Emergent science education for sustainability

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Abstract

The problems of sustainability are increasingly understood as 'emergent', in the context of complex and interconnected global ecosystems and economies. Scientific phenomena can too be seen as emergent, with macroscopic systems emerging from microscopic interactions. The mind is also a complex system, and cognitive development an emergent process. This research review provides insights into emergent science education, considering both science and the child as complex systems. The early building blocks of science understanding, in the form of young children's schematic play, are discussed as a way of thinking that can support an emergent approach to education for sustainability.

Keywords: Emergent science education, sustainability, schemes, schematic play, complex systems

Introduction

In the context of complex and interconnected global ecosystems, economies and societal and cultural practices, the problems of sustainability are increasingly understood as 'emergent'. The synergistic interaction of many separate, and in many cases relatively benign, elements in complex systems has resulted in problems that bring with them the threat of ecological and environmental danger and destruction. These 'emergent' problems are recognised as greater than, and irreducible to, any simple sum or combination of the social, economic and environmental elements from which they have arisen. In the contexts of climate change, threats to biodiversity, pollution and resource depletion, we are faced with complex, interconnected and contradictory 'wicked problems' (Rittel & Webber, 1973).

Both Piaget and Vygotsky recognised that the mind also provides a complex system, and that cognitive and conceptual development is also an emergent process (Sawyer, 2003). From this systems perspective, 'emergent science education' tells us that we cannot break down a concept into its component parts, teach each separately and then expect the child to understand the whole. Emergent science also tells us that even the most appropriate progressive scaffolding will not take the child inexorably a step closer to the final learning objective as long as the contributory elements are not already present in the child's mind. Emergent cognition tells us that, even when all of the component cognitive schemes may be in place (all of the contributing concepts, attitudes and understandings), the child may still not be able to understand until they develop for themselves (whether through encouragement, or spontaneously) those higher schemes/schema that bring everything else together (often in a *eureka* moment) in an understanding at a higher level. Scientific concepts must be recognised as emergent, incommensurate, and greater than a simple sum of their parts. The pedagogical consequences of this are identified.

Emergent science education

When the idea of 'emergent science education' was first introduced to ASE In 2000, it was simply presented as the promotion of a playful enquiry approach to be shared by adults and children co-constructing the science curriculum together (Siraj-Blatchford, 2000, p.36). This was a model of science education very much based upon an already established *emergent literacy* programme in early childhood education, but it already included references to Piaget, and argued that theories of learning and teaching had already come a long way since the constructivist models of the 1980s.

The importance of recognising reading as an 'emergent' achievement is widely recognised in early childhood education. Learning to read is understood as an individual creative accomplishment, where the child has to develop their own concept of reading before they can do it. Teachers who adopt an emergent literacy approach (Hall, 1987) encourage 'mark-making' as a natural prelude to writing. This is precisely the way in which Froebel and many other early educational pioneers saw the importance of learning through 'making' things and, in emergent science, we have similarly encouraged 'explorations' and supported the child in sustaining these explorations over time.

Teachers who have taught emergent literacy *read* a range of different kinds of text to children. In emergent science, we introduce the children to 'new phenomena'. We provide them with the essential early experiences that they must have if they are to go on to understand scientific explanations later. These early experiences include playing with a range of different materials (sand/water/air, etc.). They also include drawing children's attention to the workings of their own body and the world around them. Siraj-Blatchford (2001) encouraged more: *'"air play" in the preschools, pouring it upside down in water, playing with bubbles and balloons and bicycle inner tubes, watching the wind and catching it in kites and sails'* (p.2). Imagine how difficult it would be to understand atmospheric pressure if you had never gained confidence in conceiving of air as a substance!

Teachers who teach emergent literacy have provided positive role models, by showing children the value they place in their own use of print. In emergent science education, we do the same by talking about science and involving children in our own collaborative scientific investigations. We tell the children many of the stories of scientific discovery. In doing so we encourage them to develop an emergent awareness of the nature and value of the subject, as well as positive dispositions towards the science education that they will experience in the future. In the 1970s, Frank Smith argued that reading was a complex achievement and that literacy was best considered as being like a 'club' that children join. Just like any other club in which children or adults participate, Smith argued that it was important to recognise that we often needed to be introduced to it, even accompanied in our first visits to it, by a more established and competent member (Smith, 1971).

In all of the above, the word 'emergence' has been understood as little more than the realisation of learning progress. But in recent years, the subject has become better understood as a natural consequence of all complex systems. 'Emergent properties' are understood as the novel properties that are created in the synergistic interactions of the components of complex systems. Emergent properties are greater than, and irreducible to, any simple sum or combination of component parts.

'Schemes' as the building blocks for emergent understanding of science

Both Piaget and Vygotsky recognised that cognitive and conceptual development was an emergent process (Sawyer, 2003). They recognised that the cognitive structures that emerge in children are *irreducible* to their component parts, and that an inevitable consequence of this was that it created 'levels' of understanding[1]. Piaget (1971) wrote that while *empirical knowledge* might be acquired simply through observation, the learning of *explanatory rules and concepts* relied upon the self-conscious co-ordination of the observed with existing cognitive structures of meaning. Learning science is not simply knowing about 'natural phenomena'. It provides a set of socio-historically-established and agreed logico-mathematical constructions that explain the phenomenon.

So what is the nature of those elements that the child pulls together in gaining conceptual understanding? A child's very first proto-concepts, often referred to as 'conceptual primitives', or 'grounded metaphors' (Nunes, 2000) have been identified in their sensory motor applications of following and reproducing horizontal and vertical movements (*Trajectories)*, and in *Positioning,*

[1] Note: Despite some interpretations, neither Piaget or Vygotsky considered these levels prescriptive.

Connecting and *Containing* objects. Throughout their early years, children show us their fascination with these very first proto-concepts or 'schemes', as Piaget referred to them. As Athey (2007) found in her Froebel Early Education Project in the 1970s, one or more of these schemes often comes to dominate the child's free choice play. One of the earliest, more complex, schemes (or concepts) that was identified by Athey in her studies was the child's application of a concept of 'Transporting', which is often developed by the child as a more elaborate combination of 'Containing' and 'Trajectory', and employed (often repeatedly and with great satisfaction) as they carry different items from one location to another in different containers. Eleanor Gibson (1988, p.33) has written about the importance of this evolutionary adaptive *affordance* of 'Transportability' and refers to the ways in which the identification of new *affordances* progresses, to provide the child with an ever richer and more sophisticated cognitive world (p.34). What Piaget referred to as the child's operative 'schemes', Mandler (2004) and also Johnson and Lakoff (2002) refer to as 'image schemas', which function as a connection between embodied experience and the wider world. In the case of a child's early interactions with a cup, for example, the scheme 'container' provides meaning to the interaction: *'An image schema [or "scheme"] is a neural structure residing in the sensorimotor system that allows us to make sense of what we experience' (op cit,* p.250).

These schemes are therefore understood very much as James Gibson (1979) and Eleanor Gibson (1988) understood the concept of affordances: they are the reciprocal product of our interactions with objects in the external environment, and they provide a bridge between the objects with which we interact, and our cognitive constructions of them. Biologists recognise that every organism has characteristics that are the product of its genetic structure and environmental conditions. And, applying Gibson's terminology, we may usefully recognise that it is the 'affordances' that determine the interactions between the organism and environment (subject and object) in the creation of its ecological 'niche'. Piaget considered that this adaptive mechanism characterised cognitive functioning as well (Piaget, 1971, p.158). There is a great deal of agreement in all these accounts at the level of principles, even if each of the various research communities has developed their own idiosyncratic terminologies and, as noted in the final report and recommendations of the Cambridge Primary Review, neuroscience, and the discovery of mirror neurons in particular, has now provided us with concrete evidence of this understanding of cognition (Alexander *et al*, 2010, p.91). For both Piaget and Vygotsky, it is the child's play that provides the primary context for learning, and they both insisted upon the necessity of engaging with young children's free play in early childhood education. David Ausubel was once asked: 'If all our knowledge about educational psychology had to be reduced to one general practical principle, what would it be?'. His answer was that: '*...the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly'* (Ausubel *et al*, 1978).

In a case study included in this edition of *JES*, Yewman (2022) reports upon a pre-school that applies Ausubel's principle and a schematic (SchemaPlay™) pedagogy to support children's early learning about electricity through play. The case study provides a particularly clear demonstration of the importance of adopting a playful emergent science approach.

The application of emergent science to sustainable electricity education

Electricity is regarded as a challenging topic in science education at all levels. In the context of early childhood education for sustainability, its importance stems from our widespread concern to provide greater awareness of the need to reduce energy consumption as a contribution towards reducing our carbon footprint. Yewman's paper reports on ongoing action research aimed at finding the most effective approach that may be taken in introducing the subject of electricity to young children.

Sengupta and Wilensky (2009) and Yewman (in this issue) have found that an emergent science approach can be effective where there is a clear recognition of the potential difficulties, and where students are respected to be developing their own: *'...deep, expert-like understanding of the relevant phenomenon by bootstrapping, rather than discarding their existing repertoire of intuitive knowledge'* (Sengupta & Wilensky, 2009, p.21).

Both current and resistance are widely recognised as emergent phenomena in themselves, resulting from the interactions of electrons and atoms.

If we therefore recognise, as Sengupta and Wilensky, and Yewman, do, that electrical phenomena represent a *complex system,* where phenomena at one level *emerge* from the interactions of component phenomena at another level, then we can appreciate that a single reductionist model applied to account for both levels will be inadequate.

As Sengupta and Wilensky (2009) suggest, our intuitive understandings involve the application of the prior knowledge that we have gained actively as agents interacting with the world. As suggested above, in early childhood education there is an ever wider appreciation that these prior understandings are schematic and embodied (Athey, 2007; Nutbrown, 2011; Siraj-Blatchford & Brock, 2016). Typical intuitive understandings of electricity (often unhelpfully termed *misunderstandings*) are of electrical current flowing as a 'substance' that follows a circular *trajectory* around the circuit.

Children also commonly regard the current as being something that 'wears out', i.e. that there will be less returning to the battery than left it due to the effort it has made to light lamps, make sounds or drive motors, etc. An expert knowledge of electricity, by contrast, has to account for the emergent behaviours (in this case of current and resistance) that are neither the result of direct causality, nor a simple sum of their component parts (atoms and electrons). And yet, studies have found that deep understandings can build upon intuitive knowledge through 'analogical thinking' and the use of 'conceptual metaphors' (Clement & Steinberg, 2002; Jeppsson *et al*, 2012).

In her creation of sound foundations for the children's emerging understanding of electric circuits, Yewman builds upon their schematic understandings of *Connecting* and *Rotating* to identify the passage of current and 'flow', as an application of a more general and common 'Trajectory' scheme in early childhood, which supports the children's intuitive recognition of the electricity 'wearing out', the analogical basis for their future recognition of energy flow.

Water education for sustainable citizenship

The contribution by Feriver and Göktepe (in this issue) provides another example of how the curriculum may be structured in investigative and experiential activities to encourage the development of young children's systems thinking. Water is a critically important theme in Education for Sustainable Development and Citizenship and, even in the relatively highly privileged UK context, recent media controversies concerned with the discharge of sewage and other pollutants into rivers and coastal areas illustrate the highly complex and 'wicked' nature of its supply.

Feriver provides evidence of significant learning but, even if our contributions to the development of systemic thinking and emergent learning in early childhood education were considered modest, it may be argued that these are fully justified in discouraging the alienation from science that is inevitable whenever we adopt more traditional reductive (confused and confusing) approaches to teaching and learning science.

Early childhood education for sustainable citizenship

Many of the problems of sustainability related to climate change, biodiversity, pollution and resources are 'wicked problems' (Rittel & Webber, 1973): *'Almost all the problems we face nowadays are complex, interconnected, contradictory, located in an uncertain environment and embedded in landscapes that are rapidly changing' (op cit*, p.183).

Systems thinking, and an acceptance of the challenges of complexity, has therefore been identified as the most important competence crucial for sustainable development (Rieckmann, 2012).

The education and care of young children is also widely recognised as a complex system. Efforts all over the world have been focused upon developing more integrated multi-disciplinary approaches. Urban (2022, p.7) refers to an increasing recognition by governments, the OECD, the World Bank and the G20 of the complexities surrounding the development of adequate programmes, services and policies for young children, their families and communities.

Urban (2022, p.12) calls for nothing less than a *'..trans-disciplinary critique and reconceptualisation that enables us to interrogate the propositions made by developmental psychology, economics, neuroscience, and other individual disciplines about young children'.*

This is a transformative, trans-disciplinary project that is simultaneously being proposed in *education for sustainable citizenship* (Siraj-Blatchford *et al*, 2016; Siraj-Blatchford & Brock, 2019), and in the mainstream of *science education* as well (Tas *et al*, 2019; Blatti *et al*, 2019; Gilissen *et al*, 2020; Mambrey *et al*, 2020).

The good news is that children are natural systems thinkers (Brown & Campione, 1994; Senge, 2000) *'...who can recognize interdependencies and interrelationships long before they are schooled in these concepts. While the world around them grows increasingly complex and interdependent, schools continue to fragment and compartmentalize, reinforcing the notion that knowledge is made up of many unrelated parts and providing little opportunity for students to see recurring patterns of behavior across subjects and disciplines'* (Sweeny & Sterman, 2007, p.285).

The bad news, as Sweeny and Sterman suggest, is that radical educational reforms may be needed in order that formal schooling does not continue to suppress these 'natural inclinations' for systems thinking.

Conclusions: So what next for emergent science?

Following, and somewhat adapting, Neisser (1976) and Anderson and Spiro (1977), we may identify the following main characteristics of the 'schemes' that provide the building blocks for the child's emergent understanding of science:

- schemes are always organised by the child to provide meaning;
- they are embedded within superordinate and subordinate schemes;
- different schemes may be applied in isolation or in combination in the course of an interaction with the environment;
- schemes are reorganised when they fail to be useful; and
- they provide emergent and gestalt mental representations, they are more than the sum of their parts, and they tend to reify and bias our perceptions of the world.

One of the biggest and most enduring problems that we have faced in early years science education has been the educators' concern that they themselves do not have the prior knowledge that is needed to either answer children's questions, or to teach them science. But, in the above discussion, we can see that teachers may now need to accept, as Hodson (1998) has also suggested, that providing the 'correct answer', or the 'established scientific view', is not in any case always a practical option. Given the pace of scientific developments, perhaps it is not something that we should assume we are doing at any stage.

Anne Edwards and Peter Knight (1994) suggested that we should only ever be trying to move children from their initial limited conceptions to 'less misconceived' ideas. The sense of this may be illustrated by the example of teaching floating and sinking: while a recognition of 'upthrust' may represent a necessary schematic prerequisite to learning how an object is suspended in water, any adequate understanding of the science of flotation must involve the concept of density, and that may only be understood when a child is able to consider the possibility of an inverse proportional relationship between mass and volume. Diverse applications of the inverse proportion scheme abound, but they remain outside of most children's experience in the early years. Applying theories of embodied cognition and emergent science, we may understand that, for a young child, this might well be considered the schematic (intellectual) equivalent of rubbing their stomach and tapping their head at the same time.

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