# The Creative Sciences

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Discover the creativity that lies at the heart of scientific endeavour and how to teach for and with creativity in science.

**Abstract**

Creativity lies at the heart of science teaching and learning. However, stereotypically, creativity is more widely associated with the arts than the sciences. In this article, we challenge this perception and demonstrate how to teach for and with creativity in science. With developments in artificial intelligence, the need to foster students' creative thinking in STEM subjects is a matter of urgency. Using Joseph Wright's painting "An Experiment with a Bird and the Air Pump", the lectures of Michael Faraday, and imaginative activities we highlight how creativity is fundamental to scientific endeavour and how this can be emphasised in science teaching.

**Article**

While many science teachers will recognise the creative thinking that lies at the heart of scientific endeavour, popular perception more widely associates creativity with the arts than the sciences (Davies and MacGregor, 2016, James *et al*., 2019; Lehmann and Gaskins, 2019; Rees and Newton, 2020). For example, a recent series of information events run by UCAS, the UK's university admissions service, advertised subject events across all disciplines such as the Biological Sciences, Arts and Humanities, Mathematics etc. but also a specific event for "Creative Subjects". If these subjects are explicitly labelled as "creative" then the implication is that the other subjects are not. Many think that creative people study the Creative Arts and work in the Creative Industries. When do we hear about creative people studying the Creative Sciences in order to pursue careers in Creative Laboratories? Labelling the arts as creative pursuits implies that the sciences are uncreative. Such perceptions have important consequences for the subjects that children choose to study and their future career direction.

This perception is, of course, patently untrue and is contrary to our experience of the scientific endeavour; whether it is asking scientific questions, generating explanations, or constructing experimental tests of them. Advances in our understanding of the world have often come about by great leaps of imagination that challenged the perceived wisdom of the time such as: Copernicus imagining the solar system with the Earth rotating around the sun, Newton extrapolating fundamental laws of the universe from observing a falling apple or Pasteur imagining unseen tiny disease causing organisms floating in the air (Carey, 2012). And for the science teacher, there is another dimension: being creative in their teaching, constructing new approaches to teaching a topic, and finding different ways to explore students' ideas and explanations.

A need to foster creative thinking in STEM subjects is becoming pressing. The development of digital technology, and artificial intelligence in particular, is moving at such a pace that it is expected to take over much of the workplace that is reducible to a routine, and adapt and add to those routines to make it more effective (Bakshi, Frey & Osborne, 2015). Even teaching will change (Newton & Newton, 2019). But, at least for the foreseeable future, it meets its limits when it comes to creative thinking, and this is where there will be significant career opportunities.

Motivated by the need to redress the stereotypical perceptions of science and science teaching, and the need to foster creative thinking in students, we have sought to explore the nature of creativity in science and how teachers can teach *for* and *with* creativity (Rees and Newton, 2020), with the aim that the phrase "the Creative Sciences" becomes as widely recognised and accepted as "the Creative Arts". The education systems of some countries (e.g. Finland, Australia and Singapore) are developing creativity focused curricula to enhance future prosperity. In the UK, curricula promote scientific thinking, how scientific ideas develop and evaluation of scientific representations but teaching for creativity in science is not widespread (James *et al*., 2019).

The importance of links between the Arts and Science has been widely recognised to develop new ideas and collaborations for a long time. For example, scientists and artists would mix in learned societies like the Lunar Societies of Georgian England and these remain active today. Lehmann and Gaskins (2019) argue that there is much to be learned about scientific creativity by examining it through the lens of artistic practice. Putting these ideas into practice in the classroom, art and science can be combined to teach for creativity. For example, in our teaching with Foundation year university students exploring the nature of scientific enquiry, we present Joseph Wright's painting "An experiment with a bird and the air pump"(1768) that hangs in the National Gallery. The date is significant as it is several years before the discovery of oxygen (Figure 1.).

Figure 1. An Experiment on a Bird in an Air Pump (https://commons.wikimedia.org/wiki/File:An_Experiment_on_a_Bird_in_an_Air_Pump_by_Joseph_Wright_of_Derby,_1768.jpg)

(The painting can also be viewed online with the added capability to zoom in on fine details - https://www.nationalgallery.org.uk/paintings/joseph-wright-of-derby-an-experiment-on-a-bird-in-the-air-pump). The students were asked what they see. Many are immediately drawn to the human characters and their emotions: the illuminated, distressed face of the young child or the face of lecturer, intently staring out at us, seeking our attention, imploring us for guidance as the distressed bird lies dying in the evacuated bell jar. The focus on the human characters shows us the importance of the human story in engaging the audience. The title of the painting reads like the start of an investigation in many students' lab books but we can see that the stories about the people are just as important as the science for engagement and interest.

As the painting is explored in more detail we observe specific scientific objects and phenomena. What is in the curious jar at the front of the painting? What do we notice about the stirring rod in the jar as it passes through the liquid? What has happened to the air inside the bell jar and why is the bird dying? In the context of exploring this work of art we are also developing the key scientific skills of careful observation, asking questions and seeking explanations through creative thinking.

One of the first steps in scientific creative thinking is to produce an explanation that is potentially useful and scientifically plausible (Newton, 2010). With this painting we can consider the explanation that the observers would have given at this time; with little knowledge of animal physiology and several years before the discovery of oxygen. How different is the explanation we would provide now! Science curricula are often criticised for presenting scientific knowledge as established fact rather than as evolving and developing thought through a combination of scientific investigation and creative thinking.

Having used the painting as a stimulus, the students proceed to undertake their own investigation - not with live birds, of course, but rather with a candle floating in a tub of water, inside an inverted measuring cylinder. The lit candle burns for a while and then goes out and the water level rises inside the measuring cylinder. Engaging in divergent thinking, the students suggest as many questions as possible to investigate such as: what would be the effect of a larger candle, more candles or a larger measuring cylinder? Using convergent thinking, they then decide which question they would like to investigate and design an experiment. We often don't allow sufficient time for students to construct causal Why? questions. Often, their first two or three questions are about facts as they build a descriptive mental model of the situation ('Does it get hot?' Is that smoke from the candle?'). Only then do they begin to build Why? questions ('Why does the flame get smaller? Why does the water level rise?) to which the answer is, 'What do you think?' (Newton, Newton & Abrams, 2019).

The phenomenon of the water level rising inside the measuring cylinder is often explained by the candle using up oxygen as it burns. However, careful observation (linking back to the painting) reveals that the water level does not steadily rise as the candle burns but rather rises quickly once the candle is extinguished. This observation does not support the initial explanation as we would expect a steadier rise as the oxygen is consumed. This is explored further with our knowledge of the combustion equation which shows that, for every molecule of oxygen reacting, one molecule of carbon dioxide is produced.

Challenged with finding an alternative explanation, the students engage in creative, divergent thinking to suggest alternative explanations. This is a key moment in teaching for creativity. The teacher may find it tempting to offer the correct explanation but this should be resisted as long as possible. The students could be challenged to go away and think about it or discuss it with friends and then return with suggestions. In addition, it is important, at this stage, to tolerate ideas that are scientifically implausible in order to encourage divergent thinking. This promotes openness and creates an environment where students are more likely to contribute. Critical thinking is for the next stage, but, if applied too soon can close down creative thinking. During the next stage, convergent thinking, the most plausible and parsimonious (simple and accurate) ideas may be selected. Discussion may lead to thinking about the heat from the candle flame and its effect on the gas molecules inside the measuring cylinder. As the gas becomes hotter the gas expands and escapes from the measuring cylinder. Careful observation of the experiment may note bubbles of gas escaping around the edge of the inverted cylinder. Then, when the flame goes out, the gas cools down and the air pressure inside the cylinder is less than outside so water moves up the cylinder.

Finally, the effect of the burning candle is linked back to the bird in the painting and the students are challenged to explain the connection between them. The chemical reaction of combustion is compared to that for respiration and the realisation that they are basically the same process. Just as the candle flame was extinguished when there was no more oxygen, so was the life of the bird. Therefore, this activity uses art to explore important ideas and the links between them in physics (gases), chemistry (combustion), biology (respiration) and scientific enquiry. Science is a creative human endeavour, asking questions about the world around us, constructing plausible explanations of them, and designing experiments to test their worth as answers. The creative nature of this process is often lost when science is presented as a series of established facts simply to be learned.

To engage students in science, it is important that the human element is emphasised: putting the people back into science (Mahaffy 2006, Newton, 1988). However, pictures of great scientists in text books may be criticised for being dominated by black and white images of long-dead, old men. These people are rightly acknowledged for their important contributions, but can be difficult for some students to relate to. Instead, it helps to tie the scientific world to the everyday world of the learner. For example, a working class 14-year-old boy, Michael, is walking down the streets of London. He is from a poor family with a father suffering from ill health, and so he has left school to seek work. He passes several shops and sees a sign in a bookbinder's window advertising for an apprentice. The young boy enters the shop and spends the next seven years in the bookbinding trade. However, it is not so much the skill of putting the books together that interests him, but rather the words within. As he begins to read the books, they spark his imagination and curiosity. In particular, he is intrigued by the science books and the stories they tell of discoveries in the creative world of science. He begins to attend public science lectures and makes conscientious notes from the meetings. He decides to approach the scientist giving the lectures, who, impressed by his enthusiasm, interest and conscientiousness, offers him an apprenticeship in his laboratory. And so begins the scientific life of Michael Faraday.

Faraday is often pictured as an older man, in grand Victorian attire holding what appears to be a cigar (but is actually scientific apparatus) – an austere and grand looking character who children have difficulty relating to. However, by telling the story of his childhood, the character becomes far more relatable and we learn something of how a boy, no different to anyone else, became the great man that he did.

Faraday was a pioneer of communicating science to the general public. Were he around today, his talks would probably have millions of views on Youtube and TEDTalks, and of course, the Christmas Lectures at the Royal Institution, where he worked. However, we can only use our imagination to think what it would have been like to be crammed into that lecture theatre in London, observing the range of scientific apparatus on the bench, awaiting the arrival of Faraday. Fortunately, full transcripts of his lectures "On the Chemical History of a Candle" were published (Faraday, 1865) and provide us with valuable insights into the man, the natural philosopher and communicator. Using these transcripts for inspiration, the lectures were brought back to life (see Figure 2) by Simon Rees to stimulate people's imaginations and explore creative thinking in science.

Figure 2.  Recreating Faraday's lectures.

In the course of the lectures, Faraday demonstrates how careful observation of an everyday phenomenon, such as a burning candle can promote many questions.

"*How is it that this solid gets there, it not being a fluid? Or, when it is made a fluid, then how is it that it keeps together? This is a wonderful thing about a candle."*

Faraday is asking the audience to consider how the solid wax is able to make the journey to the end of the wick.  Or if the solid wax becomes a liquid then why does the candle not fall apart and form a puddle on the floor? Rather than simply providing answers, he consistently encourages his audience to ask questions about what they observe.

*"….and I hope you will always remember that whenever a result happens, especially if it be new, you should say, "What is the cause? Why does it occur?" and you will, in the course of time, find out the reason."*

Through observations made of simple experiments, he demonstrates how these promote creative thinking - asking questions and developing explanations:

"*I will blow out one of these candles in such a way as not to disturb the air around it by the continuing action of my breath; and now, if I hold a lighted taper two or three inches from the wick, you will observe a train of fire going through the air till it reaches the candle.*"  And "*Suppose I take this candle, and hold a piece of paper close upon the flame, where is the heat of that flame? Do you not see that it is not in the inside? It is in a ring,"*

What do these observations (Figure 3) tell us about the "smoke" (or more accurately – the vapour) and the nature of the flame itself?  If the vapour will relight then what must it be made of?  Why is the hottest part of the flame on the outside?

Figure 3. A charred ring formed on a piece of paper held briefly in a candle flame.

This demonstrates how the simplest of experiments and observations can act as stimulus for creative thinking, further questions and tentative explanations.

The performance interweaves the human and scientific narratives to create an engaging and thought-provoking experience.  As one event organiser said:

"*A huge thank you for your Faraday performance today - it was really amazing, and the children absolutely loved it.  I sometimes used to say in primary school that we had moments of awe and wonder, and your presentation was one of those moments*".

Thinking of and exploring alternative What if? worlds is the essence of finding explanations in science. The students are encouraged to ask What if? questions and learn that science is not just about learning known facts, but is also about thinking creatively about the world around us; to ask interesting questions, design investigations, develop explanations and imagine possibilities.  And science teachers enjoy exploring creative teaching as they invent ways of making this happen.

With their teachers, the children (age 6 – 10 years old) then investigated different scientists and devised their own performances to present to their peers and an invited audience including "Michael Faraday".  This provided the opportunity for the teachers and students to identify a wide range of scientists (e.g Mary Anning, Marie Curie) whose lives and contributions could be explored.

Now close your eyes and imagine you are shrinking down so small that you are the size of a piece of dust on the floor.  Look around and what do you see? How different would the world look from this perspective?  Imagine you are shrinking even smaller to the size of the molecules of wool making up the carpet and even smaller to the size of atoms making up those molecules until you are stood on the nucleus of a carbon atom.  Open your eyes and what do you see? What do you hear? What do you feel?

Everybody's answer to this will be different and many are likely to say "I don't know".  However, from an early stage in science education, it is this journey that we ask our students to do –  to imagine the sub-microscopic world of molecules, atoms and sub-atomic particles.  Typically represented by dots and crosses on a piece of paper, is it little wonder that students can struggle to engage their imagination with this invisible world?  In the same way that great authors such Pullman or Tolkien create imaginary worlds, science teachers are the authors of their students' scientific imagination and need to think carefully about the stories they tell.

Astronomy is a popular subject that captures wide public interest. TV programmes on the subject take the viewer on journeys of imagination to far off distant galaxies and worlds that we will probably never be able to see or feel. In order to help the viewer, the presenter visit various locations around planet Earth such as arid deserts or the arctic ice to help the viewer imagine these unchartered regions of space. The programme would struggle to capture people's imaginations if it relied on drawings of dots and crosses on a page! Every chemistry lesson is a journey of imagination into the unchartered sub-atomic waters of chemical reactions and it is our role as science teachers to help the students to think creatively and imagine.

An important part of creative thinking is to challenge and critically evaluate established scientific knowledge, models and representations; resulting in new perspectives and understandings. The Periodic Table is often presented as "fait accompli" and the arrangement is left unquestioned. With my students, I ask them to critically evaluate the Periodic Table and to identify any possible shortcomings. They make observations such as the variable position of hydrogen, the separate block for the lanthanides and the actinides or the discontinuum of the atomic number sequence caused by the Periods being in rows and the need to jump from the end of one row to the start of the next.

The students are challenged to come up with alternative arrangements. After the initial phase of evaluative or critical thinking, we now enter the divergent thinking phase and the generation of ideas. Some students find this very challenging and struggle to imagine different ways of arranging the elements; seeing no reason to change the current arrangement. Others, on the other hand, more readily explore possibilities and create new ideas with elements arranged in different ways such as spirals that developed into a snail like shape to include the lanthanides and actinides (Figure 4).

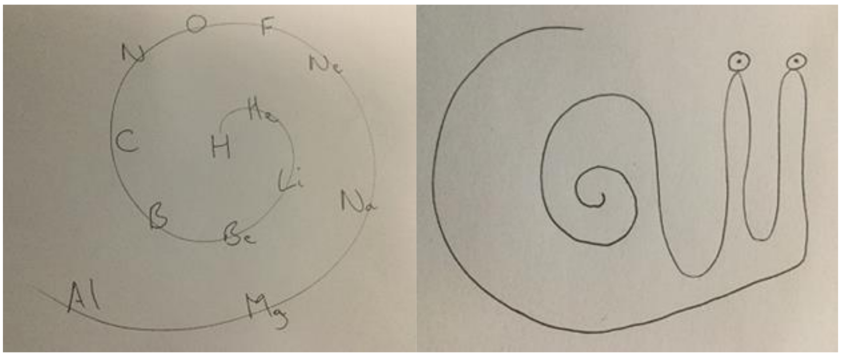


Figure 4. Student generated alternative arrangements of the elements.

Having presented their ideas, the students are introduced to some examples of the extraordinary array of alternative periodic tables that have been developed (see the internet database of periodic tables). Prevalent amongst these, are arrangements based on 2D or 3D spirals. Indeed, one of the earliest examples of periodic sequencing was the so-called “Telluric Screw” by Alexandre-Emilé Béguyer de Chancourtois. This involved wrapping the elements around a cylinder and thereby maintaining the atomic number continuum. Mendeleev himself stated “*In reality the series of elements is uninterrupted, and corresponds, to a certain degree, to a spiral function.*” (Jensen 2002, p. 56). It is suggested that the main reason this arrangement did not become established was the difficulty of reproducing the 3D arrangement on the printed page.

The students now engage in convergent thinking, reflecting on the different ideas and when they may be used in different contexts. For example, if we were focussing on the uses and availability of elements in the world then it would make sense to use the Periodic Table of Scarcity.

In this article we have demonstrated the central importance of creative thinking in science and science teaching. Making this more explicit and widely acknowledge would have significant benefits for engagement and understanding in science. Exploring creative approaches can make the subject more accessible and relatable for students. It also has benefits for teachers, enhancing professional identity and job satisfaction. In so doing, we hope the phrase “the Creative Sciences” will become as well established and recognised as “the Creative Arts”.

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