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Aboard the helicopter: from adult science to early years (and back)

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ABSTRACT
This paper links early foundations in science for young children to the eventual achievement of science literacy for adults. There are five key arguments being made: (i) the early-years foundation stage (EYFS) specialists need to have a view for exactly what foundations *are* being laid in classrooms; (ii) that they all need to be – minimally – scientifically literate, despite the variety of definitions of that term; (iii) becoming scientifically literate is a long-term process of engaging with and developing an interest in 'matters scientific' that are easily available in the public domain; (iv) that there is a plethora of informal learning opportunities in science across the UK to foster adult engagement, and (v) taking a 'helicopter view' on occasions helps shape planning and processes in the nursery/ reception school classroom. To illuminate this, we offer two examples from materials science that grow out of traditional block play, and from all things plastic.

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Introduction

We begin by going backwards. One of the central goals of science education is to help engender a scientifically literate population. That would mean – say – a middle-aged couple of middle income, living in the middle of the country, having a:

> Good sense of how science operates – along with a basic inventory of key science concepts as a basis for learning more later – so they can follow the science adventure story as it plays out during their lifetimes. (American Association for the Advancement of Science [AAAS], 1993, p. 3)

The science literacy of that 'middle England' couple might, in part, be derived from their workplaces (depending on their occupations), some from popular culture (TV, radio, galleries, magazines, museums, zoos and the like), some from evening classes or leisure activities (bird-watching, gardening, home renovations, pet-owning). Going further backwards, some might be derived from university or college studies and, of course, from their A-level (pre-university) studies and, perhaps, vestiges from their secondary and primary school curriculums. Moreover, for the purposes of this discussion, some might even have been derived, a very long while back, from their early-childhood experiences and nursery schooling. In 2010, the UK Government's Science and Learning Expert Group (SLEG) demanded that the school curriculum as a whole be ' … more engaging and related to real life contexts, as well as the desire to improve the scientific literacy of all young people' (SLEG, 2010, p. 4). So, it is schools that are charged by the government with generating the 'good sense', the engagement, the 'basis for learning', those 'key concepts' and 'real-life contexts' required for scientific literacy for all. And, since early-years education provides the foundations for all of that, it must surely fall

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to early-childhood specialists to prepare the ground for the scientific literacy that is to be achieved by later life. After all, that is the very nature of laying foundations.

Understandably, there is immediately an enormous challenge involved: exactly what science can be developed with very young children that would provide, for example, that 'inventory of key science concepts' required by (say) a 50-year-old in his or her immediate – and continuing – life context? Peoples' lives are so very varied and their needs are all so very different. This is a challenge, of course, not only for early-years specialists but for all science educators across the board: it would be an enormously difficult task to agree an inventory (list) of 'key concepts' for today's adults, more difficult yet for what might be just around the corner, let alone hazard a guess for what might be extant in 50 years' time – concepts that will stand our current cohorts of reception-class children in good stead at that future point in life. Both science and society are changing much too swiftly for any such list to be straightforward or meaningful. Meanwhile, the Department for Education (DfE) sets out the requirements for the early-years foundation (EYFS) stage and, under the heading 'Understanding the world' (DfE, 2017), obliges early years providers to guide children in making sense of their 'physical world and their community through opportunities to explore, observe and find out about people, places, technology and the environment' (p. 212). Children, says the DfE, are to know about similarities and differences in relation to places, objects, materials and living things, they can 'make observations of animals and plants and explain why some things occur, and talk about changes' (p. 214).

Leaving aside what a scientifically literate adult *should* eventually know – or even what they might eventually *want* to know – there is a hearty debate about the effectiveness of science education in the lead-up to this (Hodson, 2008; Holbrook & Rannikmae, 2007; Millar, 2006; Osborne, 2007). For example, the UK's National Curriculum for secondary schools (DfE, 2015) is notorious for 'switching off' many, many more youngsters that it ever inspires (Confederation of British Industry [CBI], 2016; Office for Standards in Education [Ofsted], 2013). And while the primary school curriculum may cater for some of younger children's natural curiosity and inquisitiveness, it plays a distinct 'add on' second fiddle to literacy and mathematics throughout this phase of schooling (Ofsted, 2017). Recent assessments have shown, too, that the current method of teaching science to young children is not effective, and contributes to negative attitudes and poor performance in science that persist in the higher grades and affect later academic, professional and 'lay' choices (Sackes, Trundle, Bell, & O'Connell, 2011; Trundle, 2015).

More about scientific literacy

Scientific literacy (SL) 'for all' does not involve turning all people into scientists. Instead, for Hazen and Trefil (2009), it can be summarized as the knowledge a person needs to understand public issues, a mix of 'facts, vocabulary, concepts, history and philosophy' (p. xii) – a mix that allows the person to understand, for example, the news of the day as it relates to science. If the term 'superconductor' is used in a newspaper article, say Hazen and Trefil, then it is enough to know that this refers to a material that conducts electricity very, very efficiently. It helps to know, too, that conductors like this operate only at very low temperatures, and that a major goal of research into materials science is to find ways for superconductors to give this level of efficiency at more normal (easier to work with) temperatures. They say,

> You can be scientifically literate without knowing how a superconductor works at the atomic level, what the various species of superconductors are, or how one could go about fabricating a superconducting material. (p. xii)

In fact, Hazen and Trefil make the point that an intense, highly specialist study within a narrow branch of science really does not make that scientist scientifically literate – in fact, many working scientists are quite illiterate outside their own specific field of professional expertise. In the USA, the National Academies of Science, Engineering and Medicine Study Committee (NASEM, 2016) describe scientific literacy as being more than a basic knowledge of scientific facts, but needs to include an:

> Understanding of scientific processes and practices, a familiarity with how science and scientists work, a capacity to weigh and evaluate the products of science, and an ability to engage in civic decisions about the values of science. (p. 1)

This kind of definition certainly ramps up the demands on scientific literacy – not least because we authors, too, would want to add in some requirements. For example, we have written extensively elsewhere about what is entailed in being scientific and in 'making everyday scientists' (Salehjee, 2018; Salehjee & Watts, 2018a) – here we limit ourselves to just two of these:

(i) 'Purposive curiosity' and 'vital relevance'. In our view, these are key driving forces behind engagement with science, and we side with Schwab (1960) who maintains that a scientifically literate person is a man/woman engaged in 'enquiry-by-doing', where the order of scientific enquiry differs from one problem to another, from one field to another, among different subject matters and from one context to another;
(ii) Scientific modes of argumentation. In many respects this relates to NASEM's 'scientific processes' and 'how scientists work', and – for us – science argumentation is a key distinguishing characteristic between science and other forms of inquiry, exploration and experimentation.

We discuss both of these in some more detail below. One key consequence of the discussion so far is that, while early-years teachers clearly need to be early-years specialists, they should also – minimally – be scientifically literate.

Our intention now is to go forward. We explore two 'topics' – with an eye on both EYFS and SL – in order to discuss how the EYFS's 'similarities and differences in relation to places, objects, materials and living things' in these two examples might form the foundations for what might mature into adult scientific literacy. Our two topics are 'blocks and glue' and 'plastics'. Our intention is to offer a 'helicopter view' – in this case through materials science. In any classroom situation, it is commonplace to be caught up in the immediacy of the situation; the metaphor of the hovering helicopter implies a moment to see a wider, bigger picture. So, the questions here are, 'What would this classroom situation look like to someone who is "sciencey"?', 'What meaning might they give to this situation?', 'Do I, the early years teacher, have clarity of purpose and direction for what I am doing?', 'Can I anticipate where this teaching might lead?'

Blocks and glue

Possibly initiated by Freidrich Froebel back in the 1880s, early educators have long been persuaded of the virtues of block play. As Froebel said nearly two centuries ago,

> Each [block] is a self-contained whole, a seed from which manifold new developments may spring to cohere in further unity. They cover the whole field of intuitive and sensory instruction and lay the basis for all further teaching. They begin to establish spatial relationships and proceed to sensory and language training so that eventually man comes to see himself as an intelligent rational being and strives to live as such. (cited in Gura, 1992, p. XX)

Block play offers natural exposure to likenesses and differences of shapes, counting, sizes, and amounts. For three-, four- and five-year-olds, block play becomes a doorway to the discovery of maths, technology, engineering, design and even architecture. Frank Lloyd Wright recalls his early decision to become an architect being shaped by playing with blocks. While blocks are wonderful for designing structures such as towers and arches, these are only ever temporary, and block-built assemblies are particularly susceptible to easy demolition (both a blessing and a curse).

Similarly, children are introduced to 'fastening' mechanisms from an early age, whereby one object can be connected to another in a temporary or more permanent fashion. So, for example, they quickly build knowledge of mechanical 'fixers' such as Velcro, zip fasteners, shoelaces, staples, sewing stitches, screw lids and Lego blocks. Some of these prove more permanent than others but none is particularly good at 'connecting', say, wooden blocks in block play. They also become familiar with other kinds of fasteners such as 'cow gum', Pritstick, sellotape, flour-and-water paste – maybe even Post-It notes and chewing gum. Some of these would certainly work with wooden blocks to create more permanent structures, but – as always – there are advantages and disadvantages to each of them for that particular purpose.

At the 'scientific heart' of this example lies the notions of cohesion and adhesion, both are terms based on the root word 'hesion', meaning 'to stick'. They are nouns that describe a state of molecules sticking together. The difference between the two is that cohesion refers to the clinging of like molecules, and adhesion refers to the clinging of unlike molecules. So, the defining feature of cohesion is that it occurs between like substances, it describes the mutual attraction between like molecules that causes them to bind together, and so becomes a description of the 'internal strength' of an object. The word can also be used in a more general sense to indicate that something, such as a story or a narrative, is coherent – remains the same throughout. So, what keeps the wooden blocks 'whole' is that all the 'like' molecules in the wood cohere (stick hard together) to form the strength, and so shape, of the block.

Adhesion, on the other hand, is the mutual attraction between unlike molecules that causes them to cling to one another. Again, the more general sense of the word refers to any clinging property (for example, glues and tapes can be called adhesives) and, again, the defining feature is that adhesion occurs between two different substances. For example, the adhesion of water molecules to a plastic beaker causes water to cling to plastic – even at a high level around the edges. When a child or a teacher introduces glue between two wooden blocks, the glue is unlike the wood and so its molecules are described as adhering (sticking) to them. Cohesion is responsible for surface tension, such as droplets of water beading together on waxed paper. Adhesion is responsible for a meniscus when water is observed in a glass container, because the water clings to the glass around the edges.

Run forward from nursery block-play some 40-odd years to mid-life home ownership. What are the properties of the materials that are being used in that kitchen extension the couple are building? What are the advantages of traditional bricks and mortar over many other building materials currently available on the market? There is a common-sense understanding that building using just bricks alone would not be sufficient – as with the block-play, the structure would be very unstable and very prone to demolition. Neither would that archway remain standing for long. Nor would cement, mortar, on its own be sufficient. While bricks have high levels of internal cohesion that gives them shape, strength and durability, mortar does not – and simply pouring cement to make a supporting wall would mean it would crumble and break relatively quickly. Mixing the cement with gravel, stones and small pebbles to make concrete, then threading through steel rods (to make reinforced concrete) *would* work, but this is a far cry from mortar alone. One advantage of using relatively 'soft' mortar to adhere solid bricks is that the subsequent walls have a small degree of 'give', of flexibility. So, when heavy vehicles such as trucks or buses rumble past the house, it is an advantage for the walls to flex slightly with the vibrations rather than, say, be brittle, and crack with the movement.

A thought, for a moment, about arches: there are many creative forms such as bridges, vaultings and domes made, apparently, from unsupported brickwork. The building of a brick arch first requires the construction of a wooden 'former', which has the intended shape of the arch. The former is positioned and supports the bricks as they are laid individually. After the adhering mortar has set, the former is removed and the brickwork arch is now left as a new self-supporting and freestanding structure.

Plastic

The name plastic is short for plasticity, derived from the Greek word *plastikos*, which means able to be shaped or moulded: plastics have the capacity to change shape and be deformed without breaking.

Unlike mortar in the example above, plastic flexes, does not crumble and, in many circumstances returns to it previous shape when it is released. Plastics are synthetics, some made from organic materials found naturally in the environment, although the majorities are made from petro-chemicals (originally crude oil) in industry. For example, sellotape is made from cellulose, a natural polymer, while nylon is entirely factory-made. The key concepts here relate to the kinds of polymers being used: the long chains of molecules that form the basis of a plastic. The properties of a particular kind of plastic depend on how it is made and what is added in the process, for example, colourants or stabilizers. Some plastics can be made into solid shapes (such as wheelie-bins, car bumpers, washing-up bowls, toys, toilet seats, toothbrushes, clog shoes, computers) while others can be very flexible (like shopping bags, tape, raincoats, wrapping or cling-film); some are transparent, others not. This is, of course, some of the enormous advantages of using plastic, it is cheap to make, can be moulded into millions of shapes, be soft or extremely durable, be used in a myriad ways, and some plastics can be heated and remoulded, re-used over and over again. Plastics are very poor conductors of electricity and this makes them ideal insulators (electrical plugs and appliances); they seldom dissolve in water, which makes them excellent containers (water butts and watering cans); they are poor conductors of heat and make good thermal insulators (polystyrene containers, ceiling tiles); can be made into paints to provide water-proofing on walls and ceilings. As a side note, about one-third of plastics are manufactured for packaging, not just in packaging food but also in the transport of millions of items around the world; another third is used to make pipes and cabling to carry water, gas, electricity, and sewage.

There is, of course, a downside. Developed societies make enormous amounts of plastic, much of this is low-cost and disposable and eventually becomes unwanted waste. Because of all their 'ideal' properties, they are difficult to dispose of – they become pollutants in the natural environment. Newspaper coverage, and the media, in general, tackle a range of solutions to plastic waste and, as we discussed earlier, being scientifically literate entails making some sense of this public debate. For example, while plastics are enormously useful, adults and children might be increasingly cautious of littering the countryside or seaside with plastic bottles or crisp packets; they may choose to use paper bags for food, or re-use supermarket shopping bags, they might pay a lot more attention to recycling. Wales was the first of the UK home nations to introduce a charge for plastic shopping bags in 2011, England followed suite in 2015. Similarly, recycling is becoming increasingly more regulated. In the processes of recycling, for example, plastics need to be sorted into broad groups that can be treated together without contaminating each other. There are seven kinds, and these are numbered 1–6 (and null), numbers that can be seen (on close inspection) on plastic packaging. Oddly, two of the items that give great concern are plastic drinking straws and ear-buds: there is a major initiative at the government level to curb their use and disposal.

Becoming 'sciencey'

There is no known pill that converts early-years specialists into early-years *science* specialists, no one single transformative experience that converts non-scientists into science literates. Moreover, we are keenly aware of the pressures on teachers of all stripes, certainly including those who work with very young children. There are numerous competing pressures on their time and energies, numerous demands on their skills and capacities. Nevertheless, all schools and Ofsted-registered early years providers must follow the EYFS, including child-minders, preschools, nurseries and school reception classes. The Department for Education's EYFS requires early teaching of the 'similarities and differences in relation to places, objects, materials and living things'. We see a need to integrate a true sense of scientific literacy for all pupils, an education for scientific literacy that requires a broad knowledge of concepts and processes (Australian Curriculum Assessment and Reporting Authority [ACARA], 2017). But what does this mean for early-years and nursery teachers?

There are various avenues for continued professional development available for in-service teachers but – with increasing local austerity – these are rare and precious commodities. Instead, we see 'becoming' an early years scientist as a gradual but steady process over time. We have an 'ecological model of becoming' (Salehjee & Watts, 2019/ in press) where a person lives within a particular kind of social context, and chooses to grow and develop within the opportunities and constraints provided by that context. While is possible to 'transplant' the individual from his or her immediate context, his or her patterns of growth would then change accordingly. So, in the terms of this paper, we see adults growing and developing their knowledge and understanding of science, becoming increasingly 'sciencey', within the context of the UK, with all of its opportunities and constraints that offers. It is relatively easy to do this as an adult in the UK compared, say, to a much less developed country: our lives here are surrounded by science and technology, with numerous organizations and institutions related to the public information about science, alongside a myriad of information media. As one example, 500 public free-to-attend open-to-everyone events occurred in British Science Week (2017), a 10-day programme of events aimed at celebrating STEM subjects, coordinated by the British Science Association and funded by the Department for Business, Innovation and Skills.

Our approach is to boost self-directed 'learning-to become' through informal science approaches (Watts, 2015), suggesting those modes and media best suited to each individual's preferences and resources. Therefore, we encourage early-years teachers to watch David Attenborough's *Blue Planet* on TV, Dara O'Briain's You-tube videos, listen to Jim Al-Khalili's *Science lives*, or Brian Cox's *Infinite Monkey Cage,* follow up a scientist featured on *Desert Island Discs* on radio. On occasions, they might check out health ideas online, pick up a copy of *National Geographic*, follow science news items closely, listen out for local environmental issues, find the local science centre, explore field studies centres and city farms, visit local industries. More actively still, they might take 'environmental rambles' or engage in 'citizen science' projects from astronomy to zoology, wildlife surveys such as *Budwatch* or Zooniverse's coastal project, *The Plastic Tide.* There are even public lectures at local universities.

In our view, it is only by becoming more science literate that early-years' teachers can have a broader foundational view for *where* their everyday classroom practice might lead – and *why*.

Boarding the helicopter

The metaphor of the 'helicopter view' entails 'zooming out to see the big picture'. When looking at a large wall map or a painting, one has to step back to see the whole thing better. And, from that wider view, some issues will be seen as short-term and urgent; others may need long-term solutions. Becoming more sciencey is one of the latter.

First, we envisage a classroom process that encourages curiosity, what Beckley, Compton, Johnston, and Marland (2010) call an enabling environment. People, in general, are inquisitive and possess an enquiry-based nature, want to find out things – particularly in cases where these 'things' have powerful relevance to their lives (Watts, 2015). In our view, this is a natural process that begins early. We do not have in mind an entirely aimless, unsupported or undirected classroom activity – the skill of the early years specialist is to balance between enabling a child's self-direction while providing over-arching direction; in inspiring and fostering whimsical curiosity while at the same seeing where such curiosity might lead – in having a 'helicopter view' of the relevant science that might be called into play.

Second, not all inquiry is science-inquiry. It is hugely important that children follow their own interests in numerous directions, so that both imaginative unstructured and creative structured play, for example, are both encouraged and developed. There is, though, a clear role for science-based-inquiry, where the topics, terms, tools and techniques relevant to science are brought into the activity. Words like 'only' and 'all', for example, gain importance: not *all* plastics are cheap and nasty, not *all* bugs and bacteria are harmful, not *all* blocks are solid and long-lasting, not *all* glues are constantly sticky. How do we know? How can we find out? What would tell us? What evidence do we need? How might we get it? Where might this evidence lead us? What are the building blocks of the school wall? What sticks them together? How long will they last? Why is that important? Why not make the whole classroom out of plastic?

Third, we have discussed some elements of scientific thinking in other papers (c.f. Salehjee & Watts, 2018) and have noted that scientific thinking depends upon many different skills such as induction, deduction, metaphor, analogy, problem-solving, categorization, analysis, synthesis – all of which are objects of study in their own rights. McClelland and Thompson (2007) maintain that children as young as three to four years of age are sensitive to the causal structure of events. They are capable of making reasonable judgments about objects' causal properties after witnessing a few events in which objects appear to play causal roles. As young children encounter new situations, they commonly participate in informal conversations with teachers who look to foster understanding through explanations (Watts, 2014). So, for example, one of us (MW) saw three-year-old Sally pulling on her outdoor boots on a sunny morning in order to jump in a puddle in the school grounds, and witnessed her disappointment when she realized the puddle was no longer there. Where had the water gone? The teachers' answer was that it had 'dried up'. Sally's frown and clear puzzlement prompted the teacher to reach for a secondary explanation:

T: Does your mummy dry your hair for you? When you have a bath?

Sally nodded.

T. Where does all the water go then?
S. In the towel.

Both might have been confronted at that moment by an image of an enormous towel appearing from somewhere to dry the playground puddle; the teacher set off again:

T. Does she use a hairdryer?

Sally nodded, said,

S. To blow the wet away.

The teacher smiled, possibly seeing an opening to a wind-borne evaporation solution,

T. So maybe that's what happened here …

She paused as Sally studied her face intently – both might then have been confronted by the image of an enormous hair-dryer appearing from somewhere above the puddle. Sally shook her head solidly. Animals had come in the night to drink it up, she said. Her dog liked licking puddles.

A conversation like this trades on the 'theory-evidence' relationship, and the ways that children manipulate these in real situations. Callanan's (2012) research indicates that children who engage in explanatory talk with adults can grow quickly in their conceptual understanding of concepts, and it is a very good sign that Sally is prepared to be sceptical of the teacher's ideas and to advance an hypothesis or 'mini-theory' of her own to account for her observations. A key aspect here is the ability to suggest alternatives in the face of competing theories, and her description indicates a fast and quite complex interaction between explanation and evidence – an interaction that is an important aspect of scientific reasoning. Her 'animals in the night' theory is broadly plausible but highly unlikely: the skill of the nursery teacher is to retain Sally's interest in the problem while now exploring some of the alternatives for what might have happened. 'Oh, where would all the animals come from?' 'Why would they come here to drink?' 'Look all the rain has gone too. Where has that gone?'

Summary comments

The eventual goal of science education is to produce individuals capable of understanding and evaluating the science information and of reaching decisions using that information appropriately. To quote Albert Einstein, the goal of education is 'to produce independently thinking and acting individuals' – and, for us, that is both the teacher and the children in the classroom. Science is everywhere in society; a part of each person's everyday life – even supermarket shopping is better informed by having a useful understanding of science. In our view, this means teachers taking a helicopter view repeatedly throughout classroom planning and activities in order to help answer the questions: 'What is this about?' and 'Exactly why am I doing this?' 'What else could I be doing?' That is, 'zooming out' and 'zooming in' from time to time in order to have a view of the future without losing sight of the present.

The most important way of people, early years teachers, becoming increasingly engaged with – excited about – science is when issues have high personal relevance, when science becomes part of their they're real-life situations and concerns. The challenge of engagement affects the whole of education, and science subjects, in particular, are often perceived as difficult, boring or simply 'not for them'. We are not supposing that teachers' short-term learning of a few scattered facts constitutes them being scientifically literate. It is though one step on the way. Accruing and using knowledge and understanding depends crucially on context and, in this case, we are arguing for teachers to have sufficient overview of 'health', 'how things work', 'what things are made of', etc. that they are in a position to guide children in their lines of inquiry.

We do understand, of course, the many hindrances that stand between five-year-olds and the extent of their scientific literacy at 50, not least hurdles related to their science choices at 15 and career choices at 25. But, in our view, science literacy foundations can only be built by early-years teachers and specialists who themselves are working on their own science literacy, who are working on that helicopter view of scientific matters. Our two examples here have focussed on materials science, block, bricks, mortar, glue, and plastic. We might easily have chosen glass or ceramics, steel or rubber. We could have chosen plant biology or the chemistry of bleach, the shrinking of the Arctic ice-cap, new space telescopes, the spread of diseases like influenza, evidence for water on Mars, the development of new medicinal drugs.

2018 is officially the 'Year of Engineering' and will see a national drive in all corners of the UK to inspire young people to 'shape our future'. Once upon a time, these targeted young people were children in nursery and reception classes, and the argument we make here is that, had their early educational foundations been really successful, there would be no need at all for a 'drive' or for a 'year of' in 2018.

Disclosure statement

No potential conflict of interest was reported by the authors.

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