STEAMing ahead: why and how science and science education need the arts

Martin Braund.

Cape Peninsula University of Technology, Cape Town, South Africa

Abstract

There are ongoing concerns that pupils are not enthusiastic about learning STEM subjects and that decreasing numbers of young people pursue STEM into higher education or as a career. For science, efforts to invigorate teaching along IBSE/IBL lines have so far fallen short. There are now efforts to improve and raise engagement and outcomes in STEM adding the ARTS, turning STEM into STEAM (Science, Technology, Engineering, ARTS and Mathematics). In this paper I show ways in which science and science learning benefit from the arts. At the macro level STEAM is best organised as a transdisciplinary exercise to solve real-life problems, and at a micro-disciplinary level utilising creative approaches such as fine arts, creative writing and drama.

Keywords: Science; Arts; STEAM; Pedagogy; Curriculum

Corresponding author e-mail address: martin.braund@york.ac.uk

Introduction

For more than a hundred years there have been concerns that many pupils are not enthusiastic about learning STEM subjects and that decreasing numbers of young people want to pursue STEM into higher education or as a career. Meta-analysis of research for the *Royal Society* shows these attitudes have hardly shifted over the last 10 years in the UK and Europe, in spite of huge investment to improve STEM teaching (Bennett, Braund and Sharpe, 2014). In the US similar concerns over the quality and depth of science education to interest and engage students have been expressed (Schmidt, Burroughs and Cogan, 2013). The Relevance of Science Education (ROSE) Project found that, while pupils value the importance of science to society, in many countries this does not translate into a liking for science as a subject (Søberg and Schreiner, 2010). For science in particular, the main focus of this paper, efforts to invigorate teaching along IBSE/IBL lines have so far fallen short of providing the extent of change needed to address these issues and provide a scientifically literate population able to cope with the knowledge needs of 21st Century citizens (Kirschner, Sweller and Clark, 2006). Additionally, over-reliance on practical work as a possible 'saviour' for science education has been criticised on the basis that teaching has failed to provide clearly appreciated routes to learning including linking activity with concept acquisition (Abrahams & Millar, 2008; Hodson, 1993).

In the last 10 years there have been increasing efforts (particularly in the US and Korea) to address issues and criticisms of teaching methods in STEM subjects designed to improve and raise engagement and outcomes in STEM by incorporating the arts thereby turning STEM into STEAM (Science, Technology, Engineering, ARTS and Mathematics). Arguments in favour of drawing on the arts to enhance science education are positive actions given the, often fractious, relationship between the arts and sciences as embodiments of culture, as distinct domains of knowledge and through a history of their separation by educational systems. It has been argued that seeing only distinctions between arts and sciences ignores the ways in which they benefit each other and contribute to a more holistic education for individuals (Snow, 1959; Wilson, 1998). To understand why and how the arts can contribute to improvements in science and STEM education requires some discussion of how science itself, as sphere of activity and knowledge generation, can be enhanced.

I begin by providing three warrants in support of my claim that science benefits from the arts. First, that science requires arts-style creativity to enhance thinking needed for the development of new ideas, theories and processes. The second draws from neurobiology and psychology to show how scientific (and other STEM) thinking might benefit from the arts, and finally how cutting edge scientific and technological enterprise gain from Sci-Art collaboration. In the final part of the paper I turn to educational arguments showing that learning in STEM and science benefits from transdisciplinary and disciplinary approaches. I illustrate this first, at a macro level where STEAM is organised as a transdisciplinary exercise to solve real-life problems and then, at a micro-disciplinary level, showing how creative approaches such as fine arts, creative writing and drama enhance classroom teaching and learning.

Science and STEM thinking require some creativity

Traditionally, critical and linear rather than creative and horizontal thinking are seen as foundations of science. Kuhn (1999) proposed that critical thinking is important at an evaluative level when assertions are considered to be judgements using criteria of argument and evidence, where knowledge is subjective and uncertain. While this is appropriate and important, there are leaps in science that would not have happened without some more horizontal, creative thinking. An example is the Bohr model of the atom. Bohr's model involved looking at electrons and their behaviour in new ways. He maintained that the paths electrons took depended on how you looked at them. Thus electrons were not, like the conventional thinking of the time, seen as little planets orbiting a sun; instead they were like one of Picasso's deconstructed guitars, a blur of brushstrokes that only made sense once you stared at them for long enough, and from different perspectives. For Bohr the art that looked so strange was actually helping reveal a scientific truth. I do not claim that without cubism Bohr's theory would not have existed, but the important point here is that the existence of new ways of looking at the world in the arts open up spaces in which new thoughts about how the physical world works are made more likely. To use a culinary metaphor, the main course of scientific rationalism needs a little side dish of creativity.

Some think that doing science involves closely following a series of steps, with little room for creativity and inspiration. In fact, many scientists, like Bohr, 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. Creativity is about imagination and as Einstein put it:

"Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand."

(Included in Einstein, 2010)

'Scientific brains' benefit from the arts

There have been claims for some time that the arts (in particular music, drama, poetry, fine arts and dance) contribute to general development of cognitive abilities (Deasey, 2002). Claims for arts and science-based thinking have been associated with differentiation in brain structure and function. Since the mid-19th Century there was increasing evidence, from studies of patients with brain impairments, that the left and right hemispheres of the cerebral cortex might be differentiated, and hence control different physical and cognitive functions. Sperry's research on patients with a severed *corpus callosum* (the region between the two hemispheres) showed that language ability was clearly associated with left hemisphere function and discrimination of shape and design with the right (Sperry, 1965). Drawing on Sperry's work, Herrmann went on to postulate different abilities and types of thinking associated with the two hemispheres. 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). This led to the reductionist view, that Arts learning is associated with 'right side brain thinking' and learning science and mathematics with 'left brain thinking'. Reading about left and right brain differentiation led drama educator Dorothy Heathcote to advocate drama activity as a way to strengthen scientific reasoning, as she reasoned that the right-brained activity of drama could lead to a 'left-handed way of knowing', and would thus benefit scientific, logical-mathematical reasoning (Wagner, 1979).

Modern brain biology has challenged these ideas of separated brain functions. Morris (2006) points out that most cognitive scientists and educators today favour a more 'whole brain function 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. Pink (2005) believes conceptual, creative thinkers have to draw on right-brained thinking to supply what is required by top businesses and enterprises in the 21st Century. According to Pink and also to Philips (2008), these types of thinkers know how to detect patterns and opportunities and, "create artistic emotional beauty, craft narratives and combine unrelated ideas into something new" (Pink, 2005: 12). The Dana Foundation in the US supported a number of studies using functional Magnetic Resonance Imaging (fMRI) to establish differential cognitive activity in the brain, for individuals carrying out tasks on creative thinking and problem solving. These studies show advantages for those who have been involved in arts training such as, in music (Moreno, 2009). It is worth noting that biographical studies of STEM laureates and academicians show they are between twice and seven times more likely to be active in the arts than their counterparts in other academic areas (Root-Bernstein *et al.*, 2008). There are thus many cases where arts activity has been shown to benefit scientific lives and achievements.

Science and the arts both grow through collaboration

Billions of dollars are invested worldwide in science-arts collaborations in universities and industrial spaces. So far, gains have been mainly for the arts-based industries such as fashion and design, but there are knowledge gains from the arts for science too. An example is fundamental new knowledge about black holes that only became evident through mathematically modelled CGI sequences commissioned for the 2015 film *Interstellar*.

On many campuses arts and sciences have been traditionally separated but recently a new centre has been established at UCLA (University of California Los Angeles) that combines departments of media and arts with architecture and nanoscience. Centre co-director Jeff Burke puts the possibilities of this new venture like this:

"What is interesting to us is when cross-disciplinary collaborations radically alter the expressive possibilities available to artists and storytellers—whether professional or from the public—and at the same time, open up new areas of exploration for scientists and engineers."

Claudia Luther, *UCLA Magazine*, March 27, 2014

In the UK there is a collaborative network called the 'Knowledge Quarter', a partnership of 35 academic, cultural, research, scientific and media organisations based in London at Kings Cross, Euston and Bloomsbury. The hub of the network is Europe's largest bioscience laboratory, the Crick Institute. This collaboration draws on unique expertise and knowledge in the arts and sciences ranging from the world's earliest books and manuscripts (at the British Library) to the latest fashion and creative designs at

Central St Martin's College all in touch with cutting-edge bioscience researchers at the Crick Institute.

Innovative collaborations like these are providing science with new audiences and enhanced perceptions as they serve to increase the cultural and knowledge capital of both arts and science. A report on SCIART, Wellcome Trust's 10-year scheme to stimulate art-science links, found that artistic outcomes of ten case study projects evidenced widespread dissemination to sizeable audiences and positive media and critical review (Glinkowski and Bamford, 2009). It seems, however, 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.

How can the arts improve science and STEM teaching and learning?

In this part of the paper I consider how warrants for the arts in the thinking and enterprise of science and STEM lead to hopes that drawing on the arts might produce better engagement and learning in schools. There are two levels at which this might be achieved. At a macro level the example is of curriculum organisation that lies at the heart of a STEAM approach centred on problem based learning (PBL) and, at the level of the classroom, examples are shown where pedagogical approaches drawing on the arts are used to increase engagement and conceptual understanding.

STEAM as transdisciplinary learning

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 emergence in the UK, US and some Asian countries of 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 the occurrence and effects of STEM collaboration and interdisciplinary work in schools are somewhat unconvincing. In many cases the concept seems remote and poorly understood by teachers. For example, the Royal Society commissioned a series of meta-analyses of research as part of its STEM Vision Report (Royal Society, 2014), one of which considered to what extent the STEM concept was embedded and had made differences in schools (Howes, Kaneva, Swanson and Williams, 2014). They report 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.

The links between technology, and (particularly design technology and engineering) and science are often concerned with enhancement of science lessons rather than being fully integrated as subjects. Thus the nature and level of integration has often been fragmentary, resulting in poor capitalisation of the advantages of disciplinary links. In contrast, in the STEAM rationale the idea is to work in a transdisciplinary way that avoids some of the more artificial combinations of subject disciplines. In the pyramid diagram provided by 'steamedu.com' (Figure 1), STEAM educators promote the idea of 'life-long holistic teaching' as 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.

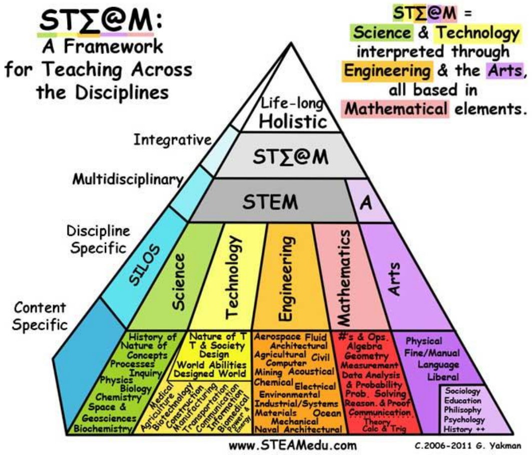

Figure 1. The STEAM framework as a pyramid (www.STEAMedu.com)

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 planning and implementation of STEAM teaching in 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. Arts (visual and communication) and humanities (social sciences) were used to explain human dimensions of aesthetic design and in communicating students' views on developers' proposals. A STEAM literature is only just emerging but there are already encouraging signs that teaching increases motivation, engagement, and effective disciplinary learning in STEM areas (Henriksen *et al*., 2015).

Using arts to enhance STEM learning at the micro (classroom) level.

Methods from the arts such as creative writing, poetry, physical model making, visual media including painting and drawing, drama and role-play have been part of STEM and science teachers' repertoires for some time. But why should these methods and approaches offer possibilities for better learning in science and STEM? To begin to answer this question we have to look at ways in which STEM is structured and communicated. STEM subjects uniquely use symbolic and semiotic systems of representations and specific but different meanings for everyday words making them seem almost like a foreign language (Bleicher, Tobin and McRobbie, 2003). STEM teachers communicate ideas using mathematical and other symbols, such as in equations, chemical formulae and technical diagrams. These communication modes create significant subject-specific barriers to student learning. Thus communication using a variety of visual, spoken, and alternative language modes (especially alternatives to written expository texts), drawn from the arts, offer ways of breaking down these barriers that many pupils find hard to cross.

Fine arts (painting and drawing) use expressive modes for school pupils to communicate scientific ideas in creative ways. Figure 2 shows an annotated painting of an insectivorous plant with its feeding and reproductive adaptations drawn by a high school pupil after studying original letters written by Charles Darwin (Stafford, 2015: 43). The painting shows a high level of integration between artistic creativity and substantive scientific writing. The act of producing a painting provides a visual frame on which to hang ideas such as nutritional processes (enzyme activity, attracting insects as 'prey') and seed dispersal (from hairs transferring seeds to a passing animal). It is likely that these artistic activities work in science lessons because they tap into visual thinking of learners. It is often said that today's school pupils inhabit a visual world dominated by television, games, computers, tablets, films and so on. Visualisation reigns supreme. Although many teachers would warn about overusing images at the expense of other modes of communication including talking and writing, drawing on visual thinking may be no bad thing. Horn (cited in Gangwer, 2009) believes visual thinking is far more effective at conveying convoluted ideas than conventional methods of communication. It has also been claimed that visual thinking translates into problem solving ability as visual thinkers literally see the answers to problems enabling them to build entire information systems using their imaginations (Ganwer, 2009: xi). Visualisation is also an aspect of another art-based approach, drama, that has had some success in science classrooms.

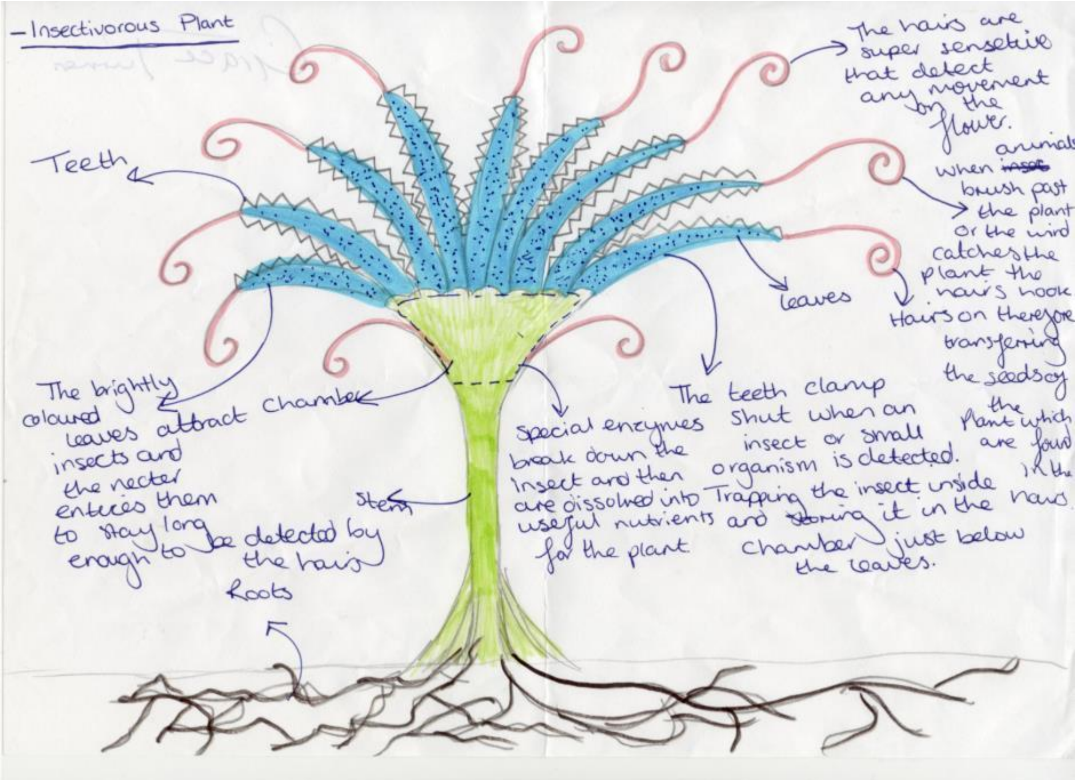

Figure 2. An insectivorous plant drawn by a high school student after studying original letters of Charles Darwin. (From Staffford, 2015, *Darwin Inspired Learning*, used with permission)

The various 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 pupils 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 pupils sceptical of its worth (Ødegaard, 2003).

Science is partly characterised by abstract ideas relying on conceptualising invisible components (energy, molecules, electrons, biological cells and so on) making learning for pupils, already having a number of alternative views of how the world works, even more problematic. Rationalising between these two worlds, the science and the everyday, requires differentiation between and integration of two ways of explaining and seeing (Scott, Mortimer and Ametller, 2011). Integration of ideas requires accommodation of new ideas with those already held that provide more workable, rational and generalizable explanations of the world. To achieve integration means making abstract ideas and theories of science more plausible. In the science teacher's pedagogical toolkit this is often done by the use of analogy and metaphor (Aubusson, Harrison and Ritchie, 2006). Drama, especially in the form of acted out simulations, offers analogues that are plausible and accessible alternatives for understanding abstract ideas.

Physical role-play involves pupils, through their positions and movements, providing analogues for structures such as parts of a cell or depictions of processes or sequences, such as sound propagation and its transmission, peristalsis along the gut or energy transformations. Role-play can be used to model and reveal entities, concepts and sequences that are abstract and hard to portray through practical work or by other means. Examples include ionic and covalent bonding and the behaviour of atoms and molecules in phenomenological events such as expansion, boiling, condensation, dissolving and so on.

In the example shown in Figure 3, 13 year old pupils were asked to portray what they understood of fertilisation and sex determination in humans.

Figure 3. A fertilisation role play. (From Abrahams and Braund, *Performing Science*, 2012, used with permission)

Through the use of the simple props, movements and positions of the pupil-players a sometimes hard to visualise process has 'come alive'. Of course video or computer simulations could have been used to show the same thing, but how much more does pupils' personal and physical involvement in devising a role-play and acting it out add to their understanding? In movements and tableaux, that take only minutes to perform, a complex set of interacting concepts are portrayed through performance: the entry of a sperm nucleus across the ovum membrane, the mix of genetic material that defines the moment of fertilisation, the genetic determination of gender by combinations of X and Y chromosomes and the ovum membrane as a barrier to further entry of sperm once fertilisation has taken place. The drama task helps pupils appreciate the complexity of interacting processes that are often overlooked when using other learning media (Colucci-Gray *et al*., 2006). Using drama is a powerful tool for the science teacher mainly as it provides the sorts of mental spaces and physical interactions and opportunities for pupils to engage with narratives that are lacking in some other methods that constitute the rather impoverished diet for science learning provided by many schools. Ultimately drama works because it helps provide relief from the tedium of much science teaching with the bonus of improved engagement and interest for pupils who experience it.

The power of approaches from the arts described in this section and others, such as poetry, creative writing and music, that there is not space to discuss in depth here, is that they offer STEM science teachers a greatly enhanced pedagogical toolkit to help pupils learn in STEM subjects.

Conclusions

In arguing for the contributions that arts might make to science and to science education I do not claim that there should be full integration, on the basis that these areas of human activity are the same. As literary critic George Steiner cautions in his lecture on the 'Two Cultures' in 2013, the intentions, procedures and products of the arts and science are not, and never have been, shared (Steiner, 2013). Art does not, like science, proceed from a less complete and less satisfactory representation of the world to a better or more complete one. The paintings of Giotto are not less worthy than those of Pollock or Renoir. They are products of their own times and cultures. Science, though like arts culturally and socially bound, is different to the arts as it proceeds by empiricism testing out and establishing better representations of the world. Today's views of the universe and its origins are more complete and better (though never wholly complete) than those of Einstein, Newton, Galileo, Copernicus, Ptolemy or Aristotle. As in science, technology aids endeavour and makes new things possible for the arts but it does not necessarily provide for better products, only different ones. In science, technology enables advancement of knowledge making new explorations and improved understanding possible (for example through better telescopes and microscopes).

In this paper I have put forward arguments for the enterprise of science in the 21st Century increasingly requiring and gaining from modes of thinking and opportunities for collaboration from the arts. The activities of scientists are changing rapidly to accommodate these opportunities. The arts and the sciences are accelerating in gaining cultural and knowledge capital from each other. In an article with Michael Reiss (Braund and Reiss, 2006), we proposed that science education has not accounted for the changes in science that have broadened its scope and spheres of operation (to encompass science done in other places than in traditional laboratories) nor in the advances in psychology and neuroscience that have improved our understanding of how people learn. Thus we saw an increasing divergence between science and the way it is changing in the real world (and some educational research) and science represented in STEM teaching. This divergence is made even starker when the extra dimensions of arts' contribution to science and arts-based pedagogy in teaching are considered. The drivers of STEAM add new dimensions to the nature of science in the 21st Century and will make it likely to diverge even more rapidly from STEM in the school system unless new pedagogies, including those form the arts, help close the gap drawing the nature of learning science closer to the changing nature of science in the real world. It is my hope that drawing on the arts for STEM teaching might result in a more authentic, engaging and holistic experience of learning relevant to the needs of citizens in the 21st Century.

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