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VIEW POINT

# The 'Great Divide': How the Arts Contribute to Science and Science Education

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**Abstract** In recent years, there has been a rapid growth in interest about the relationship between the arts and the sciences. This article explores this developing relationship and the suggestion that science and science learning are not complete without the arts. We see three levels at which the arts might improve the teaching and learning of science. The first is at a macro-level, concerned with ways in which subjects (including the arts and sciences) are structured and options for studying them provided and packaged. The second is at the meso-level, guiding approaches constructing science curricula that engage learners through using STS (Science, Technology and Society) contexts. The third is at the micro-level, of pedagogical practices in science and teaching that can be drawn from the arts. The drivers of STEAM (Science, Technology, Arts, Engineering and Mathematics) add new dimensions to the nature of science in the twenty-first century and make science likely to diverge even more rapidly from school science unless new pedagogies, including those from the arts, help close the gap. The result could be a more authentic and engaging school science, one more relevant to the needs of the twenty-first century.

**Résumé** Les dernières années ont marqué un intérêt grandissant pour les liens entre les arts et les sciences. Cet article propose d'analyser ces liens en développement, ainsi que l'idée que les sciences et l'apprentissage scientifique ne sont pas complets sans les arts. Nous distinguons trois niveaux où les arts sont susceptibles d'améliorer l'enseignement et l'apprentissage des sciences. Le premier, le niveau macro, s'intéresse aux façons dont les sujets scolaires (y compris les arts plastiques et les sciences) sont structurés, et comment les différentes options pour les étudier sont proposées et présentées. Le deuxième niveau, intermédiaire, guide des approches visant à la construction de curriculums scientifiques qui stimulent l'intérêt des apprenants par le biais de contextes STS (sciences, technologies et société). Le troisième, soit le niveau micro, se penche sur des pratiques pédagogiques en sciences et en enseignement qui sont dérivées des arts. Les facteurs qui influencent les sciences, les technologies, les arts, l'ingénierie et les mathématiques ajoutent de nouvelles dimensions à la nature des sciences au 21ième siècle et augmentent le risque que les

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sciences se démarquent encore plus rapidement des sciences en milieu scolaire, à moins que de nouvelles pédagogies, y compris celles qui proviennent des arts, ne contribuent à réduire cet écart. Le résultat de telles pédagogies pourrait déboucher sur des programmes de sciences à l'école plus authentiques et plus motivants, et aussi plus pertinents compte tenu des besoins du 21ième siècle.

**Keywords** Curriculum · Policy development · Science-arts collaboration

In recent years, there has been considerable growth in the literature devoted to relationships between the arts and the sciences. A development and application of this is evidenced in the moves in several countries to consider a STEAM curriculum instead of a STEM one—in other words, adding 'Arts' to 'Science, Technology, Engineering and Mathematics' (Marshall, 2004; Lunn & Noble, 2008; Colucci-Gray, Burnard, Cooke, Davies, Gray, & Trowsdale, 2017; Harris & de Bruin, 2018; Skorton & Bear, 2018). This comes at a time of continuing unease about the effectiveness of science education and trends in low youth engagement with science (Archer, DeWitt, Osborne, Dillon, Willis & Wong, 2013; Schmidt, Burroughs & Cogan, 2013; Royal Society, 2014). This article, while not a formal review, explores the developing relationship between the arts and sciences and the suggestion that the enterprise of science and of learning it increasingly benefit from the arts and that science and science learning at all ages are consequently less complete. The questions we address are:

- What might the arts provide that would make the sciences more complete?
- In a world where many young people turn from learning science and involvement in it, what can we learn and take from the arts that might improve the teaching and learning of science?

As will become clear, we understand the arts as including more than the visual arts; we also refer to 'the sciences', to make a parallel with 'the arts' apparent and to acknowledge that science includes a range of disciplines. We start by providing a brief historical overview, so as to contextualise contemporary issues on which we subsequently focus. Our particular interest is in the science education provided by primary and secondary schooling and our main intention in this article is to present the argument that the current way science is perceived and adapted for science education has substantial shortcomings for contemporary science education.

## Science and Art in Culture and Civilisation

Art seems to be as old as cognate human existence. It is commonly recognised that art, in expressive visual form, dates as far back as the late Palaeolithic (about 40,000 BCE). Figurines, beads and decorative art on functional objects such as handles, implements and simple vessels for food and water are evident from Mesolithic to Neolithic times and later, with the first emergence of pottery (Preziosi, 1989).

With refinements in hieroglyphics and the advent of written languages, art in storytelling and illustrated texts evolved, often simultaneously, alongside the extraordinary visual art of civilisations across Africa, Arabia, the Eastern Mediterranean, Central and Southern America, Australasia and Polynesia-Micronesia. With the development of language, new literary art forms of poetry, fiction and theatre became possible. It seems that humans across their diaspora simultaneously advanced their art as an essential part of progressive civilisation. Today, the arts can be considered to include the visual arts (including drawing, painting, sculpture, filmmaking, architecture, photography ceramics), literature (poetry, drama, prose fiction) and the performing arts (theatre, dance and music).

As far as the earliest manifestations of 'science' in culture are concerned, these are more difficult to pin down. Partly this concerns the word 'science', which only came into common use (at least as we now understand it) in the early nineteenth century (Heidegger & Grene, 1976). This is not to say that science as a distinct activity did not exist in prehistory. Observations and calculations of, for example, the Earth's precession around its axis and the solar year and lunar month are known from Mesopotamian and Babylonian carved tablets of around 3500 years BCE (Steele, 2000).

In modern times, historians and philosophers have come to a consensus that sees science as a body of empirical, theoretical and practical knowledge about the natural world, produced by people ('scientists') who emphasise observation, explanation and prediction of real-world phenomena (Whitehead, 2011). As such, modern empirical science is a development of what was called 'natural philosophy' from the time of Aristotle through to the eighteenth-century Enlightenment and nineteenth-century origins of modern science. Stemming from Baconian beliefs of inductivism and empiricism, scientific 'methods' were considered to be fundamental to modern (empirical) science, especially of the physical and biological kind. Thus, the enterprise of doing science (and to some extent of learning it) has often been (and still is) presented as a progressive narrative in which true theories replaced false beliefs (Bereiter, 1994).

Alternative, expansive interpretations of science, such as those of Thomas Kuhn, portray science in more nuanced, terms, such as that of competing paradigms or conceptual systems in a wider matrix that includes intellectual, cultural, economic and political themes, considered by traditional 'Baconists' to be outside science (Kuhn, 1970). Unfortunately, for many school students, the more restricted view of science founded on Baconian traditions has often led to perceptions of science as a fact-driven enterprise divorced from the culture in which it exists and serves. These views have prevailed in the history of education in science (Driver, Leach, Millar & Scott, 1996). At the same time, as we discuss below, there are, thankfully, many examples of teachers attempting to introduce students to a more creative and engaging experience of science (e.g. McGregor, Wilson, Bird & Frodsham, 2017). Our own view is that it remains the case that one of the great strengths of science (which we take to mean the natural sciences—principally biology, chemistry, physics and earth sciences) is that science does seek for reliable knowledge that has a substantial underpinning objectivity—so that, for example, chemical reactions undertaken in the same environmental conditions proceed independently of who is observing them. We are very well aware of arguments within science and the philosophy of science about the ways in which observers affect what is observed (Schrödinger's cat, quantum entanglement, etc.) but our argument does not rely on any particular resolution of such issues.

## The Arts and Science: How Science Might Be Made More Complete by the Arts

We use the word 'complete' in the phrase 'science might be made more complete by the arts' with two emphases. First, we make the claim for science, independently of education. Let us be clear that we do not mean there is an absolute requirement for the arts in order for science to exist or proceed. Science seems to have done quite well in recent times without much overt recourse to the arts. There are, however, subtle and more covert ways in which the arts and the sciences co-exist and are (or should be) interdependent. Some of these are seen in the personal lives of scientists. Root-Bernstein et al. (2008) showed that Nobel Prize winners and members of the National Academy of Sciences and the Royal Society were more likely than other scientists, or even the population at large, to have hobbies or abilities in the arts. Secondly, we make the claim with reference to the successful teaching of science.

We now put forward four main premises in our argument that science is made more complete by its relationship with the arts. We use these to lead to a fifth premise, establishing a case for the arts to enhance the ways in which science courses and teaching methods might change to make science learning more authentic and engaging.

1. *The subject boundaries premise*: Divisions between curriculum areas (school subjects) run counter to the life experiences of learners of all ages.
2. *The cognitive premise*: The work of science needs creative as well as critical thinking to allow discourses that empower and fuel discovery and innovation and allow risk-taking.
3. *The neuroscience premise*: Thinking in science is stimulated by artistic activity.
4. *The collaborative, economic premise*: Collaboration between arts and sciences and *vice versa* is at the heart of the modern economy.
5. *The pedagogical premise*: The final justification is embedded in science education: organising curricula to accommodate science and arts and drawing on pedagogy normally associated with the arts offer fruitful ways to engage learners in school science and help them learn and to help prevent young people turning away from science.

We now consider key aspects of these five premises in more detail. Our focus is on the teaching and learning of science, so we spend less time on the aspects of these premises that are more to do with science than with science education—which is particularly the case for premise four. However, we feel that for the argument about teaching and learning to hold, and to change how science is typically taught in schools, it is important that educators believe they are still being true to science.

## Cultural and Subject Boundaries

It has been suggested that the subject disciplines of the curriculum have evolved structures and characteristics that create boundaries between them and that this limits cross-disciplinary collaboration (Phelan, Davidson & Cao, 1991). Indeed, Goldberg (2008) argues that the panic that the launch of Sputnik in 1957 caused among US government not only, as is widely acknowledged, gave rise to a new drive to improve the teaching of science and mathematics in schools but also meant that education, instead of being seen as a way of cultivating an engaged member of society, became the vehicle for discrete subject expertise. Dillon (2008) sees disciplinary borders favouring a utilitarian view of knowledge and creativity, often undervaluing disciplines, including the creative and performing arts, not directly associated with the primary means of economic production. Subject discipline boundaries, generally strengthened by an accountability and performance culture embedded in school systems, often mitigate against a more open agenda and epistemology where collaboration and creativity contribute to investigative and problem-solving approaches (Breimer, Johnson, Harkness & Koehler, 2012; Colucci-Gray et al., 2017; Harris & de Bruin, 2018).

## Science Relies on Creative as well as Critical Thinking

Often science is seen as concerning mainly ‘critical’ rather than ‘creative’ thinking. This is largely because critical thinking is perceived as a set of vertically operated cognitive skills used for decision-making in complex but logical situations, or for solving ‘ill-structured’ problems (Kuhn, 1999). Critical thinking is valued as a meta-cognitive tool to strengthen assertions and enhance domain-specific understanding in science. This particular understanding of the nature of assertions as judgements coincides with essential components of the nature of science (see, for instance, Abd-El-Khalick, Lederman, Bell & Schwartz, 2002) as science relies on logic in empirically testing competing claims to assess the strength of evidence-supporting claims.

This all seems very logical and appropriate for science but there are many cases where leaps in scientific discovery and innovation would not have happened using critical thinking alone. A possible example is Neils Bohr’s model for the atom that in 1913 paved the way for one of the great leaps forward in science: quantum physics. Bohr needed a new way of conceptualising the atom to allow for the erratic behaviour of electrons, stepping beyond the classic planetary model of electrons orbiting a nucleus in a planar ellipse. It has been argued that his model of atomic structure was stimulated by contemporaneous changes in literature and the arts, such as Cubism (Clarke, 2014). Bohr maintained that the form electron paths took depended on how you looked at them. Their very nature was a consequence of our observations. This meant that electrons were not like little planets at all. Instead, they were like one of Picasso or Braque's deconstructed pictures, a blur of brushstrokes that only made sense once you stared at it for long enough. We are not claiming that without Cubism, Bohr's theory would not have arisen. The important point is that the existence of new ways of looking at the world in the arts opens up spaces in which new thoughts about how the physical world works are more likely.

There are now an increasing number of initiatives that use such approaches. For example, the University of California Davis Art Fusion programme was co-founded by entomologist/artist Diane Ullman of the University of California Davis Department of Entomology and Nematology and the ceramicist Donna Billick back in 2006, building on an undergraduate course, 'Art, Science and the World of Insects', that they initiated in 1997 (Garvey, 2018). The programme has been described as transformational as its innovative approach has helped facilitate learning in both formal and informal settings and has helped engage members of the local community as well as students and academic staff. Similarly, the NSF Art of Science projects have funded a number of activities that intersect art and science. For example, Susan Eriksson, geologist and artist, uses metal, wood and minerals to create unique pieces that are often inspired by the geological world. Eriksson notes that scientific concepts are used when she creates her art. For instance, quantitative skills are used to divide tonal systems, while her metalwork incorporates various chemistry principles (National Science Foundation, 2009).

Many people think that doing science involves closely following a series of steps, with little room for creativity and inspiration. In fact, many scientists, like Bohr and in the examples above, recognise that creative thinking is one of the most important skills they have—whether that creativity is used to come up with an alternative hypothesis, to devise a new way of testing an idea, or to look at old data in a new light. Creativity is critical to science and sits alongside criticality; it does not replace it.

## The Brain and 'Scientific' and 'Artistic' Thinking

The third premise in support of our argument for the arts 'in and for' science comes from neuroscience and some of what is known about human brain function. There have been claims for some time that the arts can contribute to the general development of cognitive abilities (Deasey, 2002). Early claims for brain-associated arts- and science-based thinking were based on presumptions about brain differentiation. It was suggested that the left and right hemispheres of the cerebral cortex control different physical and cognitive functions (Sperry, 1968; Hermann, 1990). Analytical and sequential reasoning (useful in mathematics and science) was said to be associated with left brain function while the right side was seen to deal with interpersonal, imaginative and emotional thinking (Herrmann, 1990; McGilchrist, 2010). This led to a simplistic view that arts learning is associated with 'right brain' thinking science and mathematics with 'left brain' thinking. Consequently, some educators such as Dorothy Heathcote advocated arts-derived pedagogy arguing right-brained activity such as drama could lead to a 'left-handed' way of knowing and thus benefit scientific, logical-mathematical reasoning (Wagner, 1979).

However, recent brain biology has challenged ideas of separated brain functions. In a review of the field, Morris (2010) points out that most cognitive scientists favour a 'whole brain' view, acknowledging that activities drawing on as wide a range of stimulation as possible inevitably improve brain function, especially for higher order activity and critical thinking (see also Howard-Jones, 2010). The point we wish to suggest here is that artistic activities may stimulate the brain in ways that might not be engaged by traditional science activities. There are now a number of initiatives that explore the implications of the arts for neuroscience, including FUSION, a group that meets every four weeks in Edinburgh (Edinburgh Neuroscience, 2018). For example, FUSION artist Michele Marcoux explores the fragmentary nature of identity, memory and perception, providing new insights into the work of scientists.

Before leaving this third premise in support of the arts for science, it is worth mentioning the work of the Dana Foundation in the USA. This organisation supports a number of research studies on brain functioning. Work using functional magnetic resonance imaging (fMRI) has shown benefits in cognitive reasoning for those who have been involved in music training (Moreno, 2009), dance (Cross & Ticini, 2012) and drama/theatre (Hough & Hough, 2012).

## A Collaborative and Economic Perspective

A new STEAM age driving economic development in modern science and technology is emerging making disciplinary subject boundaries of schools seem rather out of date. The 'capital' of art and science (i.e. the broad accumulations of knowledge and skills that contribute to and are fundamental to the enterprise of the arts and the sciences) is made greater by closer collaboration between them. In the business world, art-science collaborations have led to large-scale investment and smaller scale innovation. A country-wide approach placing the arts firmly within the STEM agenda in the USA has been stimulated in a movement championed by the Rhode Island School of Design (RISD), now adopted by institutions, corporations and individuals throughout the USA (RISD, 2018). The initiative's key aims are to help hire artists and designers to drive technological innovation and promote possibilities for integration of arts with science and technology subjects across all phases of education. Examples of collaborations involving the RISD STEAM initiative include design students working alongside marine ecologists and oceanographers to conserve coastal sites and nature-lab interns making animated films to teach about marine ecosystems and work with universities in Germany to design and test advanced solar-powered vehicles. Other US examples include the Stanford Art + Science programme (Stanford Arts, 2019), the hiring of artists to solve problems in government agencies (Los Angeles County Arts Commission, 2019), collaborations between the worlds of fashion and science (Office of Communications, 2017) and Janet Echelman's monumental, fluidly-moving sculptures that respond to environmental forces, including wind, water and sunlight (Echelman, 2011).

In the UK, there is a collaborative network called the 'Knowledge Quarter', a rapidly growing partnership of over 50 academic, cultural, research, scientific and media organisations. The hub of the network is Europe's largest bioscience laboratory, The Crick Institute in London. This collaboration draws on unique expertise and knowledge in the arts and sciences from conservation of the world's earliest books and manuscripts (at the British Library) to fashion and creative designs at Central St Martin's College, all in touch with researchers at The Crick Institute (Knowledge Quarter, 2018).

The possibilities thrown up by art-science collaborations have resulted in new applications of science and technology in product design and use. The fashion industry has been quick to take advantage. Figure 1 shows an example of a dress devised by London-based, techno-fashion house *CuteCircuit*. The dress has thousands of micro LEDs sewn into the fabric, allowing a garment to change colours and patterns. These 'smart textiles' have the potential to evolve into even more dramatic creations, especially with advancements in nanotechnology. One already classic piece is the 'Kinetic Dress'. This Victorian-style evening dress has sensors in the fabric which communicate to the electroluminescent embroidery when the wearer is moving. The faster the movement, the brighter the embroidery, translating kinetic movement into colour and pattern design.

Collaborations like this serve to increase the economic and knowledge capital of both art and science. A report on SCIART, Wellcome Trust's 10-year scheme to stimulate art-science links in the UK, found artistic outcomes from ten case studies evidenced widespread dissemination to sizeable audiences and an unusual longevity of audience and professional interest (Glinkowski & Bamford, 2009). It seems that contribution to scientific capital is not so much a shift or development in scientific processes or outcomes, but rather that scientists' involvement with artists encouraged speculative approaches to research and being more prepared to take risks.

**Fig. 1** Eiza González wearing a CuteCircuit dress by Edgar Meritano © CuteCircuit, used with permission

## How Science Education Benefits from the Arts and How the Arts Make a Contribution to 'Better' (More Authentic and Engaging) Science Education

For the hundred years or more of compulsory schooling in the developed nations, there has been an almost constant concern that students are less enthusiastic about learning science than other subjects and that decreasing numbers of young people want to pursue science into higher education or as a career. A meta-analysis of research for the *Royal Society Vision Report* shows these attitudes have hardly shifted over the last ten years in the UK in spite of huge investment in improving science teaching in schools, teacher training and professional development (Bennett, Braund & Sharpe, 2014). In the USA, similar concerns over the quality and depth of science education to interest and engage students, particularly from disadvantaged backgrounds, have been noted (e.g. Schmidt, Burroughs & Cogan, 2013). The Relevance of Science Education (ROSE) Project carried out surveys of 15-year-old students in 40 countries and found that, while students in all countries see the importance of science, in many this does not translate into liking for school science as a subject, particularly for girls (Sjøberg & Schreiner, 2010).

So, our questions remain what might the arts provide that would make the sciences more complete and what can we learn and take from the arts that might improve the teaching and learning of science? We can envisage consequences that the arts might have *on* science, *for* science and *in* science. Our interest is particularly in science education and we see three levels at which the arts might improve teaching and learning of science. The first is at a *macro-level*, concerned with ways in which subjects (including the arts and sciences) are structured and options for studying them provided and packaged. The second is at the *meso-level*, guiding approaches to the construction of science curricula and schemes of work that engage learners, for example through using STS (Science, Technology and Society) contexts. The third is at the *micro-level*, of pedagogical practices in science and teaching that can be drawn from the arts. These three levels are not entirely distinct—in particular, the meso-level overlaps at one pole with the macro-level and at the other with the micro-level. However, the three levels provide a useful heuristic. In the second half of this article, we consider each of these levels, paying the most attention to the third one—arts practices in and for science teaching.

### *The Arts and Sciences at the Macro-Level: Curriculum Provision*

Countries vary greatly in the extent students specialise early or are required to learn a broad and balanced range of subjects until the end of compulsory schooling. It is not uncommon for students to be pushed towards a specialism in the arts and humanities or the sciences and mathematics, though few countries specialise to the extent that England does where most students take only three subjects from the age of 16.

In the last ten years or so, to broaden and diversify science in schools and link it to technology, engineering and mathematics, there has been a push in the UK, the US and some Asian countries towards the concept of STEM – Science, Technology, Engineering and Mathematics. While there is some sense in taking a lead from wider communities of modern economies that link these disciplines needed for development, evidence of how STEM has impacted the occurrence and effects of collaboration and interdisciplinary work in schools is unconvincing (Archer et al., 2013; Colucci-Gray et al., 2017), despite the widely acknowledged benefits of interdisciplinary approaches (cf. the work of Leonardo da Vinci). Too often, the concept of STEM seems remote and poorly understood by teachers. For example, in the UK, the Royal Society commissioned a series of meta-analyses of research as part of its STEM Vision Report, one of which considered to what extent the STEM concept was embedded and had made differences in schools (Howes, Kaneva, Swanson & Williams, 2013). In one section of their report the authors cite research studies showing that:

> STEM remains a misleading curriculum concept: it is not an integrated reality in high schools anywhere in the world that we know of, and STEM integration is not well understood by teachers. In many projects, the focus is on science and maths, leaving out engineering and technology. (Howes et al., 2013: 9)

The ASPIRES (Young People's Science and Career Aspirations 10-14) project found STEM subjects were viewed by students as lacking creativity and unrelated to images or aspirations that they had for themselves (Archer et al., 2013). Drawing on the arts to reinvigorate science education might provide the sorts of post-human education advocated by Quinn (2013) and alluded to by philosophers such as Biesta (2018), one where individuals play a part in knowing about themselves as part of a greater whole, rather than being seen as subservient participants in an epistemology valuing information and knowledge as superior to the individual.

An example of 'macro' integration can be seen in a US-originated project calling for STEM to integrate with Arts into a 'STEAM' curriculum (see www.steamedu.com). This has been picked up by the South Korean government which has instituted an associated curriculum and teacher training programme (Baek et al., 2011). The STEAM rationale explicitly draws on a formula of smart technology with 'cool design', once promoted by the late Steve Jobs. It may be that a STEAM curriculum appeals to the agenda of 'Pacific Rim' countries that value an innovation-based reform of education for a competitive knowledge economy. In the pyramid diagram provided by STEAM Education (Fig. 2), STEAM educators promote the idea of 'life-long holistic teaching' as a more progressive and 'FUNctional' alternative to conventional integration or multidisciplinary views of STEM and Arts (A). The idea is to work in a transdisciplinary way, avoiding artificial combinations (or separations) of subject disciplines.

STEAM educators promote a more progressive alternative to conventional integration or multidisciplinary views of STEM and Arts (A) that retain separate identities and traditional subject disciplines with associated content-related structures (e.g. High Tech High, 2019). Rather than taking a problem or topic and using it to focus teaching in subject time or through a multidisciplinary approach that can produce artificial connections between subject content, a STEAM approach constantly reiterates the importance of a local, relevant problem to solve, drawing in the arts and humanities as well as STEM content as a natural consequence of researching and communicating solutions. For example, Herro and Quigley (2016) describe STEAM teaching using the context of a local housing development adjacent to a school. STEM content included sound insulation, geological and geophysical data and the mathematics of cost impact and design. The Arts (visual and communication) and Humanities (social sciences) were used to explain human dimensions of aesthetic design and in communicating students' views of developers' proposals. According to Howes and colleagues, such a STEAM approach for schools might have attractions for Arts-led work

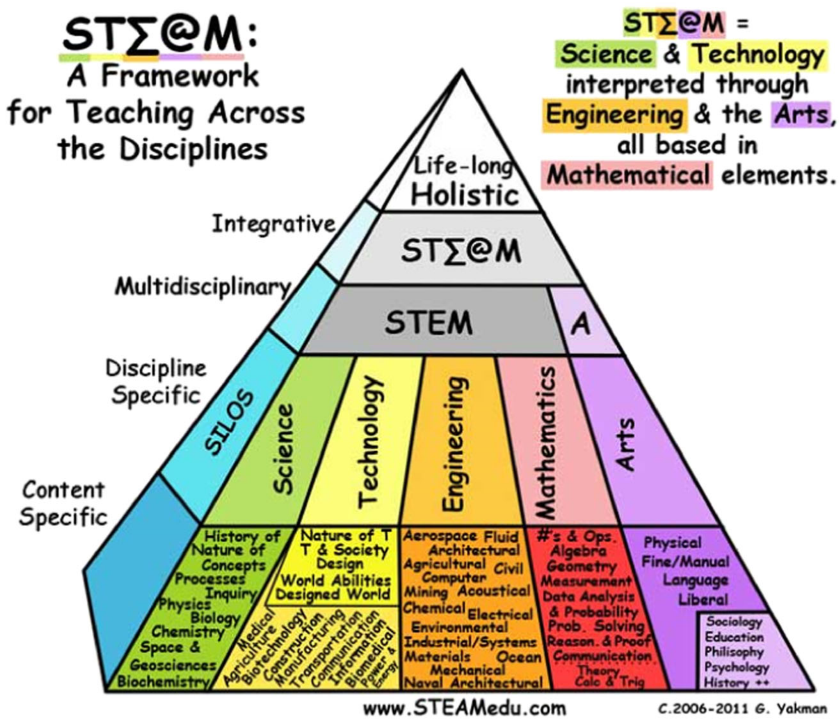


**Fig. 2** A framework for STEAM education © Yakman, G. (2010), used with permission

with learners who are not apparently predisposed towards or interested in STEM, but who might thereby maintain contact with STEM in some form:

> Rather than seeing such students as having leaked from a STEM 'pipeline', perhaps we should see them as travelling by a different route, to a later rendezvous.
> (Howes et al., 2013: 10)

*Arts and Sciences at the Meso-Level: Engaging Learners Through Arts-Related STS Contexts*

At the 'meso' level, we consider ways in which places of learning operationalise the curriculum in terms of the courses, schemes of work and textbooks used to teach science. Although institutions might espouse an educational stance valuing creativity, even one that alludes to integration between the arts and the sciences, it is often the case that aspirations are 'thwarted by mandated, all-time consuming packaged programs' (Manley, 2008: 36). Craft (2010) sees a curriculum controlled by assessment regimes limiting schemes that include creative approaches because they are seen as time-consuming and less likely to 'deliver' against assessment targets.

In response to the perceived problems of students' disaffection with science and claims that science teaching is boring and irrelevant, science educators and teachers have turned towards course design that sets science in contexts relevant to the real world (e.g. Gilbert, Bulte & Pilot, 2011). In the USA and some other countries, the term Science-Technology-Society is broadly synonymous with a context-based approach and so this definition, provided by Aikenhead, is helpful:

> STS approaches… emphasise links between science, technology and society by means of … a technological artefact, process or expertise; the interactions between technology and society; a societal issue related to science or technology; social science content that sheds light on a societal issue related to science and technology; a philosophical, historical, or social issue within the scientific or technological community.
> (Aikenhead 1994: 52-53)

Given the arguments made above for closer links between STEM and the Arts, and examples of how science now draws on and is complemented by arts-related activity, it seems opportune to include STEAM examples that provide the 'technological artefacts', 'processes' and 'interactions' of Aikenhead's definition for STS. If STS approaches better engage students already signed up to science courses, then including arts applications of science, such as in fashion, film, music, dance and theatre, has the potential to draw in more of those who did not choose science courses in the first place, or for people to re-engage with science learning at a later date. In cultures where the contribution of indigenous knowledge systems is important to science education, recourse to the arts has currency for students' wider involvement in science learning and for addressing curriculum development in post-colonial contexts, where the contributions of indigenous cultures are taken respectfully and equitably (e.g. Alsop & Bencze, 2014). Furthermore, it is increasingly appropriate to refer to arts-related STSE (science, technology, society and environment) contexts, since STSE has become more important in science education (e.g. Pedretti & Nazir, 2011) and as the arts have engaged more substantively with environmental issues (O'Brien, 2008).

*Arts in Science Teaching at the Micro-Level: Pedagogical Practises Drawing on the Arts*

UNESCO's decade of educational effort (2005–2014) centred on interdisciplinary reform rather than on subject-focussed change. Central to its 2005 resolution was an emphasis on holistic teaching practices encouraging uses of multiple methods of instruction, for example, writing, art, drama and debate (UNESCO, 2005). There is nothing radically new in using such methods to help explain science and make it more accessible to those studying science. The methods of creative writing, poetry, physical model making and visual approaches including painting and drawing, drama and role-play have been part of a few science teachers' repertoires for some time (e.g. Goldberg, 2016). We suspect, though, that as science education (and all education for that matter) has moved towards more examination-oriented and standard-driven accountability, these methods have become rarer. Those teachers who are 'committed believers' in these approaches might continue to use them, but even they are under continuing pressure in a time-constrained system that values evidence of achievement in a restricted core of subjects, examined for a narrow set of linguistic and mathematical skills, over outcomes concerned with holistic development of learners. This is despite the widespread acknowledgement that in the twenty-first century, a greater range of skills are necessary (Deming & Noray, 2018).

In primary schools, in many countries, the primary teacher has been seen as both expert and champion of subject integration. Because they typically teach all subjects, the idea of integrating science, and using contexts and methods from the arts and humanities to teach science content, seems more natural. But even these teachers can be under pressure to restrict holistic teaching and learning. In England, these pressures were manifest in critiques of integration from the so-called New Right, culminating in a report on the curriculum by Alexander, Rose and Woodhead (1992). They claimed that subject content outcomes were submerged, weak and at a low level in topic work which at the time was typically cross-curricular. Since then, the curriculum pressures on science and the arts in English primary schools have increased to the extent that these subjects, along with others, are often downgraded and squeezed into short-afternoon slots after the main business of the day (teaching of 'literacy' and 'numeracy') has occupied the morning's work (cf. Access Art, 2019, for a response to the pressures on curriculum time for art).

But why should we claim that methods and approaches from the arts offer possibilities for better learning in science? To begin to answer this question, it helps to look at some of the ways in which science is structured and communicated. Science uses symbolic and semiotic systems of representations and employs specific but different meanings for everyday words making it often seem like 'learning a foreign language' (Bleicher, Tobin & McRobbie, 2003). Science teachers employ mathematical, chemistry and physics symbols and these communication modes can create significant subject-specific barriers to student learning that do not occur in other school subjects (Wellington & Osborne, 2001). Thus, communication through a variety of visual, spoken and alternative written language modes (alternatives to written, expository texts), drawn from the arts, offers ways of breaking down the barriers that students find hard to cross.

In the University of California Irvine School of Medicine, medical students used masterpieces by Van Gogh, Rembrandt, Kandinsky and Da Vinci to improve observation and pattern recognition skills in clinical situations (Shapiro, Rucker & Beck, 2006). An additional (and unexpected) outcome was that medical students following the fine arts programme developed better skills in emotional recognition, cultivation of empathy, identification of story and narrative and awareness of multiple perspectives.

More routinely, perhaps, there are documented examples of painting and drawing being used in expressive modes for school students to develop and communicate scientific ideas in creative ways. Figure 3 comes from a California art-chemistry project. In a workshop on 'Hydrogen Fuel-Cell Cars', students discussed the basic workings of a fuel cell and then designed their own 'car of the future' (Halpine, 2004). In a similar vein, Fig. 4, showing an insectivorous plant with its feeding and reproductive adaptations, was drawn by a high-school student after studying original letters of Charles Darwin (Stafford, 2015). The picture shows evidence of integration between artistic creativity and scientific writing. In her edited work, *Drawing for Science Education*, Phyllis Katz brings together a large number of international examples of how drawings are being used in science education (Katz, 2017).

Perhaps these artistic activities work because they tap into the visual thinking of learners. It is often said that today's young people inhabit a multimodal world dominated by television, video games, computers, tablets, films and so on. It has also been claimed that visual thinking translates into problem-solving ability. Visual thinkers literally 'see' their answers to problems, enabling them to build entire information systems using their imaginations (Gangwer, 2009).

An appreciation of structures, processes and concepts can be enhanced by 3D representations. In many primary school classrooms, around the world, one sees food web mobiles and papier-mâché planets hanging from ceilings. In secondary school chemistry lessons, one might see molecular models made from plasticine and cocktail sticks, and in biology lessons, plant cells made from plastic bags and wallpaper paste.

Part of the appeal of art approaches, such as those described so far, is that they offer alternatives to the usual modes of science teaching. Begoray and Stinner (2005) argue that the science classroom is dominated by expository text, representing the dominance in science lessons of comparison, description, sequencing, listing, cause and effect and problem solution. They claim that, as narrative text is more common in the life experience of learners (from films, novels and oral story telling) and is less abstract than expository text in organising knowledge, its use in science lessons can lead to better empathy with science and more effective cognitive learning.

One method from the arts, perhaps above others, stands out in this regard of narrative alternatives providing the benefits of visualisation: drama. Forms of drama (scripted plays, role-play, movement, mime and dance) make science ideas, theories and processes, at varying degrees of complexity and abstraction, more comprehensible to students through their more active involvement in the reconstruction processes, necessary in a constructivist approach to learning (Braund, 2015). Additionally, drama in science models ways in which scientists develop and validate theories and provides a productive platform for debating the social, political and cultural dimensions of science, that help give science a human face, especially for students sceptical of its worth (Ødegaard, 2003).

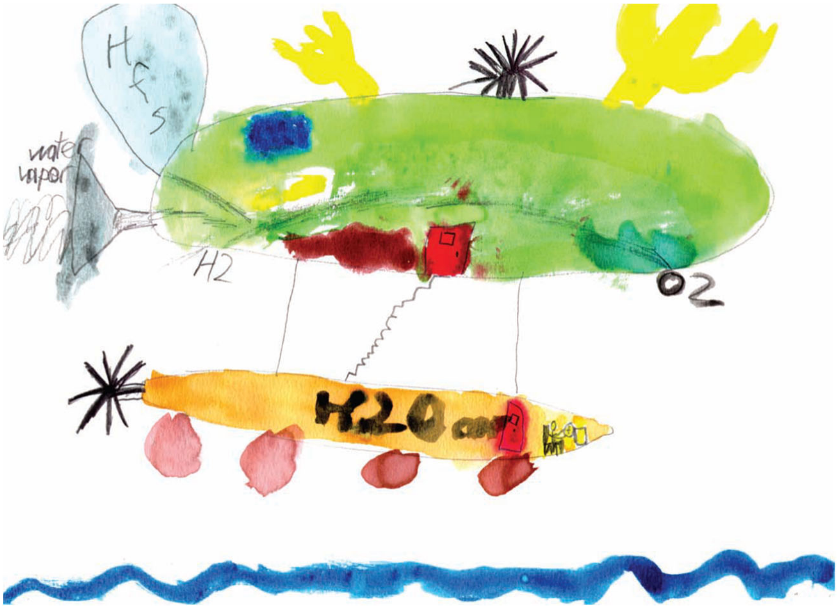


**Fig. 3** An example of an $H_2O$ car designed by a third-grade student during a workshop on hydrogen fuel cells Halpine, S. M. (2004: 1432)

Among drama strategies to enhance science learning, role-plays of the physical kind, where students portray molecules, components of biological cells or model processes such as energy or behaviour of electrons in circuits, offer particular advantage. According to Scott, Mortimer and Ametller (2011), rationalising ideas between learners' conceptions of the world and canonical science requires differentiation between, and integration of, these two ways of explaining and seeing the world. To achieve integration of ideas requires making the less visible (molecules, electrons, cell components) and abstract ideas (energy,

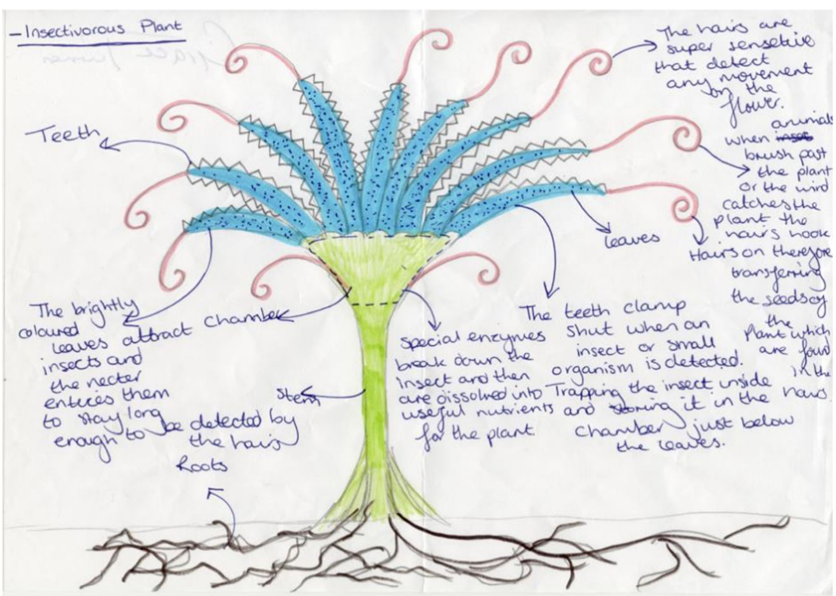


**Fig. 4** An insectivorous plant drawn by a high-school student after studying original letters of Charles Darwin. Stafford, S. (2015) In C. J. Boulter, M. J. Reiss & D. L. Sanders (Eds), *Darwin-Inspired Learning*, 35-44, Rotterdam: Sense Publishers

photosynthesis, entropy) comprehensible to students without obstructions embodied in the symbolic and sometimes obtuse language of science used to communicate these ideas that we referred to earlier. This is why science teachers often use metaphors and analogies to help students access ideas, explanations and theory (Aubusson, Harrison & Ritchie, 2006). For example, analogues such as the hot water system of a house or ski lift have been used to explain current, voltage and resistance in electrical circuits. A criticism of these approaches is that the analogues themselves may not be fully understood or using them could foster development of problematic alternative conceptions for the target concepts being taught (Harrison & Treagust, 2006). It is here that the use of physical role-plays offers an alternative, still drawing on analogues for learning, but through physical interactions that more closely involve learners with the content being taught (Braund, 2015). One cautionary note here is that any analogy, whether arts- or non-arts-derived, communicates only a partial reality. The skill of the teacher is required to provide cognitive space, through discussion, allowing learners to critique whatever analogous model or method is used so that its successes in promoting understanding and its limitations as a version of scientific reality are clear (Braund, 2015: 115).

The arts pedagogies described in this section, and others, including poetry (Pollack & Korol, 2013), creative writing and music (Crowther, 2012), offer the science teacher an enhanced pedagogical toolkit to help students learn science. A tradition in science teaching has been to use practical work to help students access ideas and teach concepts, but this has been criticised for being too focussed on practising and performing rehearsed routines and procedures rather than on ensuring that students understand what is going on (Hodson 1991; Abrahams & Reiss, 2017). It is, however, possible that approaches derived from the arts have a place to play to enhance practical work. For example, Warner and Anderson (2004) studied different classes that were investigating the biology of snails, through observation and experiment, with and without a prelude of role-plays involving students as expert zoologists. They noticed better accuracy in writing and increased levels of anatomical knowledge for students who had taken part in the role-plays.

## Conclusions—Towards a More Authentic and Engaging Science Education Using the Arts

We have argued that in considering the contribution that the arts might make to the sciences, particularly in terms of *teaching* the sciences, it is useful to envisage the contribution as potentially operating at three levels: the macro-level (the ways in which subjects, not only the arts and sciences, are structured and options for studying them provided), the meso-level (guiding the construction of science curricula and schemes of work) and the micro-level (pedagogical practices that can be drawn from the arts when teaching science). It is not, we contend, the case that all three levels must simultaneously exist for improvements to be made. For example, one can envisage a single (albeit passionate and determined) science teacher making changes to their teaching (i.e. at the micro-level) without any corresponding changes at the meso- or macro-levels. Nevertheless, it seems reasonable to presume that if appropriate changes are made at two of the levels, ideally all three, the benefits are likely to be correspondingly greater.

In arguing for the contributions that the arts might make to science and science education, we are not claiming there should be full integration nor that the epistemology or ontology of the arts and sciences are the same. As literary critic George Steiner (2013) once claimed, the intentions, procedures and products of the arts and science have never been the same. Art does not proceed from a less complete and less satisfactory representation of the world to a better one; the paintings of Giotto are not less worthy than those of Degas or Pollock. Science, though (like the arts) culturally and socially bound, is different and proceeds by empiricism, testing out and establishing better representations of the world. Today's views of the universe and its origins are more complete (though never wholly complete) than those of Aristotle, Ptolemy, Copernicus, Galileo, Newton or Einstein.

Our main intention in this article has been to show that the current way science is perceived and adapted for science education has substantial shortcomings for the science education of the twenty-first century (see

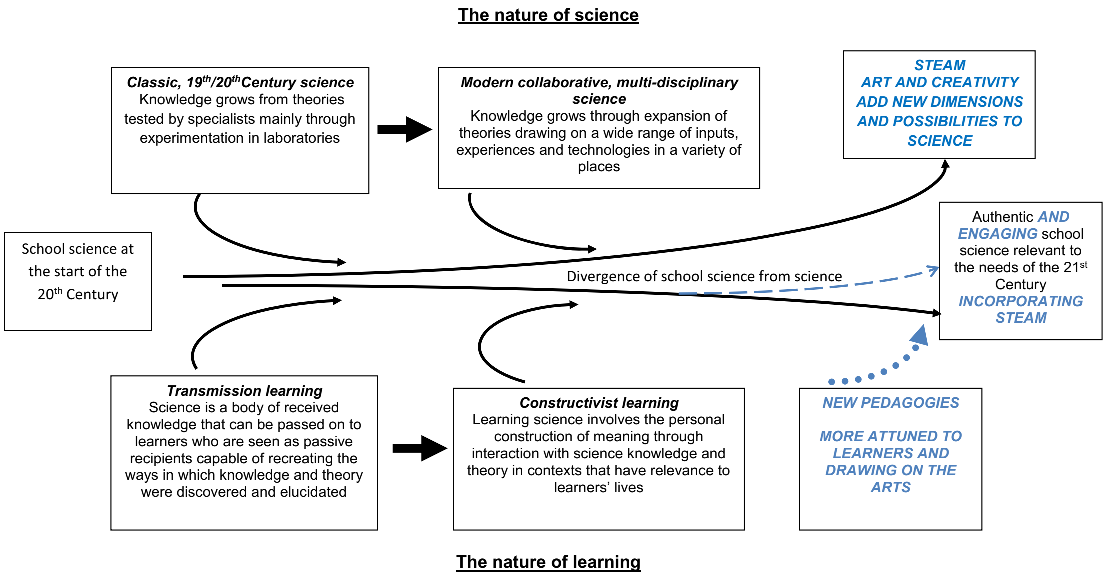


**Fig. 5** Towards a more authentic and engaging school science *(drawing on STEAM)*: an evolutionary model (Mark II)

California Alliance for Arts Education (2015) for examples of how many of our arguments apply to school mathematics as well as to school science). An arts-informed view is helpful here. In 1967, theatre director and theorist Peter Brook gave a series of lectures collectively entitled *The Empty Space* (Brook, 1968). Brook's phrase 'the empty space' was used metaphorically to critique the state of theatre in Britain, as he saw it being staid and stuck with methods of communication and presentation that had changed little over the previous 100 years. Audiences were turning away from theatre and so Brook envisioned and pioneered more enlightened ways of presenting and communicating through drama. His ideas revolutionised theatre in Britain and beyond for generations.

Brook's concerns for the late twentieth-century theatre echo those of science educators today in many countries who recognise the lack of enthusiasm of students for science and the reducing likelihood that they will choose further study of science or science-related careers (Millar & Osborne, 1998; Sjøberg & Schreiner, 2010). In Brook's terms, then, the trick for science educators is to turn increasingly away from the 'dead hand' of traditional, non-interactive methods such as book and board work (and even some versions of practical work) to see what gains can be made from employing strategies involving more collaborative learning effort and innovation from students (Braund, 2015: 107). It is our contention that drawing on the arts for inspiration and new approaches will help. The argument here is not only that the arts can engage and inspire students; it is that using the arts as a language to help learners understand scientific concepts can be a powerful way of enabling such learning.

In an article we wrote over ten years ago (Braund & Reiss, 2006), we proposed an evolutionary model for science and science education, accounting for changes in science that have broadened its scope and spheres of operation (for example, to encompass science done in other places than traditional laboratories). We argued that these changes in science were generally not paralleled by advances in science teaching methods and that greater attention needed to be paid in school science education both to changes in how science is viewed and to the potential of out-of-laboratory learning. Such attention would also help lead to a shift in school science from 'transmission learning' to 'constructivist learning'. Our model thus indicated increasing divergence between science as practised in the real world and science as represented in schools, and we argued that such divergence was unhelpful for science students.

It is our contention that the model gains when extra dimensions of the contribution of the arts to science and of arts-based pedagogy to science teaching are added (see Fig. 5). We call the model a 'Mark II', the text in bold upper case italics in Fig. 5 and the dotted and hashed arrowed lines being additions to the 2006 version. The drivers of STEAM add new dimensions to the nature of science in the twenty-first century but additionally make science likely to diverge even more rapidly from school science unless new pedagogies, including those from the arts, help close the gap, drawing the nature of learning science closer to the changing nature of science in the real world (shown by the dotted and dashed arrowed lines). The result could be a more authentic and engaging school science, one more relevant to the needs of the twenty-first century.

We acknowledge that the addition of the boxes at the right-hand side of Fig. 5, building on our five premises, places additional demands on teachers. Not all science teachers will welcome the new pedagogies for which we have argued in this article. We also acknowledge that there are some students who may not welcome these new approaches either. Nevertheless, we argue for these new approaches for two main reasons. The first is that they present students with a more authentic vision of science. In this sense, we feel that STEAM can be understood as being a contemporary enhancement of STEM. Were we historians or philosophers of science, this reason would have been the sole one on which our argument rested. However, we are both science educators and while we wish to remain true to developments in science, as indicated above, our main intention, as also indicated above, is to provide a better science education for students. This is our second reason—we contend that these new pedagogies, with associated shifts in content, can help many students to engage in science when they would otherwise have not done so *and* can help them to learn science better.

We need our science students not to lose their creativity. For people to be educated in the twenty-first century, they need to study both the arts and the sciences throughout their schooling. People talk about literacy as if it means only to be educated and proficient in using the language we speak, but there are other literacies especially of STEAM that are equally part of what it is to be educated. Today's and tomorrow's citizens need both the arts and sciences to equip them with the criticality and creativity of mind and the aesthetic and emotional capacities essential for being rounded and cognate humans.

**Compliance with Ethical Standards**

**Conflict of Interest** The authors declare that they have no conflict of interest.

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