EARLY CHILD DEVELOPMENT AND CARE, 2017
VOL. 187, NO. 2, 274–283
http://dx.doi.org/10.1080/03004430.2016.1237566

Routledge
Taylor & Francis Group

OPEN ACCESS

But is it science?

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ABSTRACT
Early years science education is not science, but a curricular construction designed to induct young children into a range of ideas and practices related to the natural world. While inquiry-based learning is an important approach to this, it is not of itself unique to science and there are a range of logico-mathematical constructions that come closer to the essence of science. In this paper we discuss just three: empirical question-asking, transgressive play, and good thinking. The challenge, of course is to induct early years practitioners to a different way of shaping early science.

KEYWORDS
question-asking; transgressive play; scientific thinking

Introduction

Allow us to introduce three working scientists. Peter takes pleasure, maybe somewhat perversely, in standing thigh-high in slow-flowing water, principally cold mountain lakes and rivers. Garbed in heavy waders and water-proofs against the weather, he monitors the health of fresh-water fish, concerned with the effects of the wash-off of organo-phosphate fertilizers from local farmland. He has always been an environmentalist and conservationist, and is now a scientific officer for a government agency – a job he thoroughly enjoys. Jane is employed by a large company to design new inks for computer printers. The ink must be able to form a very fine spray, dry extremely quickly (to prevent it sticking to other surfaces) yet never clog the spray nozzle and retain its colour consistently at all times and circumstances. These days, inks must be faster, brighter and smarter – she works at the molecular level, discussing her ideas with a team of like-minded colleagues. Chris's life is split between his university laboratory and Arizona, where he instals gamma-ray cameras into the nose cones of rockets for space exploration. At take-off, the rocket experiences a heinous pounding and, given that the cameras are required to have fastidious precision once in space, their inner workings must be extraordinarily robust. It is not unusual to see Chris knocking his cameras around the lab with an old croquet mallet to test their resultant accuracy. These scientists illustrate Macdonald's (2014) point that the range of opportunities and career destinations in science are vast – some 28% of the UK workforce is currently in science and science-related occupations – and the demand grows inexorably.

Peter, Jane and Chris took fairly traditional routes into science: good examination results at age 16 years, strong pre-university science subjects and grades, productive university degrees and post-graduate study. But there are many more ingredients at work in their 'science lives' beyond simple study-based success. In Salehjee and Watts (2015), we have differentiated between academic scientists and non-scientists in terms of their early (often very early) childhood dispositions: a small number of our respondents were 'always going to be sciencey', a comparable group were 'never –

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ever – going to be sciencey' and, understandably, a larger group mid-way, who might go in either direction, or who remained suspended somewhere between the two poles. There are many people who 'come' to science in later life, either through the work they do or from personal interests (Morris, 2015; Watts, 2015). It is the case, too, that science may or may not be for everyone, and this can be manifest from a very early age. In our recent follow-up work (Naugah, Reiss, & Watts, in press; Salehjee, Watts, & McCormack, 2016), we explored school, peer and parental influences on young people's choice (or not) of school and university science subjects and, while this support can be apparent in some guises ('We will be with you, Darling, in whatever you want to do'), these were not seen to be overwhelmingly important and lead inevitably towards (or away from) science. More important were our respondents' 'dispositions', 'inclinations', 'tendencies' and 'preferences'. Those who were more science-orientated tended to enjoy 'exploring things', 'chasing things down', 'problem-solving', being 'fixers' and 'satisfying curiosity', a finding echoing a survey of women engineers by UKEngineering (2013).

Driving this discussion down into early childhood education has opened the possibility that very young children develop – and can be encouraged to develop – very early dispositions towards science and technology. Gelman, Brenneman, Macdonald, and Roman (2010), for example, label pre-school children as 'scientists-in-waiting', not least when engaging in science-like activities, guided and encouraged by adults (Bourne, 2000; Enfield & Rogers, 2009; Inan, Trundle, & Kantor, 2010). In addition, Gelman et al. (2010) note that, through the processes of observing, questioning, predicting and evaluating, 'young children construct knowledge and learn to coordinate evidence and theory … they can and do develop abstract concepts in domains that fall within the content of science' (p. 2). Farmery (2002, p. 13) makes the argument that 'science, as a subject, is intrinsically fascinating to children and involves them in exploration and "finding out" for themselves'. It needs to be noted here that science education *per se* is not science. While it may well have science-like characteristics, is not science but a curricular entity constructed by policy-makers and educators to shape practice in school classrooms? Campbell and Jobling (2012) argue that science education in the early years is vital in assisting young children to come to know about and understand the world around them, and the early years foundation stage (EYFS, Department of Education, 2014, p. 31) guidance, as one example, gives specific 'scientific' targets towards achieving this. Rogers (2012) goes further: young children, with their 'natural inquisitiveness', would benefit from exploratory play in scientific areas, to provide a good basis for future learning; 'To achieve this, we need to allow more time for scientific learning in the early years' . Thornton and Brunton's (2006) series of books on early years science argues for a study of force, friction, electricity, sound, light, air, floating and sinking, magnetism, sound, life cycles and change, among many other issues to be explored. Similarly, Goss (2011) makes a case for children to understand a 'multitude of scientific concepts', including those in physics (flow and motion), chemistry (solutions and cohesion), biology (plant and animal life) and mathematics (measurement, equivalence and volume). Mastery of these concepts, she maintains, will support children's understanding of academic subjects in later schooling and life. In our view, this is all very important and well-meaning, but is it science? The topics on such lists are certainly part of the world around us – but the argument we make here is that they are not of themselves science. As Siraj-Blatchford (2001) points out, learning science is not simply knowing about or experiencing a 'natural phenomenon'; it provides a set of socio-historically established and agreed logico-mathematical constructions that set out to explain these phenomenon. Topics like these can, of course, not only be studied through science – but could also just as well be taught and learned through history, geography, art, business, photography, poetry, theatre, music, etc. The debates about what actually constitutes science and being a scientist are legion and not really rehearsed here at any great length. Instead, we choose to discuss 'But is it science?' through just three ingredients central to education in the early years: first, 'empirical question-asking'; second, 'transgressive play'; and third, 'good thinking'.

Questions, inquiry and science

At its heart, the scientific enterprise is driven by inquiry at both the individual and the group level. For the individual scientist, the quest for understanding is fostered by an insatiable curiosity about how things work and why things are the way that they are. For the discipline as a whole, progress is measured by the successful progression of responses to questions about the fundamental working of nature. In their classic text *Teaching as a Subversive Activity*, Postman and Weingartner (1971) take this sense of questioning into an educational context and say: 'Once you have learned how to ask relevant and appropriate questions, you have learned how to learn and no one can keep you from learning whatever you want or need to know' (p. 37).

Through inquiry methods, the teaching of science aims to enable young children to obtain experiences that are authentic to scientific experience (Peters, 2006) and this is thought to make their learning more meaningful and to improve their scientific understanding (Hogan, 2000; Hogan & Maglienti, 2001). But, and it is a big 'but', Rop's (2002) work suggests that questioning – inquiry – is necessary but not sufficient: there need also be 'receptive contexts' for questions. When faced with an outpouring of questions, teachers and parents are actually ambivalent at best. They commonly listen to a child's open curiosity with contradictory feelings: the need to 'honour' the child's question, give her or him time and patient support in the struggle to understand content – all of which is then weighed against the seemingly incompatible need to maximize 'teaching time', 'cover the expectations of the school' and 'get on with things'. Even less compassionate is when teachers perceive a child's questions as annoying, 'going against the grain', an impediment, overbearing and a test of patience, particularly when these arrive too frequently, or seem set to challenge received 'common wisdom'. There are only so many times an adult can answer 'why' questions one after the other in rapid succession without losing patience or exhorting a greater power ('Because I say so!!'). These different teacher attitudes impact upon the ways questioning is encouraged or discouraged during school or nursery time. In reality, teachers are very concerned with such 'micro-politics' of ('real') classroom life. Recent work (e.g. Pedrosa de Jesus, Moreira, da Silva Lopes, & Watts, 2012) illustrates just how context-sensitive is the asking of questions. In this sense, a 'receptive context' is the set of entities that influence action in a particular setting, situation or on a specific occasion (Brezillon, 2003, 2005), in particular the 'physical, emotional, and intellectual environment that surrounds an experience and gives it meaning' (Caudron, 2000, p. 55). A 'positive, receptive, context for questioning' moves beyond usual practices in teaching; it is the prime criterion for building an environment where children's classroom questions are the norm. Not all classroom contexts are positive, and there are numerous instances where children's questions are dismissed, not welcomed, let alone acted on.

Moreover, there are many types of questions, some that are answerable and many that are not (Watts & Pedrosa de Jesus, 2006). Of interest here is a mode of questioning that focuses on empirical work, those questions that can lead to investigation, experiment and some resolution. 'Investigable' questions (Chin & Kayalvizhi, 2002; Graesser & McMahen, 1993) require a particular form of construction. They entail identifying an issue derived, commonly, from experience, a simple 'data gap', discrepancy in knowledge or a need to extend knowledge in a particular direction. However, in our view, much of the literature in this field too often mistakenly slides and interchanges between 'inquiry' and 'science': they are too commonly treated as synonymous. The direction we take is that inquiry, questioning, thinking, experimenting, testing and evaluating are all indeed key elements of doing science, of being a scientist and important to children's experiences in the early years. But, and it is a substantial 'but', these processes are not (i) the only processes required in science by any means and are not (ii) exclusive to science: there are many other areas of life that use inquiry in abundance. So, our tack is that inquiry-based learning, manifest within the three ingredients above, is vastly important not solely because it allows entry into science, but because it works powerfully well across different disciplines. Second, there are many more processes entailed within science that also need to be encouraged before it can appropriately be called science. A scientist by definition is naturally an inquirer, but an inquirer need not necessarily be a scientist. And while much of the professional development that a scientist undergoes is seemingly about 'learning the lay of the land', the truth of the matter is that a key feature of scientific inquiry is developed in scientists through an individual and group mentoring process over a considerable length of time: science is commonly an apprenticeship to a 'master inquirer' to learn how to ask 'good' questions, ones that lead to fruitful answers (Watts & Pedrosa de Jesus, 2006).

According to Chin and Kayalvizhi (2002) and Arnold (2009), a good investigative question requires learners to generate and collect data for a selected pathway; represent, analyse and interpret their findings using the data collected; draw a conclusion using their results and justify their findings to the question based on the data they have collected. Chin and Kayalvizhi (2002) further suggest that in order to fully engage children and sustain their interest, these questions should be conceptually challenging, meaningful and relevant to their personal experiences, while remaining broad enough to enable critical and creative thinking. Such challenging questions can spring from odd events, passing thoughts or conversations, a technological problem, some difficult results, a curious occurrence, a chance observation, a fascination with some particular area of life, a claim on a TV advert, a pet's habits, a family discussion, a sporting occasion, family obsessions or hobbies. That is, the processes of 'disequilibrium detection', of problem finding (Watts & Pedrosa de Jesus, 2010), come from children's interactions with life – and often from the clash between experience of 'life issues' and the overlay of knowledge derived from school and other informative sources throughout the early years (Watts & Alsop, 1995). In some ways, this is a precurser to the Cognitive Acceleration in Science Education notion (for older children) of cognitive dissonance (McCormack, Finlayson, & McCloughlin, 2014). That said, Walsh and Sattes (2005) make the point that formulating investigative questions is a skill that needs to be explicitly taught in early years and beyond.

Thornton and Bruton (2015) point to this kind of early-years inquiry as the 'Reggio Emilio approach', where children are encouraged to develop their own theories about the world and to explore these collaboratively in great depth. Strong value is placed on different experiences, ideas and opinions so that when a child stands at the centre of a paved playground after a heavy spate of rain and asks, 'Where does all the water go?' the child's ideas are respected and taken seriously, and are used as the start point of investigations. Thornton and Bruton say it is important to create an environment in which 'children are unafraid of making mistakes or of reconstructing their ideas' (2015, p. 17). The adult intervenes as little as possible but observes, listens, interprets and facilitates the child's inquiry by providing interesting experiences and resources. In this respect, there is no predetermined curriculum to determine what children must learn; the educational experience is generated on an ongoing basis from the questions, ideas and theories put forward by the children supported by the 'skills, expertise and experience of the educators working alongside them' (p. 86).

Transgressive play and rational contingency

The anthropologist Desmond Morris sees curiosity, inquisitiveness, as an essential human trait:

> We never stop investigating. We are never satisfied that we know enough to get by. Every question we answer leads on to another question. This has become the greatest survival trick of our species. (Morris, 1967, p. 16)

Ethologist that he is, Morris has long understood play – his own and that of others – as a set of behavioural patterns the human animal shares with many other species. Particularly in early childhood, he and other students of animal behaviour have argued that play is vital to the acquisition of complex skills. The kitten pouncing on a ball of yarn, for example, learns behaviours necessary to hunt well before survival depends on the outcome. For most species, play primarily occurs early in life. But humans exceed cats and, indeed, all other playful animals. In our species the evolutionary development of *neoteny*, which involves the retention of juvenile physical characteristics in mature individuals, has also prolonged the play impulse well into adulthood. Newton's famous quote is apposite here,

> I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me

This means that exploratory behaviours, driven by curiosity for the novel and pursuit of the effective, do not disappear with childhood or youth, but persist, especially in the play-like endeavours of art and science. '[A]dult play', Morris has said, 'is what gives us all our greatest achievements – art, literature, poetry, theatre, music and scientific research'. Play must involve pleasure: where there is no pleasure, no fun, no enjoyment, then there is no play. When play becomes tedious, is imposed or required, then it ceases to be play. When the fun ends, players become disillusioned, frustrated and bored – one can signal an end to play by simply leaving the play-setting, leaving behind any budding science. Alongside this, play entails an opportunity for risk – low risk in some settings, high risk in others, for example, walking along the top of a wall, swinging high on a tyre over a river or appearing shy or embarrassed in talking about 'what ants like to eat' or 'how snails breath'. Our view is that a 'transgressive', mischievous element of play is important (Crowe & Watts, 2015). Hughes (2006, p. 57) has recognized this as the 'darker side' of play, the kind that involves impulsive unorthodoxy, 'breaking loose', being counter-cultural, acts of subversion, going 'against the grain' and crossing obvious boundaries. So, a scientist like Chris 'plays' with the construction (and destruction) of his gamma-ray cameras as much as Jane 'plays' with her colleagues with ideas about printer inks. Science is indeed 'serious play' (Wassermann, 1990, p. 107). The philosophers Karl Popper and Imre Lakatos have spoken of 'the game of science': the best scientists are the ones who make the best guesses. But just having the ability to guess is not enough; one has to come up with the right answer – and somewhat before the competition does. Scientists and engineers not only play at outguessing one another (Petroski, 2003), but they also play with toys. In fact, many scientists like Chris amuse themselves by tinkering with the various toys of their trade, coming up with ingenious (serendipitous) devices to get a particular job done or divert a piece of commercial equipment from its original purpose for novel scientific uses (Roberts, 1989). They are often the ones who played with chemistry sets, construction toys, Meccano, bug-hunter kits, microscopes and telescopes in early childhood. It is increasingly well established that construction experiences with blocks and other manipulative toys provide an experiential base for children to build mechanical understanding. Creativity like this is increasingly popular as a subject for discussion and publication; numerous conferences on play are held in the UK, and the recent appointment of a LEGO 'professor' at Cambridge University made headline news.

But young children are capable of much more than experiencing the forces of gravity and laws of friction while building; they also can form theories about how and why their buildings stay up or fall down. Why might foam work as a foundation for Emma's building but not Oscar's? What will happen if the green block is removed from Ruairi and Rosie's bridge? What is the best kind of material for Ruth's roof, and why? Importantly, the teacher's role involves more than asking just questions. The teacher selects the materials and stages the creative environment, a staging that may include exploring materials alongside the children, without interfering with their own exploration. Children shake a sealed can. They weigh it, listen to the sounds and try to guess what materials or objects are contained inside. In one early setting, the teacher created an enormous beanstalk in the corner of the class that appeared to continue onward up through the ceiling. Apparently Jack had climbed the beanstalk and was now trapped up there somewhere, with no clear way down. The children had to devise mechanisms by which Jack could return to Earth (relatively) safely, and they tested soft-landing systems, parachutes, slides and the like. But a worse calamity: at some point, Jack had tipped upside down and all his money (to buy the cow) had fallen from his pocket and landed (fortuitously) in the sand-tray below. The children were tasked with finding the coins in the sand and then checking to see that they had recovered it all. What do you think would happen if … ? What if not … ? are two questions that use the principle of exclusion and exhaustion, and hint at intellectual efficiency in making firmer judgements. Scientific inquiry is not unbounded, but rather is corralled by a desire to fit into the particular developing self-consistent worldview, that is, the current scientific paradigm. A key feature of this paradigm is the repeatability of results and the use of mathematics as a consistent tool for maintaining self-consistency.

Good thinking

While inquiry and play are key elements in science, the conduct of science itself works hard to maintain rational contingency: basing decisions, within the play arena too, on the merits of evidential reasoning. There is a Calvin and Hobbes cartoon in which Calvin poses the question to Dad: 'Why does ice float?' Dad responds: 'Because it's cold. Ice wants to get warm, so it goes to the top of liquids in order to be nearer to the Sun'. 'Misplaced' thinking in early science is commonly used in a well-intentioned but incorrect form, giving incomplete or oversimplified expositions of ideas. Rational contingency, on the other hand, aims for consistency in the use of significant and relevant issues, like important ingredients within a game or levels of play: for science to work, there is a need to dispel any 'capricious magic' involved. And, while there can be arbitrary leaps of the imagination, these have – eventually – to be tethered back to the evidence available. So, while superman can clear buildings in a single bound, scientific imagination most usually must be tethered to existing evidence of human capability. As Psillos, Tselfes, and Kariotoglou (2004) have suggested, establishing connections between the material world, ideas and evidence is essential in assisting children's understanding in science and their scientific thinking. There needs to be, generally, clear and invariant outcomes to similar actions, so that there is some predictability in what is happening.

An example of scientific thinking in the early years can be illustrated through anecdotal observations of Lily, age 4 years, experiencing her first visit to a city farm. She stood on the lower slat of a wooden fence, her chin resting on the upper bar, staring intently into a pig enclosure for a long, uninterrupted, 20 minutes. It became clear later that this was time spent trying hard to reconcile this first meeting with a live pig in all its brown, long-bodied, hairy, muddy, smelly, snorting reality, versus the soft, round, pink, cuddly entities in her bedroom and those she encountered in TV cartoons and bedtime stories. It said 'pig' on the gate to the sty and, unless someone somewhere was telling mighty untruths, she had to square two deeply contrasting images. A little later, walking alongside and listening to a young male 'Farm Explainer', she carefully circumvented a large fresh cowpat in the centre of the farm lane. The Explainer stopped, pointed out to her that the cow dung was actually very important, because, he said, 'we put it on our vegetables'. Wide-eyed, Lily gazed up at him, down at the cowpat, back up at him, again gauging her trust in this adult's words and the unlikely possibility of ever spreading this stuff over her lunchtime potatoes, carrots and broccoli. One datum point is not sufficient to identify a pattern, or to decide what is or is not interesting or exceptional. Signal-to-noise ratio is a term derived from communication systems engineers, and used to describe the degree of usefulness found in information, the ratio of useful information to useless information in any given statement. Lily was calculating the ratio on this city farm.

Moreover, scientists commonly engage in 'reductio absurdum', reducing things to the absurd, pushing things to their logical limit, because there are limits. The process of reducing to the impossible, disproving an argument by showing the absurdity of following it through to a logical conclusion, is as old as Aristotle, used throughout history in both formal and philosophical and scientific reasoning. The Earth cannot be flat; otherwise, we would find people falling off the edge; a sign says not to pick the flowers, a small child protests to teacher, 'But it's just one flower'. The teacher responds, 'Yes, but if everyone who came by picked just one flower, there would be none left at all'.

The table below relates particularly to the teaching and learning of junior chemistry. It is not intended as an exhaustive list, but is indicative of the kinds of demands made by the subject and illustrates some of the 'good thinking' required in science.

Cognitive demand	Associated skills
Classification of materials and reactions	Recognition of relevant properties
Logical thinking and causal thinking	The role of evidential data to generate and refine models and theories, also to assess the suitability and limitations of models in particular contexts
Modelling and codifying	Using specific words, numbers, pictures, drawings, symbols
Quantification	Ability to measure materials and energy in different ways
Experimental design	Identifying and manipulating single and composite variables
Direct correlation, proportionality	Ability to identify correlation; ability to distinguish correlation and causation; ability to account for causation scientifically
Probability in individual entities and populations	A sense of the likelihood of events occurring,
Energy transfers as a means of bringing about changes in materials	Understanding conservation of properties

When we refer to science as a 'discipline', we also draw attention to the fact that it constitutes an intellectual enterprise that has a distinct set of demands like these, and that these rules are normally (or properly) adhered to by that particular academic community we know as 'scientists'. For a child (or for anyone else) to think 'scientifically' means to comply with these skills, demands and rules. As a minimum, they must keep an open mind, to respect yet always to critically evaluate evidence, and to participate in a community that encourages the free exchange of information, critical peer review and testing. This latter point is crucial because, as Driver, Guesne, and Tiberghien (1996, p. 44) have put it: 'Scientific knowledge is the product of a community, not of an individual. Findings reported by an individual must survive an institutional checking and testing mechanism, before being accepted as knowledge'.

The key question, of course, is the extent to which any of these bear relation to young children in early settings. Akerson, Buck, Donnelly, Nargund-Joshi, and Weiland (2011) make the clear point that children as young as kindergarten are developmentally capable of conceptualizing science like this when it is taught to them. Where the teacher has a strong grasp of scientific thinking, then children can follow suit.

Summary

There are several points to make in summary. First, not all young children will become scientists like Peter, Jane and Chris. However, Peter, Jane and Chris were once young children, and something(s) 'sciencey' in their early lives either resonated with them and their early youthful dispositions, or, at the very least, did nothing to deter them from eventually becoming scientists. And, for those of us interested in the development of older scientists from the young, this is an area of considerable interest. While Peter, Jane and Chris, along with many other professional scientists, may have come to science by following different routes after their early years, or through a variety of 'triggers' or critical incidents later in life, there is something about science that has retained and fostered their interests and fed their inclinations.

Second, science education is not science. It may well be 'science-like' in some respects, but it is not science per se; it is a construction distilled and transformed through several layers of reworking, from scientific papers to science textbooks, texts to educational policies, curricular guidance to classroom practice, from teachers' science to children's activities (Gilbert & Zylberstajn, 1985). However, in our view, there is considerable onus on educators to make science education as 'science-like' as possible, and here the emphasis is on what might be constituted by 'early years science' as an educational entity. In this sense, we need to set not science topics but a 'science tone' at an early stage. We see our three elements of open inquiry, transgressive play and 'good' thinking as three aspects of this, but only three. The practice of inquiry is a way of thinking, of processing, of operating in the world. For us, it is essential to have an initial curiosity about something, and then a positive, encouraging, enabling, framework within to ask and foster ensuing questions.

Third, neither personal interest nor individual inquiry can be taught simply as a 'process skill' irrespective of and independent of the topic of study. We disagree with Tifi, Natale, and Lombardi (2006) who argue that a crucial ingredient of doing science – the development of process skills – should be taught first in content-free investigations, where more attention can be paid to the spontaneous discovery, elicitation, generalization and sharing of principles captured by authentic problem-solving. From this starting point, children can move on to content-based enquiry. However, in our view, having a 'topical project core' to the inquiry is important, although there are certainly no 'essential science' topics that need to be 'covered' at this age. Nothing, but nothing, is 'off the science table'. As Thornton and Bruton (2015) say about the 'Reggio Approach', 'In Reggio there is no predetermined curriculum. Children's learning is developed through their involvement in long- and short-term projects which develop out of first-hand experiences and their theories about the world' (p. 17). Questions are intended to provoke thought and inspire reflection. Strong, sometimes capricious, questioning skills fuel and steer the inventive process required to 'cook up' something new. Without such skills, children become prisoners of conventional wisdom and the conventional wisdom of the day. Probing questioning explores the underlying principles, characteristics and possibilities of any given situation. For children to develop a knowledge and understanding of the world, they need adults who are knowledgeable and able to respond to their interests (Louis, 2008, p. 23).

Fourth, science is serious play. Whether smelling the air, tasting a flower's nectar, feeling the texture of a smooth rock, rolling a toy car down an incline, building a tower or looking at a cicada shell, children have been learning since birth. Pretence and make-believe can be particularly valuable for problem-solving and developing creative thinking, exploration, negotiation and reflection (Robson, 2012). Needless to say, the role the adult adopts in this is important. As Schulz (2012) says, there's a trade off of instruction versus exploration: 'If I instruct you more, you will explore less, because you assume that if other things were true, I would have demonstrated them' (p. 385).

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributor

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