignores the concrete practices of artists and scientists. The argument is that these practices are much more complex and more similar to each other than the idealized picture we will be presenting. Yet, in spite of these practical similarities, a wide gulf still separates the worlds of art and of science, in terms of culture, education, public perception, funding, and societal impact. Artists and scientists are trained in a very different way, think differently about what they are doing, and do not use or get access to

the same resources. The gap between the two cultures remains wide and deep. Bridging it will require new ways of thinking about the two disciplines, both separately and in synthesis, new forms of institutionalization, and new funding models. But that is not enough: to come to a more integral approach, artists and scientists need to develop novel conceptions of the research they are doing, and learn to understand, appreciate and apply each others' way of thinking. That requires extending the outdated, but still prevailing epistemology, which opposes scientific rationality and objectivity to artistic imagination and subjectivity.

One approach is to study how art and science are performed in practice. This is the domain of venerable research traditions, such as science and technology studies, art theory, and the ethnography, sociology, psychology and economics of science and art (e.g. Borgdorff et al. 2019; Latour 1999). The common conclusion from these studies is that these practices are highly context-dependent, difficult to delimit, and much messier than the idealized epistemology suggests. There does not seem to be one well-defined “scientific method”, nor a general “artistic method”. Both scientists and artists tend to use whatever systems, tools or methods that are available and that appear to be effective for what they want to achieve. Some of these may be more “rational” or “systematic”, others more “intuitive” or “imaginative”. Most are just pragmatic and opportunistic. For example, the philosopher and sociologist of science Latour (1996) has explored actor-network theory to explain how large-scale innovations, such as the development of nuclear energy, depend on a complex coalition of human, institutional and physical actors and actions. Similar complexes of interactions drive the practices of science, art, and the growing number of art-science collaborations. The latter have started to be investigated by several authors (Borgdorff et al. 2019; Schnugg 2019; Schnugg and Song 2020; Sormani et al. 2018). This study of art-science practices will undoubtedly teach us important lessons. However, it falls outside the scope of the present paper, which focuses on the conceptual foundations of ArtScience—a crucial issue that has not really been addressed yet (Wilson 2017; Wilson et al. 2015).

Our approach will be to examine the standard, “Western” concepts of art and science—which are still based in the Romantic dichotomy between ratio and emotion, or between subjective and objective. Research on cognition has shown that the concepts we use in our thinking, whether “art”, “science”, “democracy”, or any other broad category, in general do not allow a strict definition. That means that you cannot formulate a list of all the necessary and sufficient conditions that determine whether some phenomenon belongs to the category or not. In the human brain, a concept rather appears to be implemented in the form of a *prototype* (Goldstone et al. 2012): an implicit abstraction that captures the common properties of typical examples of the concept—such as a Van Gogh painting for “art”, or the theory of relativity for “science”. The boundaries of such a concept are fuzzy: a phenomenon is considered to be an instance of the corresponding category depending on the degree to which it resembles the prototype—and in particular how many properties it shares with the prototype. In practice, few (or no) instances share all the properties. Therefore, most concepts do not have any logical “essence”, i.e. canonical features that define the category. They should rather be seen as clusters of typical properties that often, but not always, go together. That means they are *open-ended*: new cases may appear that lack some of the properties, but that possess enough of the other properties so that we would still accept them as instances of the concept. This is a common occurrence in art, where new forms, such as conceptual art, installations or performance art, have tested and extended the boundaries of earlier conceptions of art.

The art theorist Gaut (2005) characterizes art in general as such a “cluster” concept, by proposing a list of fuzzy criteria that artworks typically—but not universally—satisfy:

- being an artifact or performance that is the product of a high degree of skill
- having aesthetic properties
- being an exercise of creative imagination
- expressing emotion
- being intellectually challenging
- being formally complex and coherent
- having the potential to convey complex meanings
- expressing an individual perspective
- being the product of an intention to make a work of art
- belonging to an established artistic form

We do not intend to present this or any other list as a canonical characterization of art. Yet, it seems to us that Gaut's list captures pretty well the standard conception in our present, Western society. A similar list could be developed for science, but given that people are more inclined to agree about whether something is science than about whether it is art, this does not seem necessary for our purposes. Instead, we will start from the common conception that science is a type of objective inquiry based on formal reasoning and empirical testing—without going into further details about what is in practice a much more complex cluster of methods and assumptions. It is these standard conceptions of art and science that we will now examine, compare and attempt to bridge—while noting that the actual practices can never be truly formalized.

3 Where Science and Art Intersect

The easiest way to characterize the meeting ground between artists and scientists is to focus on what they have always had in common: creativity and the search for a deeper understanding of the relation between humans and the world (Root-Bernstein and Root-Bernstein 2000). Both scientists and artists first of all seek to make sense of the phenomena that surround us, exploring different meanings, approaches and tools in doing so. We could say that they do this by creating novel concepts, representations or objects, occasionally developing brand new languages. Both try to look behind the appearances. They help us to step outside of the system of conventions that govern society, critically examining standard assumptions and explanations, in the search for a deeper insight. They do this through an on-going process of exploration, experimentation, or trial-and-error, in the hope of discovering something genuinely new. This exploration is always a bit playful and intuitive, the way children learn by assembling incongruous objects and materials and by using make-believe, pretending e.g. that the ditch is a river full of dangerous crocodiles.

Yet, both artists and scientists still interact with physical processes, if only via their local instantiations in the laboratory or studio. That distinguishes them from philosophers and mystics, whose search for understanding takes place wholly within the thought processes themselves. Artistic and scientific ideas eventually and at least in part get materialized in some form—in a document, artwork, performance, installation, paper or experiment. This concrete realization provides the creator with essential feedback, because the external form typically does not behave the way it was expected to. This forces the creator to correct ideas that do not work as intended, thus improving the creation. The painter who starts to work with colors on a canvas will, looking at the result, conclude that the design she had in mind needs to be further developed in myriad ways. The psychologist who sets up an

experiment to test a hypothesis is likely to note that the subjects do not react to the setting as he expected, and that questions or circumstances need to be adjusted. The philosopher, on the other hand, can be satisfied that her reasoning or “thought experiment” leads to (or not) the logical conclusions she wanted to prove, without having to worry whether such an experiment could ever be performed in the physical world.

Artistic and scientific creativity rely heavily on the mechanism of *stigmergy* (Heylighen 2016a, b; Parunak 2006). Stigmergy was originally proposed to explain the unexpectedly intelligent and creative activity exhibited by insects, such as termites or ants, when they build their complex nests, or develop a network of pheromone trails that connect their nest with different food sources (Grassé 1960). Stigmergy is a form of self-organizing coordination between actions, in which the result of an action (e.g. a pheromone trail) incites an additional action (e.g. further exploration along that trail). Any provisional result, left as a trace of the work done in an observable and editable medium, invites further activity to extend or elaborate the result. Thus, there is on-going feedback between an agent shaping the medium, and the shape stimulating an agent (the same or a different one) to perform further shaping. For example, the traces of paint left on a canvas (medium) invite the painter to correct or complement them with additional patches of color. Similarly, during a scientific discussion, the formulas and schemes drawn on a blackboard inspire further extensions by the participants. This self-reinforcing activity shapes the medium into an increasingly sophisticated expression of the results achieved. Much of the progress in art and science consists in the invention of new languages, methods and mediums that make it easier to express, register and process insights and ideas.

A related characteristic of scientific and artistic creativity (at least in its Western conception) is a relentless drive to explore and experiment, so as to further improve a theory, performance or work. This drive is fueled by the intrinsic passion, curiosity and perseverance that characterize the truly gifted creators (Heylighen 2006; Kerr 2009). The on-going feedback provided by stigmergy further keeps that drive alive by supporting the pleasurable experience of *flow* that tends to accompany goal-directed, creative work (Csikszentmihalyi 1997; Heylighen et al. 2013). Next to feedback, the requirement for flow is that the work challenges individuals to go further and further, using all their skills to tackle the remaining difficulties. This is another feature that science and art have in common: the issues they address are *open-ended* and therefore no result is ever final. There are always challenges that remain and opportunities to further improve and go beyond the present design.

But what precisely is it that artists and scientists are trying to create? Traditionally, science is supposed to search for truth, and art for beauty. Yet, philosophers have concluded that both truth and beauty are ill-defined, relative and subjective notions (Johnson 2008). Therefore, they are poor criteria for judging a work’s (creative) value. A more appropriate criterion may be insight, understanding or meaning (Johnson 2008). Both a good work of art and a compelling scientific theory help us to make sense of our personal life and experience within the larger scheme of things (Klein et al. 2006; Park 2010). They do this by bringing up connections between at first sight unrelated phenomena, directly or indirectly uncovering an unsuspected *coherence*, *pattern* or *order* (Bohm and Peat 2010). In this way, experiences or ideas that can seem confusing or disconnected acquire a deeper meaning, as we discover how they fit in a larger network of phenomena we already intuit and understand.

The sense of coherence, order or harmony that goes with such appreciation often underlies what we call “beauty”. An elegant or beautiful theory is typically one that explains a multitude of observations through a few simple principles that show how these facts fit into a larger whole. However, the insights we get from science and art do not need to be

beautiful in the conventional sense. The evocation by poets or movie directors of the life of soldiers in the muddy trenches of war may be poignant, but it is not beautiful. The scientific observation that certain parasitic insects eat their host from the inside out, while the host is still alive, is certainly not beautiful. However, the biological theory of evolution provides a simple and coherent explanation for why such apparently revolting phenomena occur in nature, thus providing “beauty” at a more abstract level.

This more abstract sense of beauty can perhaps be captured by the notion of *Gestalt*: the perception of an array of data as a coherent whole with a clear meaning (Stadler and Kruse 1990; Van de Cruys and Wagemans 2011a). This occurs by filtering out irrelevant details, adding elements that may be lacking, while bringing forward the pattern or coherence that makes the pieces fit together. A scientific theory, or more generally any cognitive schema, is first of all a *compression* of information: it provides a description of some system or phenomenon that is much shorter than a mere list of all its observed features (Gell-Mann 2003). Similarly, an artwork, such as a theatre play or a portrait, is not a mere recording or photograph that accurately registers every detail of the subject: it is a highly selective representation of the most important or meaningful aspects, bringing into focus their inter-relations. Grasping the Gestalt means being able to fill in the missing parts (see Fig. 1), to reconstruct the whole from the compressed representation, and thus being able to infer the elements that were not yet perceived (Kesner 2014; Van de Cruys and Wagemans 2011a, b).

The art/science of compression consists in unraveling an underlying *pattern* that gives the subject structure and meaning. A pattern can be defined as a motif that recurs in different instances, times or places, albeit with variations. Sometimes the variations are regular and predictable, like in the symmetries that characterize a geometric tiling pattern. Such symmetries are popular subjects of both scientists (e.g. mathematicians, physicists, crystallographers) and artists (e.g. Islamic decorative patterns, or the tilings of M.C. Escher) (Gell-Mann 2003; Strosberg 2001). However, the variations can also be irregular and endless in their diversity, as illustrated by the pebbles on a beach, each of which is both similar and different to any other pebble. The recognition of the deeper similarities behind such superficial variations allows us to make sense of them, by grasping the essential “pattern which connects” (Bateson 1980) these diverse instances, so that we can situate them in our broader understanding of the cosmos. This uncovering of an unsuspected order at a higher level is what makes a pattern beautiful, truthful and meaningful (Bohm and Peat 2010). Both science and art are driven by the search to find, recognize and represent such

Fig. 1 At first sight this picture is just a chaotic array of black dots, but the brain quickly recognizes it as a Dalmatian dog, thus implicitly filling in the missing parts such as legs and tail in order to create a coherent pattern or Gestalt



predictive patterns, albeit that science prefers to focus on their regular, precisely repeating, universal aspects, while art tends to approach them by expressing unique, specific instances—as we will now examine in more detail.

4 Where Science and Art Diverge

After reviewing what science and art have in common, it is worth examining in which ways they differ. In other words, what precisely constitutes the conceptual gap that separates the “two cultures”?

Science is supposed to strive for objectivity, precision and universality. It tries to create representations of phenomena that are unambiguous, and independent of a particular perceiving subject, perspective, time or place (Heylighen 1999). In its idealized conception, the output of scientific research is a “natural law”: a statement that is true always, everywhere and for everyone. To achieve this, science tries to make its methods as explicit as possible, so that everyone can follow every step of the reasoning to check whether the right conclusion was reached. This tends to prevent any uncertainty about what was concluded. Such explicit, step-by-step reasoning is what we call *rationality*. But science goes even further than the rational reasoning that a philosopher might use. To avoid the ambiguity of language, science uses *formalization*: expressing concepts in an as explicit as possible way, ideally using mathematical definitions and axioms. To link theories back to the real world, science relies on *operationalization*: specifying the precise operations, such as experiments, set-ups or measurements, that establish how theoretical concepts are to be translated into concrete observations (Barad 2007; Heylighen 1999).

Thus, science tries as much as possible to eliminate the role of the human subject—ideally creating representations, such as those of mathematics, that even machines can understand, test and apply. The advantage is that scientific knowledge is the most reliable of all forms of knowledge: you do not need to worry whether a particular law is applicable to you, here and now: in principle, it is universally applicable. To achieve this, science preferentially focuses on phenomena that are regular, predictable and simple, so that they can be captured in formulas or laws that are invariant across multiple domains.

Art has chosen the opposite route: prioritizing the subject and her personal perspective and experiences. Since every person experiences phenomena differently, this means that art has embraced *ambiguity*: the same artwork may mean one thing to one person, and a completely different thing to another person, or even to the same person at another moment or in another context. Thus, art does not aim to establish universal truths. Rather, art likes to investigate the unpredictable, the transient and the subject(ive). In that respect, art has a much greater freedom of exploration and imagination than science, because it does not need to stick to formal or operational procedures that supposedly map “objective reality” onto a representation. However, this does not mean that artistic creations are merely random or chaotic: as we noted earlier, art searches for patterns, insights and connections that are meaningful or *significant*, thus helping people to better understand their (subjective) situations. Art does this by creating experiences that *move* people out of their usual way of perceiving, so that their attitudes towards the subject can shift towards a deeper appreciation and understanding.

To create such (*e-*)*motions*, art does not rely on the logical, step-by-step processes of analysis and reasoning that characterize our symbolic, conscious intelligence (Heylighen 2019). It rather relies on the holistic, intuitive processes of knowing, recognition

and association that characterize the neural networks of our “subsymbolic,” subconscious brain. The general trend in cognitive science over the past half century has been to move the focus from abstract, rational thinking to the “experiential”, “situated”, and “embodied” character of human intelligence (Clark 1998; Johnson 2008). This does not deny the value of logical reasoning, but notes that it is merely the visible, “conscious” tip of the iceberg, which rests on a much larger, subconscious mass of intuitions and associations.

Whereas science relies on operationalization and formalization to support rational thinking and communication, art produces signs whose meaning is not so rigidly defined. The meaning of signs continuously emerges from the experiences and associations of the public, evoking feelings and intuitions. Two important types of such signs are *icons* and *metaphors*. In semiotics (Merrell 2001; Hawkes 2003), an *icon* is defined as a sign that conveys a particular meaning by its resemblance to the phenomenon it refers to. Thus, a marble sculpture may resemble a human body, while a painting may resemble a landscape. But this resemblance is not physical, but mental: an array of dots of paint on a canvas is completely unlike the mountains, clouds and trees of an actual landscape. Yet, the impression it makes on our visual cortex is to some degree the same, eliciting similar feelings, insights and intuitions. Here, the similarity is still rather evident and concrete. Less obvious patterns, however, like in music, ballet or abstract paintings, can equally stimulate the associative and pattern-recognizing mechanisms in our brain, thus evoking sensations, expectations and emotions at the more abstract level of intuited structures and processes rather than concretely recognizable objects (Johnson 2008).

A metaphor conveys meaning not by its resemblance to the subject denoted, but by the resemblance between the phenomenon it normally denotes and the one it metaphorically denotes. For example, saying that someone has a face like a thunderstorm suggests a dark, potentially violent demeanor that is ready to erupt. A thunderstorm is a powerful, intuitive image that evokes strong feelings and associations. Metaphors in art function in a way like formal models in science: they make abstraction of physical phenomena, while pointing out analogies or correspondences between abstract processes and features—such as the imminence of a violent outburst.

The theory of *conceptual metaphors* (Lakoff and Johnson 1980, 2008) further clarifies the link, arguing that all our abstract conceptualizations, including those of mathematics (Lakoff and Núñez 2000), in fact rest on a metaphorical understanding. This theory shows how our cognition is rooted in bodily experiences, such as moving through space or manipulating objects. Our understanding of such embodied interactions is partly inborn, partly the result of the uncountable experiences we have had interacting with the world since infancy. Therefore, it is direct and intuitive, and does not need to be explained, defined or justified. That is why we express abstract concepts when possible metaphorically, in terms of embodied, spatial and motoric notions. For example, we describe a level in a hierarchy of systems as “above” another one, an element as being “inside” a set, or a dynamic system as “moving” along a “path” through its phase “space” or energy “landscape”. These conceptual metaphors are of course not limited to science: they make up much of our everyday language and other means of expression. This includes music, where, for example, the building tension and eventual outburst typical of a thunderstorm can be easily expressed in sound. Therefore, conceptual metaphors are equally fundamental to the meanings expressed in art (Johnson 2008, ; Wilson 2017).

Icons in art function a bit like operational set-ups in science: both transform abstract ideas and feelings into observable, physical phenomena. For example, a plot may be “operationalized” or “enacted” by the actors on a stage. The arts scientist Siler (2011) has proposed to group together all these concrete—artistic or scientific—set-ups, representations,

and installations as *metaphorms*: tools that help us to think, feel and connect by giving a perceivable form to our abstract conceptions. A metaphorm can then be seen as a concrete implementation or embodiment of a conceptual metaphor (Heylighen and Petrovic 2020).

However, there remains an essential difference in the way these abstract and concrete tools are used in art and in science: the meaning of icons and metaphors is intrinsically subjective, fluid and open-ended, while the meaning of operations and formalisms is supposed to be objective, universal, and rigidly defined. Artworks appeal to intuition and imagination by bringing forth experiences that elicit feelings or generally, a subjective response. These feelings are realized as the neural activation of particular concepts in the brain that spreads to associated concepts. But this happens in a way that is strongly dependent on person, time, and context, and therefore essentially unpredictable. Therefore, the interpretation of an artwork is always ambiguous. Science appeals to systematic, rational thinking that follows formal and operational procedures to make people come to conclusions they would not have come to otherwise. It broadens our awareness by introducing new concepts, dimensions or properties that open new spaces of possibility. But these spaces are formally defined, and their exploration follows explicit, dependable rules that are not supposed to depend on personal feelings.

Cognitive science has by now recognized that both intuition and reasoning are essential mechanisms in the human mind, sometimes designating the former as “connectionist” or “sub-symbolic” and the latter as “symbolic” (Kelley 2003), or the former as “system 1” and the latter as “system 2” (Kahneman and Egan 2011). Rational thinking is slower and more deliberate in systematically considering different elements, steps, and options. Intuition is faster and more holistic, recognizing complex patterns and associations all at once at a subconscious level, yet without being able to justify its conclusions. Both have their strengths and weaknesses, and both are eminently fallible. They work best when the one supports the other—which is what happens in both scientific and artistic practice. However, in the standard epistemology and education model, scientists are still admonished to insist on rational thinking and artists to focus on intuitive feeling and intimate understanding. This is counterproductive, because it makes them miss out on the great potential synergies between these two modes of cognition.

A final divergence between art and science may be captured by the distinction between “idiographic” and “nomothetic” approaches (Thomae 1999). This distinction was proposed in psychology to express the fact that understanding people requires both universal and unique elements. On the one hand, each person is a unique subject that can only be understood by a specific, *idiographic* description of what makes that person different from others—such as that person’s biography or portrait. On the other hand, all people share characteristics, such as memory, love and fear, that are best expressed as general, *nomothetic* rules about human psychology. More generally, science is nomothetic, as it seeks for universal laws, while art is idiographic, as it tends to focus on unique, individual phenomena. This epistemological difference may explain why such a high (monetary) value tends to be placed on original, unique artworks, such as paintings. On the other hand, no one in science would care about the original piece of paper on which an equation was first written down: they would just use the equation in their work, with at best a cursory reference to the originator of the theory.

To summarize the differences according to the standard view, science focuses on the properties of phenomena that can be universally observed and formally reasoned about. Art focuses on the subjective experiences and intuitions of one or more individuals confronted with a unique situation. Our envisaged artsience synthesis would re-emphasize the existing commonalities between art and science, while trying to bridge the remaining

differences—albeit well-aware that new differences are likely to emerge when theory is implemented into practice. That means that it would seek an explicit synergy between logic and intuition, subject and object, or the universal and the unique. This may be achieved by creating “metaphorms” that appeal to both our personal feelings and our rational powers of analysis. What should really count are the insights produced, not whether the metaphorm is categorized as scientific or artistic.

Let us then try to formulate more general criteria for “insight”, “interestingness” or “meaning” to replace the beauty-truth, intuition-logic, or subject-object dichotomies that separate the two cultures. For this we can find inspiration in the literature that analyses the “interestingness” or aesthetic appeal of landscapes, using the criteria of prospect, mystery, coherence and complexity (Aoki 1999; Kaplan 1988; Stamps III 2004).

5 Landscapes of Science and Art

In earlier work (Heylighen 2012), we have proposed to bridge the gap between the scientific and the narrative cultures by starting from the notion of an *agent*, i.e. a subject that is acting in the world. The agent has to deal with external, “objective” phenomena that may either facilitate or obstruct its intended course of action. This on-going interaction between subject and object can be understood with the help of the following conceptual metaphor: the agent encounters a series of *challenges* as it follows a path across a landscape of obstacles and opportunities. These challenges evoke emotions and incite actions to deal with them. They thus make the agent deviate from its initial course of action. This is analogous to the way physical forces, such as impact or gravitation, make an object deviate from its initial trajectory through its state space or energy landscape. Thus, an agent can be seen as following a meandering path through a landscape of possibilities, where this course is affected both by its internal preferences and by the outside challenges it encounters. This metaphor can be recognized in the stories, myths and fairy tales of narrative culture (Campbell 1949), but also in the dynamical systems models used in science (Heylighen 2012).

The difference between the narrative (or “artistic”) and scientific uses of this metaphor can be clarified by introducing the notion of *prospect*: to what extent is it possible to foresee the challenges or forces that will affect the agent’s trajectory? The traditional or “Newtonian” scientific approach assumes that from its “God’s eye” or “cosmic” point of view, high above the landscape, everything is in principle foreseeable: once you have carefully observed all the features of the landscape, you can accurately predict which phenomena will be encountered where and when, and thus map out the trajectory. In this view, experiments merely serve to either check predictions, or to collect the missing bits of information. The standard artistic approach starts from the local point of view of the subject on the ground, whose prospect is necessarily limited by various obstacles, the haze of distance, and eventually the horizon. Thus, subjects, and with them art, are confronted with vagueness, uncertainty and surprise: they cannot foresee everything that lies ahead, and will sooner or later encounter something unexpected. Experiments therefore are open-ended and their results essentially unpredictable.

The in-between perspective notes that the degree of prospect is variable (Heylighen 2012): some things can be better foreseen than others, but nothing is fully predictable. That means that artscience experiments can be guided by predictive hypotheses based on scientific knowledge, but that they should also leave plenty of space for *serendipity*, i.e.

the discovery of unforeseen and unforeseeable effects. An unfortunate effect of the present funding model for scientific research is that scientists are supposed to propose detailed plans specifying the different objectives they expect to reach, as well as the strategies and methods through which they intend to attain these goals. That makes it very difficult to deviate from the proposed course of action and thus perhaps discover something that is much more important than the “safe” objectives formulated in a proposal. ArtScience research, in contrast, could explicitly focus on novel, uncertain issues, where the methods and outcomes are as yet only dimly known.

A second feature characterizing landscapes and the phenomena they contain is their degree of *mystery* (Gimblett et al. 1985; Heylighen 2012; Kaplan 1987). A situation is considered mysterious if its precise characteristics are as yet unobservable or unknown, but it can be foreseen that with the necessary effort of investigation such knowledge may be obtained. Mystery, as a gap in our knowledge that calls out for resolution, is a strong driving force for both artists and scientists, inciting curiosity and the desire to explore (Kno-bloch-Westerwick and Keplinger 2006; Loewenstein 1994).

The “predictive coding” theory of cognition states that the brain is constantly trying to predict what will happen on the basis of the information it receives through the senses, but that it checks those predictions by looking for additional information that may or may not confirm them (Kesner 2014; Van de Cruys and Wagemans 2011a, b). Whenever it discovers an incongruity or gap between expectation and perception (i.e. a surprise or mystery), it focuses its attention on resolving that gap. The perceived gap creates arousal, interest, and more generally emotion (see Fig. 2). A gap that cannot be resolved tends to produce negative emotions, such as anxiety or confusion. However, the successful resolution of the gap, through the discovery of a pattern or Gestalt that restores predictability and meaning, produces a strong positive feeling. That is why artists often produce at first sight anomalous, ambiguous, or incongruous representations, like in op-art, surrealism or abstract expressionism, that however make sense on further reading, thereby forcing the mind to find non-obvious connections. The resulting curiosity, emotion and excitement adds to the aesthetic appreciation (Kesner 2014; Van de Cruys and Wagemans 2011a, b). Similarly, the most exciting scientific ideas are the ones that bring to light or resolve a paradox, mystery or gap in our knowledge, rather than merely confirming or elaborating a well-known theory.

However, in science the appeal of mystery remains implicit, since it is not part of the scientific method as taught in schools or of the criteria used to assess the quality of scientific theories or observations. Moreover, the eventual full theory is supposed to eliminate all mystery. Artists, on the other hand, often create mystery on purpose, e.g. by leaving some information about the protagonist of a story in the dark, or by hiding or leaving unfinished some parts of their painting or sculpture. The reason is that mystery stimulates the imagination, thus providing the audience with a richer sense of interest, insight or inspiration than if all the details were spelled out. A typical ArtScience work would neither artificially create mystery where there is none, nor try to deny or hide its existence, but rather make the remaining mystery more visible by highlighting the residual unknowns, and thus stimulate the audience to continue reflecting about the subject.

Prospect and mystery were initially proposed as properties that may explain the beauty of landscapes: people tend to like landscapes where they can see widely and clearly what lies ahead (prospect), but where some parts remain hidden, hinting at further discoveries if only the obstacles could be circumvented (mystery). Two other aesthetic criteria from the literature on landscape appreciation (Aoki 1999; Kaplan 1988; Stamps III 2004) may further elucidate the similarities and differences between science and art: coherence and complexity. *Coherence* is similar to what we have previously called pattern, order or harmony:

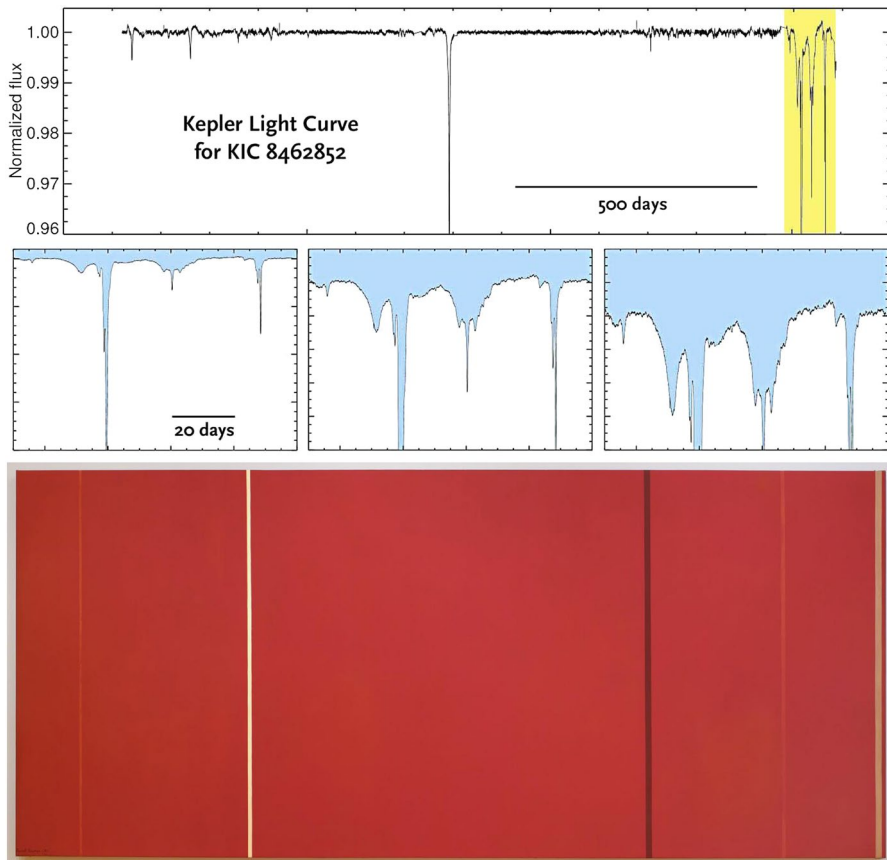


Fig. 2 Anomalies in seemingly regular patterns inspire interest and excitement both in science (unexplained irregular dimmings of the star KIC 8,462,852, above two panels) and in art (painting by Barnett Newman, *Vir Heroicus Sublimis*, 1950, below). Image source: [link](#)

the observation that at first sight disparate elements are connected at some higher level, thus forming a whole or Gestalt. Coherence helps us to distinguish signal (meaningful information) from noise (irrelevant background stimuli): the moment an apparent anomaly can be linked to other observations, it acquires a basic meaning or significance. This can be illustrated by the Cocktail Party Phenomenon: in the hubbub of many people speaking at the same time, we can still selectively attend to what one person is saying, thus picking up this one signal while effectively shutting out the background noise from further processing. However, if something is said in the background that connects to the on-going conversation (coherence), the brain will pick this up as well. Coherence is something both science and art strive for, and that as such should obviously be part of their synthesis.

Complexity, on the other hand, seems to be more typical for art investigations. In the landscape context, it denotes diversity and heterogeneity of elements, richness of detail, and the fact that structure can be recognized at different levels or scales (like in fractals). Scientific theories or experiments try to be as simple as possible, by reducing phenomena to their elementary components. While such reductionism can be useful for understanding and for prediction, it ignores the intrinsic complexity of life and nature. That is why

contemporary science has allowed complexity to enter in its models and computer simulations of self-organization, evolution, or interacting agents (Heylighen et al. 2007; Lewin 1999). Artscience too should not only allow, but embrace complexity in its designs and experiments, however, while equally seeking for clarity and simplicity where such simplicity can be found. Thus, it would be able to capture the richness of a universe that is both highly differentiated (diversity, complexity) and integrated (order, coherence) (Heylighen et al. 2007).

Let us then look at some illustrative examples of such creative work that combines coherence with complexity, prospect with mystery, and universality with uniqueness.

6 Some examples of ArtScience Research

We noted that the rapprochement between science and art came from both directions: new scientific theories accepted that creativity, complexity and subjectivity are an integral part of nature, while new artistic movements found tools, systems, and inspiration in science. Long before the term “ArtScience” was coined, artists and scientists have been producing such work, inspired among others by cybernetic theories, electronic technologies and new media that supported a much more interactive, process-based approach to the creation of meaning (Penny 2017).

A memorable example is “Corticalart”, a 1971 performance/musical piece (Arslan et. al. 2005). It resulted from the collaboration between the avant-garde composer Pierre Henry and the researcher Roger Lafosse, who had built a device that sensed brain waves—via electrodes attached to the skull—and converted them into sound. Henry gave a “concert” in which his brain waves were the source of an eerie electronic music veering being rhythmic “noise” and meditative, recurring motifs. Interestingly, Henry heard the music produced by his own brain, and thus his brain waves were influenced by their own prior output, in an on-going feedback loop. Many artists have since then created works on the nexus of neuroscience and music, specifically brain waves and sound.

This Corticalart music can be seen as a metaphorm for the activity of the brain: it “embodies” the abstract patterns in a way that we can concretely hear and feel because of our highly developed sense of rhythm and melody that engages our intuition and feelings in discerning and predicting patterns across time (Johnson 2008), and this much more so than the more traditional representation of brain waves as scribbly lines on a piece of paper. The concert is both a scientific experiment, since it registers data via the electrodes about an “objective” phenomenon, brain activity, and an artistic performance, since Henry selectively combines, amplifies and manipulates the different sound sources that correspond to differently placed electrodes so as to create a more “aesthetic” experience. The feedback loop closes the circle between science and art, subject and object, thus making them inextricably linked.

A more recent illustration of this convergence is the presently ubiquitous use of computer simulations. These simulations are based on programs that follow formal, logical rules that are often derived from scientific theories—such as the rendering of reflections from different light sources according to the laws of optics. On the other hand, these programs are often used for creative expression. Here science and art have already met, but they still go their own ways. The artist using the rendering program generally does not care about the laws of optics, and the scientist who formalized these laws in computer algorithms generally does not care what the artist would like to draw with the program.

The cross-fertilization between science and art becomes clearer when the results of the simulation are *emergent*: neither preprogrammed, nor determined by the fancy of the user, but the result of some complex interaction between rationally formulated rules and intuition-guided imagination. The work of the computer artist Sims (1994), “Evolving Virtual Creatures”, provides an elegant illustration. First, Sims created a preprogrammed virtual world that obeys laws of physics such as gravity and friction. Then, Sims generated three-dimensional “creatures” that were supposed to move in this world. The creatures were assembled from blocks that could move relative to each other along their joints. Their movement was controlled by a rudimentary nervous system that specified when and how much each block should move. Initially blocks, joints, and nerves were assembled purely randomly. The resulting creatures and their movements were understandably awkward. But Sims added a form of evolution to the program, so that creatures that moved more effectively were allowed to reproduce with variations, while less effective movers were eliminated. After many generations of such “artificial” selection, the remaining creatures moved rather elegantly in their three-dimensional virtual world, while taking into account the physical constraints of gravity and friction. One remarkable result is that some of these forms of movements, such as jumping like a kangaroo, crawling like a snake, or walking on two or four “legs”, were recognizably similar to those of existing biological creatures. But even more remarkable is that others, like rolling over, cartwheeling or even more bizarre ones for which we lack the words to describe them, are unseen in the natural world. Still, these creatures and their movements are physically plausible, inspiring and aesthetic to watch.

Are the “evolving virtual creatures” a scientific or an artistic creation? They are unique, unlike anything that exists, beautiful, while lacking an unambiguous interpretation. They also do not confirm or falsify any pre-existing rule or prediction, and do not entail any logical conclusions. In that way, they appear like the product of an artist’s imagination. On the other hand, they not only require advanced scientific knowledge for their generation, but they add to that scientific understanding, by confirming the creativity and versatility inherent in the theory of evolution and our understanding of rudimentary nervous networks, and by suggesting ways in which evolution might have taken a very different route to produce movement.

Sims’ “artistic” work is actually very similar to the one done in the “scientific” discipline of *artificial life* (Langton 1997; Maes 1995; Prophet and Pritchard 2015). Here too, researchers make simulations that illustrate how virtual creatures that resemble living organisms in their behavior and properties can self-organize and evolve in virtual ecosystems. Their focus is less on the visual rendering of the creatures, though, and more on the statistics of which kinds of creatures perform which kinds of activities. But the creatures and their behaviors are still unique, emergent, and unpredictable. Therefore, the interpretation of their behavior cannot be left to formal rules, but must include human intuition and imagination, which is helped by an aesthetic representation of the results.

Another instructive example of this kind of work is the “virtual laboratory” developed by Gershenson to experiment with different behavioral rules for artificial creatures (Gershenson 2004). These “agents” were in this case designed, not evolved. Agents were programmed to survive in their virtual environment by searching for food and water, while avoiding predators and obstacles. Since these items appear at random times and places in the landscape, each “run” of an agent is different, as it constantly needs to adapt to unforeseen challenges. Such a “run” can be seen as a unique, idiographic representation of the subjective experiences and reactions of an individual agent. Thus, it constitutes a narrative recounting of the “life story” of that particular agent (Heylighen 2012). Its visualization is

like a movie of that agent's course of action. This is the artistic perspective. The scientific, nomothetic perspective consists in collecting many runs performed by different agents following different rules, in order to extract general patterns (e.g. that agents following a certain system of rules survive better than those following different rules).

ArtScience of course does not need to remain limited to computer simulations or electronics. Two more recent examples produce patterns with actual physical materials. Adam Brown creates art and science hybrids including robotics, molecular chemistry and living systems that are expressed in interactive objects, videos, performances and photography. His installation *ReBioGeneSys—Origins of Life*, which he created in collaboration with the life scientist Robert Root-Bernstein, is a functioning scientific experiment that combines sculpture and chemistry to create minimal ecosystems capable of evolution (Brown, and Root-Bernstein 2015). Natural conditions relevant to the origin of life, such as dry–wet, frost–thaw and dark–light cycles, can be generated within the apparatus. This stimulates a variety of chemical reactions that produce an ever-growing variety of interacting molecules similar to those used by living cells. Some of these prebiotic compounds survive to participate in further evolution, others go extinct. The apparatus can be adapted to mimic a wide variety of physical conditions, not only on Earth, but e.g. on the moon Titan or the planet Mars, thus enabling endless, self-organizing, creative evolution.

Evelina Domnitch and Dmitry Gelfand create sensory immersion environments that merge physics, chemistry and computer science to visualize and explore deep scientific/philosophical issues as well as the limits of human perception. In their installation *ER=EPR* (Domnitch and Gelfand 2017), two co-rotating vortices, joined together via a vortical bridge, drift through a body of water, appearing like black holes connected by a wormhole link. As soon as the bridge rips apart, the vortices immediately dissipate, analogous to the collapse of a wave function in quantum mechanics. The work suggests that gravitational wormholes may underlie the mysterious phenomenon of quantum entanglement as expressed in the EPR (Einstein–Podolsky–Rosen) paradox. The concepts of entanglement and wormholes here are supposed to be objective and universal, as are the laws of hydrodynamics that govern the movement in the liquid. On the other hand, the actual vortices generated in the installation are each time unique, while the impression they make on the spectator is subjective and aesthetic. The installation provides a unique intuitive prospect on how a wormhole could form and disintegrate, while highlighting the mystery of whether such a process may underlie the still poorly understood collapse of a wave function.

7 Conclusion

Science and art have a long history of developing side by side. Sometimes, like in the Renaissance or in the work of architects and designers such as Buckminster Fuller, they converge to a creative endeavor that is both rational and intuitive, aesthetic and logical. In other epochs or contexts, the “two cultures” seem to be separated by a wide gulf of mutual misunderstanding and suspicion, where the one insists on a dispassionate, rule-governed search for an objective “truth” and the other on unbridled imagination and expression of subjective feelings and perspectives. More recently, there again seems to be a growing momentum for convergence, or at least collaboration, between scientists and artists. This movement is being carried forth most radically under the label of “ArtScience”, which seeks for a genuine synthesis between the two methods of creating and understanding.

This paper has tried to lay some of the groundwork for understanding the possibilities of such a synthesis, by examining both what science and art have always had in common, and where they have diverged. We argued that their common core encompasses a creative search for meaning, i.e. a deeper insight or understanding of human beings and their relation to nature, the world, or the universe. This search makes use of “metaphorms”: concrete set-ups or representations that implement or embody abstract or intuitive insights, and that thus help scientists and artists to confront their ideas with the real world, while stimulating their creativity via the mechanisms of stigmergy and flow.

The insights themselves can be seen as “patterns which connect”: initially hidden orders or Gestalts that compress or summarize an apparent chaos of experiences into a coherent whole. The significance we find in these patterns can be expressed by their degree of prospect, mystery, coherence and complexity. Science tends to focus more on the predictability, order and universality associated with prospect and coherence, and art more on the uncertainty, openness and uniqueness associated with mystery and complexity. Yet, we reviewed several examples of ‘artscience’ works that integrate all these aspects, illustrating that they are perfectly compatible.

However, there is still an essential divergence between art and science that we have largely glossed over: the one opposing the subjective, intuitive and emotional to the objective, logical and rational. In a subsequent paper (Heylighen and Petrovic 2020), we will therefore propose a model of the creation of meaning that explicitly integrates these two poles. This should allow us to formulate foundations for the domain of ArtScience, thus preparing the grounds for the project of a genuine synthesis between the two cultures in the domain of theory, perhaps leading us towards a true philosophy (aesthetics) of ArtScience work(s).

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