想象力和创造力在科学教育中扮演的角色，以及在科学教育中鼓励学生提升想象力及创造力的重要性

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The role of imagination and creativity in science and the importance of encouraging imagination and creativity in science education

想象力和创造力在科学教育中扮演的角色，以及在科学教育中鼓励学生提升想象力及创造力的重要性

Do we need initiatives such as ‘STEAM’ (Science, Technology, Engineering, Arts and Mathematics) to bring imagination and creativity to science lessons?

我们是否需要像‘STEAM’（科学、技术、工程、艺术和数学）这样的理念来把想象力和创造力带进科学课堂?

There has been a good deal of work exploring such ideas as ‘STEAM’ – looking to develop cross-curricular learning, which relates the already quite distinct areas of science; mathematics; and engineering and technology; with the arts. As one example, learners might be asked to write a poem based on some science topic they are studying.

现如今已有很多关于‘STEAM’等旨在发展跨学科学习理念的探索，这些理念将本来大相径庭的科学，数学，工程和技术领域与艺术相连结。例如，学生可能被要求写一首基于某些他们正在学习的科学课题的诗歌。

In this talk I am going to take a somewhat different focus: rather than seeking to discuss how science can be hybridised with (what are considered) creative subjects, I want to consider how imagination and creativity can be engaged with from within science and the teaching of science. This is not to suggest that there is not value in cross-curricular approaches, as there most certainly can be much benefit to learners. However, as a scientist I worry that science is widely mischaracterised as one-dimensional, and I want to argue for a more nuanced understanding of the nature of science within science teaching.

在本次演讲中，我将讨论一些不同的议题：我并非要探讨如何将科学与（被认为是）创造性的学科相结合，而是要考虑在科学和科学教学中将想象力和创造力加以融合。并不是说跨学科的方法没有价值，学习者可以从中获益是毋庸置疑的。但是，作为一名科学家，我担心科学可能会被误解为表象或是一维的特征，因此我想主张在科学教学中对科学的本质进行更细致的了解。

Three domains

三个领域

I am going to start with a caricature of the curriculum. This is at least a caricature of the subject-based curriculum in England where I have worked, and I think it applies much more widely.

我将从课程的展现开始，至少这是我教过的英格兰的课程中的基于学科的展现，我认为它有着更加广泛的应用。

I am going to suggest we might see the curriculum as addressing three domains of human activities and concerns.

我们可能会认为课程设置涉及人类活动和关切的三个领域。

One of these domains concerns humanities subjects, such as history, philosophy, religious studies, and literature. These subject are concerned with questions of what it is to be human, and how we should behave, and with trying to understand those from other places, other times, other cultures – or just those we meet who inevitably are different in some ways from ourselves. How do they feel?

这些领域之一涉及例如历史，哲学，宗教研究和文学等人文学科。这些学科探索关于人类是什么样子的，我们应该如何行事，以及试图了解来自其他地方，其他时间，其他文化的人 — 或者只是我们遇到的和我们在某些方面必然有所不同的人们。他们有怎样的感受?

How does someone feel when the person they love rejects them; or when they are subject to sexist or racist discrimination; or when told they have an incurable disease; or when their child has gone missing, or…? Clearly such matters are at the core of developing to responsible adulthood – but, perhaps not obviously anything to do with science.

当有人被所爱的人拒绝时是怎样的感受；或者当他们遇到了性别或种族歧视时；或者被告知患有不治之症；或者当他们的孩子失踪了；或者更多的或者？显然，这些问题是成长为有责任感的成年人的核心 — 但是，也许和科学毫无关系。

Another domain is the creative arts: music, painting, decorative ceramics, dance, and so forth. These subjects show us ways that have developed in our cultures to allow us to express ourselves. Music is said to be the food of love, and also to have charms to soothe a savage breast (and in regular misquoting, to soothe a savage beast!) Music can make us joyful, or patriotic, or can bring us to tears. Great art can make us feel we are one with the cosmos – or that we are insignificant. Again, it is not obvious that science has much of a role here.
另一个领域是创造性艺术：音乐，绘画，装饰陶瓷，舞蹈等。这些学科展示了在我们的文化发展中衍生出的表达自己的方式。音乐被认为是爱的产物，并且具有抚慰凶悍的胸怀的魅力（经常会被误引为，抚慰凶悍的野兽！）音乐可以使我们快乐，爱国或者流泪。伟大的艺术可以使我们感到自己和宇宙融为一体，或让我们认为自己微不足道。同样，科学在这里起到的作用并不明显。

Science seems to occupy another domain – one that is based not on feeling, or judging right and wrong, but cold logic. The application of rational thought to better understand the world and to address practical problems.
科学似乎占据了另一个领域 — 一个并不基于感受或判断是非，而是基于逻辑的领域。运用理性思维来更好的理解世界并且解决实际问题。

Misrepresenting science
科学的曲解

I am certainly not going to deny that this is a major part of the essence of the natural sciences. But I do question this as a model of a kind of demarcation of responsibilities within the curriculum.
我当然不会否认这是自然科学本质的重要组成部分。但我确实对此作为课程设置内职责划分的一种模式存疑。

Such a model sells science short, misrepresents its full nature, and so can limit the potential of science teaching to offer a fully authentic science education. So, science and science education is indeed very much concerned with logic“ and rational thought, but it is also about values. Certain core values are inherent to science itself, and so any authentic science education must address the values of science.

这样的模式低估了科学，曲解了科学的完整本性，因此会限制科学教学提供完全真实的科学教育的潜力。科学和科学教育的确与逻辑和理性思维息息相关，和价值观也息息相关。某些核心价值观是科学本身固有的，所以任何真正的科学教育必须致力于科学的价值观。

And, the application of science centrally involves issues of values, and often having to negotiate between different systems of values. It is possible to take a position that the scientist is concerned with the science, and decisions about application are matters for others – industry, the government, and so forth.
而且，科学的应用主要涉及价值观问题，并且常常需要在不同的价值体系之间进行判断。可能有些人会认为，科学家致力于科学研究，而关于应用的抉择则取决于其他人 — 行业，政府等。

However, this would unreasonably excuse scientists from responsibility for their part in developments they know could be harmful, and ignores the humanitarian motives behind much science. It also ignores how science education is not just an education for future scientists, but for those who will make decisions about the application of science – and actually, at some level, that is all of us.
然而，这将无理地责备科学家在他们认为可能有害的发展中承担责任，从而忽视了很多科学背后的人道主义动机，也忽视了科学教育并不仅仅在培养未来科学家，也是在教育那些将对科学的应用做出决定的人们 — 实际上，在某种程度上，这就是我们所有人。

Finally, and central to my presentation today, science is not just a cold, rational process, but a process that is creative, and calls upon human imagination.
最后，我今天演讲的主旨是，科学并不仅仅是一个冷酷和理性的过程，而是一个需要人类的想象力的创造性的过程。

Applying logic and rational thought
逻辑和理性思维的运用

I am not going to say much about the importance of logical and rational thought, in scientific work, as I think this is generally acknowledged.
我不会赘述在科学研究中逻辑和理性思维的重要性，因为这是公认的。

At the core of science is the interplay between theory and empirical investigation. Scientific enquiry uses logic to test out hypotheses and conjectures, and even well-established theories in new contexts. It uses deductive processes to draw conclusions from carefully designed investigations.
科学的核心是理论与实证研究之间的相互作用。科学研究使用逻辑来验证假设和猜想，甚至在新的情境下检验公认的理论。它使用演绎过程从精心设计的调查研究中得出结论。

This depends essentially upon applying sound logic to draw rational conclusions as to whether observations can – given all the provisos and caveats that enquiry necessarily involves – be considered to offer support for, or alternatively to bring into question, theoretical propositions.
这主要取决于运用合理的逻辑得出合理的结论，即在考虑到探究必然涉及的前提条件和注意事项的情况下，是否可以考虑将观察视为对理论主张的支持或提出质疑。

Adopting internal values
内部价值观的采用

However, science is also a value-heavy enterprise. Indeed, science has its own set of internal values relating to such matters as objectivity, open-mindedness, self-criticism, open-reporting (and, increasingly, open-source data), inviting critique and dialogue.
然而，科学具有重要价值。确实，科学具有诸如客观性，开放性，自我批评，开放报告（以及越来越多开源数据）的内部价值，欢迎批判和对话。

As an example, scientific work is meant to be reported openly with sufficient detail to enable another researcher to repeat the work, and check on the reported outcomes. In practice, replication may not be so straight-forward – and as science has a tacit dimension it is never possible to include every relevant detail in a scientific paper – but the principle is taken very seriously.
例如，科学研究应足够详细的公开报告以使得其他的研究人员可以重复该研究，并且检验报告的结果。在实践中，由于科学具有缄默的方面，不可能在科学论文中包含所有相关细节，也许无法那么直接的复制研究 — 但这个原则是被非常认真考虑的。

So as one example, a researcher making good progress in a new field is not allowed to publish her work with some key details missing so that others cannot copy her methods, in order to retain her advantage in the field (as was sometimes the practice some centuries ago). If this were to be attempted, then journal peer review should judge that the report is incomplete, and more details are needed before publication can be recommended.
举一个例子，为了保持在领域中的优势，一个在新领域取得良好进展的研究人员不能为了防止其他人复制其研究方法而发表缺少关键细节的研究成果（这种情况有时可能存在于几个世纪前）。如果尝试这样做，那么期刊的同行评审会判断该报告不完整，并且需要更多的详细信息才能建议发表。

Science also adopts what might be referred to as aesthetic or stylistic values, relating to such issues as simplicity, elegance, symmetry, and the ability of new concepts to subsume different existing concepts (as in the case of Maxwell's electromagnetism subsuming electricity, magnetism and light) – or, of new principles that integrate different topics.
科学还采用了所谓的美学或者文体价值，涉及诸如朴素，优雅，对称性以及新概念中包含不同的现有概念的能力（例如麦克斯韦电磁学中包含电，磁和光）— 或者整合了不同主题的新原理。

Many scientists were when young struck with awe and wonder – perhaps when looking at the night sky or at components of the living world, and this is often a factor in attracting them to science.
许多科学家在年轻时就充满敬畏和好奇 — 也许是在看夜空时或者生活中的某个组成部分，这通常是吸引他们从事科学的一个因素。

That young scientists may see beauty where others do not spot it – perhaps in the scales of fish, or the coloured patterns observed in an oily puddle, or the evolving shapes of clouds – or even in places others find distasteful – the magnified image of a fly with its compound eyes, or a dyed bacterium fluorescing under the microscope.

年轻的科学家们可能会发现其他人难以发现的美 — 也许是在鱼鳞上，也许是在油腻的水坑中观察到的彩色图案，或者是不断演变的云朵形状 — 甚至在其他人可能讨厌的地方 — 记录了苍蝇的复眼的放大图片，或者显微镜下发荧光的染色细菌。

Critics sometimes claim that the scientist's cold analytical approach must dissolve the sense of beauty in nature. Scientists will often retort that understanding only adds to the sense of awe. Moreover, with greater understanding, scientists start to perceive beauty that others may not be able to access.
评论家们有时声称科学家冷冰冰的分析方法会消除自然界的美感。科学家们经常反驳说，了解和理解只会增加敬畏感。而且，随着更加深入的了解，科学家们开始意识到其他人可能并未发现的美。

The symmetrical structure of the benzene ring has a profound beauty that is only appreciated when you understand and can visualise the molecular structure. False-colour images from satellites that observe the earth using different frequency bands to those supporting human vision reveal patterns of great beauty that no human could see directly (even from the international space station). In the story of the elucidation of the structure of DNA, scientists such as Rosalind Franklin and Francis Crick not only comment on the affordances of the structure (in terms of the genetic code, and replication of the nuclear material) but on its beauty.
只有当你了解并可以将分子结构视觉化时才能欣赏到苯环对称结构所具有的强烈美感。来自卫星的观察地球的假色彩图像，使用与支持人类视觉的频带所不同的频带，揭示了人类（即使通过国际空间站）无法直接看到的美丽景象。在阐明DNA结构的故事中，罗莎琳德富兰克林和弗朗斯希克里克等科学家不仅（从遗传密码以及核材料的复制方面）评论了该结构的功能可见性，也评价了其美丽。

Considering other value positions
其他价值立场的考虑

For most scientists, the application of science, and indeed the motivations for scientific work, are linked to extra-scientific values.
对于大多数科学家而言，科学的应用以及科学工作的动机实际与科学范围外的价值相关。

Scientists do not only go into science to better understand the natural world, but also to change it. They may want to improve crops, cure diseases, save endangered species, reduce waste, slow climate change, clear up pollution, lengthen productive life, and increase the quality of that life.
科学家进入科学领域并不仅仅是为了更好地了解自然世界，也是为了改变它。他们可能希望改善作物，治愈疾病，拯救濒危物种，减少浪费，延缓气候变化，清除污染，延长寿命，并提高生活质量。

The choice to enter particular fields of research, or to seek funding for particular projects, may be informed by extra-scientific values as much as by the inherent value of the work. Science and technology are different disciplines, but of course applied science is the basis for new technology. We are all consumers of that technology, and we can all benefit, or suffer, from its consequences.
选择进入特定的研究领域，或者为特定的项目寻求资金，可能会受到科学范围外的以及工作内在价值的影响。科学和技术是不同的学科，但应用科学当然是新技术的基础。我们都是科技的消费者，我们从中受益或者承受其后果。

Of course, some scientists are happy to be paid to do interesting work, without regard to such considerations. So, for example, the military funds much scientific research and some scientists will happily work in areas such as weapons development, even in times of peace. Some may genuinely believe that such work helps keep the peace, or is necessary because their side is good and will only fight against evil. Others may not feel it is for them to be concerned.
当然，一些科学家很乐意为了酬劳去做有趣的工作，无需考虑以上因素。例如，军方为科学研究提供了很多资金，即使在和平时期，一些科学家也乐于在武器研发等领域工作。有些人可能相信这些工作有助于维护和平，或者是必要的，因为他们的立场是善良的，只会为与恶势力作斗争。其他人可能不觉得这是他们需要担心的。

Yet, no scientists today can be so naive as to consider they can ignore such questions and be absolved from moral responsibility for how the outcomes from their labour is used. This became very clear when the 1939-1945 world war was brought to an end by the use of atomic weapons such that a single bomb could destroy a whole city, and

indiscriminately kill many thousands of people instantaneously, and leave thousands more to die painfully over periods of years afterwards, as happened at Hiroshima and Nagasaki.
但是，如今，没有哪个科学家可以如此天真幼稚地认为他们可以忽略这样的问题，并且对如何利用其劳动成果免于承担责任。这一点在1939-1945年世界大战因使用原子武器而告一段落时变得非常清楚，一颗炸弹就可以摧毁整个城市，滥杀成千上万的人，并造成数年之后更多人痛苦去世，就像在广岛和长崎一样。

At the close of that war, many scientists became actively involved in working for international controls on the development of nuclear weapons. Modern nuclear weapons are so powerful that they use such atomic bombs as just the triggers of much more destructive devices.
战争结束时，很多科学家开始积极参与国际控制核武器发展的工作。现代核武器是如此强大，以至于他们使用原子弹只是更具破坏性设备的诱因。

Using imagination and creativity
想象力和创造力的发挥

As suggested earlier, awe and wonder, may be a major part of the motivation for working in science, and of the joy of the work.
如之前所述，敬畏和好奇可能是从事科学研究的主要动力，以及科研的乐趣。

Just as important, science is a creative process.
同样重要的是，科学是一个创造过程。

We now know enough about human cognition and learning to dismiss the idea that by observing nature, it impresses the truth of reality on us. Our brains impose patterns on our perceptions, and make sense of the raw data from our senses. Our realities are mentally constructed, and are never simple copies of the external world. Learning is an interpretative, incremental, and so iterative, process.
现如今，我们对人类的认知和学习已经有足够的了解，从而消除了通过观察自然会给我们留下关于现实的真相的理念。我们的大脑给感知强加模式，并从我们的感知中获取原始数据。

我们的现实是精神建构的，绝不是外部世界的简单复制。学习是一个解释性的，渐进的，如此反复的过程。

In other words, our understandings of the world are largely based on imaginative creations. Scientific theories and models and principles and laws do not exist in nature – they are all human constructions, as much as a painting or sculpture or ceramic artefact. Theories, like symphonies, may be inspired by nature, but are the creations of human imagination.
换句话说，我们对于世界的理解主要基于富有想象力的创作。自然界中不存在科学的理论，模型，原理和法则 — 他们都是人类的建造，就像绘画，雕塑或者陶瓷制品一样。理论，就像交响乐一样，可能会受到大自然的启发，但确是人类想象力的创造。

To the scientists, nature may offer beauty to match any human-produced art. Of course, where science is very different from art, is that science seeks to build the constructions that most truly represent the natural world. So imagination is used to make ‘guesses’ at how best to make sense of phenomena, guesses that can be tested, and then also to construct the ways of testing these imaginings against nature itself. Yet even if imagination is used in a different role, it is just as essential to science as art.
对科学家而言，大自然可以提供与任何人类所创造的艺术相匹配的美丽。当然，科学与艺术截然不同之处，是科学试图构造自然世界的真正代表。因此，想象力被用来‘猜测’如何更好的理解现象，猜测可以被验证，然后去构建出针对自然本身检验这些想象的方式。然而，即使将想象力用在不同的角色上，它对科学和艺术同样至关重要。

Moreover, many of the inventions of science are not intended to literally reflect nature, but rather as thinking tools to imagine it. As one example, there are no magnetic lines of force in nature, but the invention of this way of representing completely invisible and non-substantial magnetic fields has helped generations of scientists in their work, as well as allowed others to appreciate the nature of magnetic fields. Another example is ray diagrams showing how light travels through lenses and off mirrors – these rays are completely imaginary. Non-scientists may not realise just how much science uses representational systems that are not intended to be realistic, but are purely tools of the imagination.

而且，许多科学发明并不是为了反应自然，而是作为思维工具去想象自然。举个例子，自然界中没有磁力线，但是这种代表完全不可见和非实质性磁场的方式的发明已经助力了几代科学家们的工作，并让其他人认识到磁场的本质。另一个例子是显示了光是如何通过透镜和镜面传播的射线图 — 这些射线是完全虚构的。非科学家们可能不会意识到多少科学使用了并非现实的代表系统，而纯粹是依靠想象力的工具。

Teaching science…
科学教学

So, if a full appreciation of science needs to encompass values and aesthetics and imagination as much as logic, then any authentic science education must do the same.
因此，如果对科学的全面欣赏需要包含价值，美学，想象力以及逻辑，那么任何真正的科学教育都必须做到这一点。

Where science teaching includes a good deal of enquiry, and problem-solving, we can probably be comfortable that rational thought and logic are well represented.
如果科学教学中包含大量的探究和解决问题的能力，我们可以感到满意的是理性思维和逻辑得到了很好的体现。

Enquiry also offers many opportunity to demonstrate and apply scientific values. Students can be taught to give full accounts of their work, including the relevant provisos and caveats that often limit the ability to offer strong conclusions. Students can be asked to report their work to each other and engage in peer-review (if in a supportive, constructive way, that perhaps is not always found in scientific professional practice). Credit can be given for finding the fault in one's own work and for being creative enough to suggest more than one possible interpretation of data.
问询还提供了许多证明和应用科学价值的机会。可以教会学生们详细说明自己的研究，包括那些经常限制得出强有力的结论的相关前提条件和注意事项。可以要求学生们互相汇报自己的研究，并鼓励同行评议（如果以支持性和建设性的方式，也许在科学专业实践中可能并非如此）。可以因为发现自己研究工作中的错误，并且有足够的创造力来建议不止一种数据解释的可能性而获得赞誉。

Engaging with what are known as socio-scientific issues can give students experiences of balancing different extra-scientific values when applying scientific knowledge. This will be important for all – people have to choose when to spend more on the food brand claiming more vitamins, or on the produce that claims to be produced in a more environmentally friendly way. People will have to balance the risks and costs of suggested medical treatments with likely benefits. It surely needs to be a core part of school science to offer some experience of facing such decision-making in the supportive context of the science class, before such issues are faced in adult life, sometimes with very high stakes.
参与社会科学问题可以为学生提供在应用科学知识时平衡不同科学外的价值的经验。这对所有人都非常重要 — 人们必须在花更多钱在声称含有更多维生素的食品品牌上还是声称以更环保的方式生产的产品上时作出选择。人们将不得不在建议的医疗措施的风险和成本与可能带来的益处之间取得平衡。当然，它必须是学校科学的核心部分，以提供一些在科学课堂的支持性情境下对此类决策的经验，然后才能在成年生活中面对此类问题，有时具有很高风险。

…using imagination and creativity
想象力和创造力的运用

Similarly, if science is a creative process that relies on imagination, then an authentic science education needs to reflect and represent this. Students must be given opportunities to use their imagination and be creative.
同样，如果科学是一个依靠想象力的创造过程，那么真正的科学教育需要反映和代表这一点。必须给学生们机会发挥他们的想象力和创造力。

This may sometimes involve writing stories or poems or undertaking paintings to reflect what is learnt in science; it may also mean using design flare as well as technical know-how in technology projects.
有时这可能涉及撰写故事或诗歌或绘画以反映学到的科学知识；这可能意味着在科技项目中使用设计和技术知识。

But it also means students need to be encouraged to suggest their own conjectures and hypotheses, to suggest their own explanations of scientific phenomena, and, if possible, ways of testing these. In practice, they will often have bizarre ideas (but then sometimes in science bizarre ideas may be useful – think of quantum mechanics and relativity), and it may not always be feasible to try out their tests. But that does not matter – often in science one scientist suggests ideas that others later test.
但这也意味着需要鼓励学生提出自己的猜想和假设，尝试自己对科学现象进行解释，如果可能的话提出检验这些现象的方法。在实践中，他们经常会有奇异的想法（但有时在科学中，奇异的想法可能有帮助 — 想想量子力学和相对论），尝试进行验证可能并不能总是可行。但这不重要 — 在科学领域，经常是一位科学家提出一些想法以供其他人之后进行检验。

It may mean reversing the way some practical work is employed: rather than teaching scientific ideas that are answers to questions students never had, and then offering them demonstrations – get students to make their own observations of phenomena and suggest what is going on, why things happen. This may motivate them to take more interest in the theory or principle or mechanism they are then asked to learn about as it will have epistemic relevance (as it will respond to a meaningful question for the learners).
这可能意味着要颠覆一些实际工作的方式：与其教授那些可以解决学生从未遇到过的问题的科学思想，然后为他们提供示范 — 不如让学生们对现象进行自己的观察并提出正在发生什么，为什么会这样发生。这也许会促使他们对所学习理论，原理或者机制产生兴趣，因为这将具有知识上的相关性（因为这会解答对学习者有意义的问题）。

Students should be encouraged to find creative ways of representing information they meet in science, and so bringing ideas together. This example is students' response to being asked to link ideas from biology, chemistry and physics in relation to plant nutrition.
应该鼓励学生找到创新的方式来代表他们在科学中遇到的信息，从而将思想汇聚在一起。比如学生们对被要求将生物，化学和物理的理论和植物营养联系起来的回应。

Students can also be asked to develop their own analogies and metaphors and similes for scientific concepts. It is less important that these are technically accurate than they give a creative context for exploring ideas. Scientists themselves often use such devices

both as thinking tools to develop their own work, and as communication tools to explain their ideas to others.
还可以要求学生针对科学概念发展自己的类比，隐喻和明喻。重点不在于准确性，而是其为探索思想提供的创造性情境。科学家们经常将这些作为思维工具来发展自己的研究工作，并且作为交流工具向他人解释自己的想法。

These devices always have limitations, negative aspects, but exploring these can help in understanding the core of the scientific idea. So, students can be asked to propose their own analogies, and similes, and then explain and defend them to others (as scientists need to do) and critique each other's suggestions in peer review (as scientists do).
这些工具总有局限性和消极的方面，但是探索这些可以帮助理解科学思想的核心。所以，可以要求学生们提出自己的类比和明喻，然后解释并且在其他人的质疑中捍卫自己（正如科学家们需要做的），并在同行评议中互相批判性评论对方的建议（正如科学家们所做的那样）。

Final words
结语

These are just a few comments, but I hope I have left you with the idea that it is not only possible to link science with other areas of the curriculum concerned with values and creativity, but also to emphasise science's inherent values in the science classroom, and to build into science lessons activities which allow learners to experience the essential role of imagination and creativity in science.
这只是一些评论，但我希望带给大家的想法是，不仅可以将科学和课程设置中与价值观和创造力有关的其他领域联系起来，而且可以在科学课堂中强调科学的内在价值，并将其纳入科学课堂活动中，使学习者可以体验想象力和创造力在科学中的重要作用。