The Journal of Emergent Science

Issue 23 June 2022

The Association for Science Education
Promoting Excellence in Science Teaching and Learning

why & how?
PRIMARY SCIENCE TEACHING TRUST

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Editorial

Sarah Earle

This *Journal of Emergent Science* is a special issue on the theme of sustainability. Following the most recent United Nations climate change conference (COP26, in Glasgow in November 2021), there has been renewed interest in what educators should do to try to address the climate emergency. For example, the English government's new *Sustainability and Climate Change Strategy* (Department for Education, 2022) sets out an agenda for increasing understanding of climate change and connections to nature through initiatives such as a national education nature park and climate leaders awards. The *Our Shared World* coalition argue for 'engaged active citizenship', utilising the United Nations Sustainable Development Goal (SDG) for education (specifically Target 4.7) as a call to action for sustainable development (Bourn & Hatley, 2022).

The climate emergency is a complex and 'wicked' problem, something that cannot be solved with a narrow view of causes and solutions. Sustainable development is often represented with three dimensions, or pillars, to reflect the reciprocal nature and influence of the environment, social cultural co-operation, and economy. Such a model emphasises the interconnectedness of the 'system', which requires 'systems thinking', to consider the issues and solutions as a whole. In education, this requires us to look at sustainable development in a cross-curricular or transdisciplinary way, rather than in subject silos. This resonates with early childhood education pedagogy, which is concerned with development of the whole child.

This issue begins with a Research Review from **John Siraj-Blatchford,** exploring the concept of 'emergence', whereby the interactions in a 'system' lead to outcomes that are greater than their constituent parts. He considers emergence as both a way of explaining the need for systems thinking in science and sustainability, and also to explain the way that children learn, informing emergent science education.

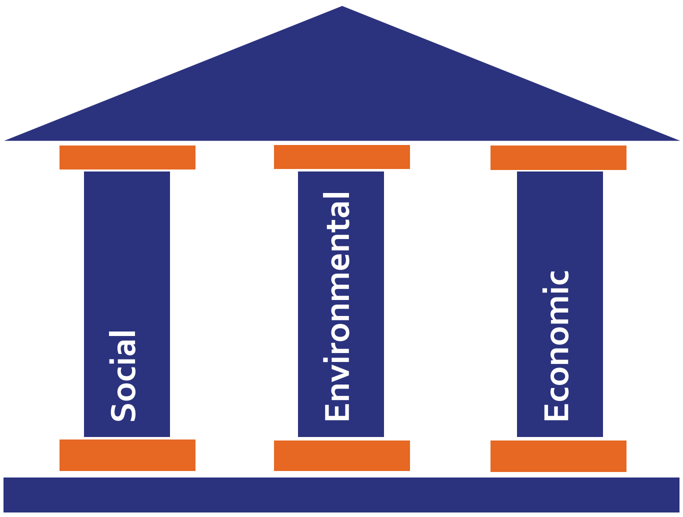

Figure 1. Three pillars of sustainability.

The next two articles explore an emergent approach within the context of particular topics. **Dianne Yewman** provides an action research case study from her nursery in England, looking at the use of *SchemaPlay* in the context of electricity. **Şebnem Feriver** and **Emre Göktepe** consider systems thinking as a way of supporting children's understanding of water in a Turkish pre-school.

In her article, **Amy Strachan** returns to the SDGs to consider their place and use within primary science, whilst **Meghna Nag Chowdhuri *et al*** describe the Primary Science Capital Teaching Approach, a social justice framework that aims to help children feel that science is 'for them' and so feel able to act on issues that matter to them.

Our global interconnectedness has become starkly explicit in recent years, making sustainable development a core priority of education. The articles in this issue provide ways to think about learners and pedagogy when considering big ideas such as emergence and systems thinking, together with practical examples of how to implement transdisciplinary approaches to support the development of global awareness in the children whom we support.

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Our Shared World https://oursharedworld.net/

United Nations Sustainable Development Goals (SDGs) https://sdgs.un.org/goals

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Emergent science education for sustainability

• John Siraj-Blatchford

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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Electricity education for sustainable citizenship: A critical case study

● Dianne Yewman

Abstract

This case study reports upon a collaborative action research project conducted in a small private nursery in South East England. The study has been developed to consider effective ways of teaching electricity in the context of education for sustainable citizenship (ESC). The pedagogical model applied in the setting is based upon SchemaPlay practice, which is founded on the assumption that cognitive development and conceptual learning is an emergent and creative individual achievement most effectively supported through free-flow play. With SchemaPlay's identification and support of children applying their dominant cognitive 'schemes' to achieve the early years (and ESC) outcomes (Athey, 2007; Siraj-Blatchford & Brock, 2016), a key question to be answered was to what extent schemes influence the children's learning of electricity.

Introduction

The nursery had completed the OMEP(UK) *Education for Sustainable Citizenship* (ESC) Bronze award in the previous year and were building upon this at the Silver level. One area of the curriculum that was identified as being in need of development was electricity, which was considered particularly challenging to the staff in theory and in practice. Given the SchemaPlay practice, an initial question was: in what way would electricity education relate to the children's schemes? SchemaPlay is a direct application of Ausubel's (2000) widely accepted principle that learning must always build upon what the child knows and can already do. SchemaPlay supports practitioners in their identification of the basic operative 'schemes' that children apply in their play (e.g. where children repeatedly spend time 'containing', 'connecting' 'positioning', rotating', 'transporting', etc.) and shows them how these may be applied to support further learning (Siraj-Blatchford & Brock, 2016). This was at first addressed in reading some of the literature on early years electricity education (Thornton & Bruton, 2007; Siraj-Blatchford, 1999) and in a staff brainstorming session, and it subsequently involved the development of resources, and a series of interventions with the children.

In a review of the professional literature, we found that there are two contrasting explanatory frameworks that could be applied to electricity in early childhood, with one relating to current flow and the construction of electrical circuits and the other to energy generation, storage and application. The common practice of beginning electricity education with experiments that use a battery and a simple lamp or buzzer to identify all materials as either 'conductors' or 'insulators' was identified as problematic. There were potential safety issues associated with the activity, as it identifies materials that can conduct as 'insulators' (Siraj-Blatchford, 1999).

Materials cannot categorically be considered essentially a conductor or insulator even in normal conditions – all materials have some 'resistance' and, in extreme circumstances, even air will conduct (as in lightning). In this project, we therefore used an electronic 'Buzz Box' (see Activities section below), because it was able to show both audibly and visually that an electrical current will flow through the human body and also through water. If electricity didn't flow through the body, then there would never be any danger of a shock and, if water was an insulator, then there would be no risks associated with having electrical devices in, for instance, the bathroom or near a swimming pool.

Siraj-Blatchford (1999) argued that a very common intuitive idea about simple circuits is that the energy 'runs out', or 'dissipates', and that this is considered a misconception to be avoided in the context of children understanding electrical current flow. In a circuit, the current does not run out when it returns to the battery. It will only be later, at a level of explanation that includes the notion of the movement of electrons, that a child will come to appreciate the reason that current may be measured at any point in a circuit and found to be the same (i.e. at both sides of the battery). So electricity and electrical circuits are best understood as a complex system where the child's progression in understanding will 'emerge' in time, as the various component features and behaviours of electricity and electrical circuits are progressively experienced and supported.

The SchemaPlay approach to electricity therefore suggested the need to build upon a child's schematic understanding and motivations for '*connecting*' and '*rotating*' to identify the passage of electricity around a circuit, and to apply the notion of 'flow', as an application of a more general and common '*trajectory*' scheme in early childhood in supporting the children's intuitive recognition of the energy 'wearing out', providing the analogical basis for a future recognition of energy flow.

Method

A Montessorian approach was adopted for selecting suitable resources, which is consistent with the schematic learning principles applied in the SchemaPlay pedagogy. Montessori developed didactic materials that provided 'materialised abstractions' – concrete materials that embody the abstract concept. For example, the Buzz Box (Figure 1 below) suited that purpose, and it had been well received by reviewers, including CLEAPSS (2000).

Following Montessori's example, the other materials were each developed to isolate a particular cognitive scheme (quality or 'sense'), to ensure that the child's attention was focused upon a particular quality. In the traditional Montessori sensorial materials, these include size, weight, shape, texture, colour, sound, or smell; in this case, for electricity education, the primary cognitive schemes were identified as the 'Circuit' (related to 'rotation'), 'Connection', and the notion of 'Energy Flow' (related to 'trajectory').

The research objectives were identified as:

- Supporting the children's emergent understanding of electricity, electrical circuits and electrical energy conservation;
- To provide controlled experiences of electrical circuits;
- To introduce switches and electrical safety; and
- To encourage the child's basic science and mathematical vocabulary.

Thornton and Bruton (2007) summarised some of the key safety principles to bear in mind when working with electricity in early childhood, and one additional provision that we added here was to avoid the use of rechargeable batteries, which can quickly become burning hot in a short circuit. We should only use rechargeable batteries where they are enclosed, and sealed by screw or tape, to avoid child access, e.g. in cameras, robotic toys, etc.

Safety first

- *Make sure that you have talked to the children about the difference between mains electricity and batteries and the dangers of touching them.*
- *Ensure that children understand that while the equipment you have given them is safe to investigate, other plugs, sockets, switches and electric lamps are not.*
- *Emphasise that batteries are safe to handle as they are, but become dangerous if they are damaged or taken to pieces.*
- *Have a safety procedure in place in your setting in the event of a light bulb being broken.*
- *Avoid children handling any form of rechargeable battery; they can cause burns when short-circuited.*

The safety advice identified online and in the professional literature generally emphasises that good habits are hard to break. Three to five year-olds can learn basic safety messages, for example, to stay away from electric sockets and to keep electrical appliances away from water.

Activities

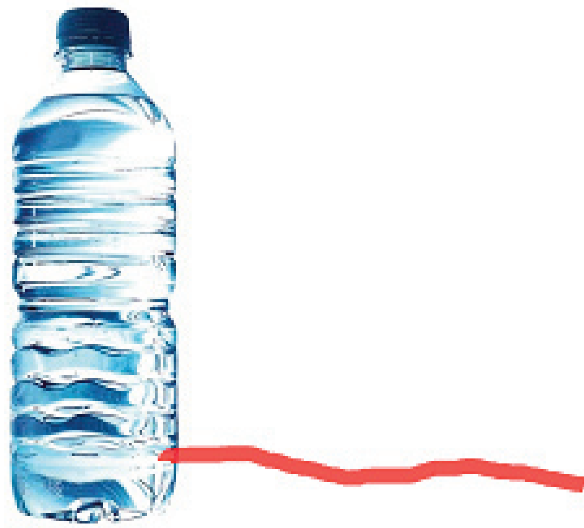
The Buzz Box – introducing the idea of electricity flowing around a complete circuit and the idea that some materials are especially good at conducting electricity, that they themselves can conduct electricity, and that most other materials conduct electricity when they are wet.

Figure 1. Buzz Box.

A Card Sort Activity – to support the children's recognition of the difference between mains and battery electrical appliances, reinforcing devices that are 'safe' (battery) and hazardous (mains). The difference in the two is described as being like water: if you have a little electricity (in a battery), it won't do you any harm as it is like a glass of water…but the mains electricity is big, it is a lot of electricity – like a river or the sea and can be very dangerous.

A 'Toy Battery' (Figure 2) was demonstrated and introduced to the water play area – to show the children how a 'battery' can be filled with pretend electricity (water) and how it 'runs out' through to a hose. The children were encouraged to pinch the tube to 'switch' it on and off. The staff kept repeating the language when they saw the children playing with it, e.g. *'Are you filling the battery?', 'Has all the pretend electricity run out?'* Later, the children were shown how it could be used with a waterwheel – and how this was like a motor connected in a simple circuit.
A demonstration was also later given to show how the water flow could drive a generator to produce electricity (light an LED lamp).

Figure 2. 'Water' battery.



A low voltage 'Light Board' (Figure 3) was constructed with a domestic switch and a small lamp on it to demonstrate the need for a complete circuit and the role of the switch in connecting the wires. This provided a free-to-access play resource that came to be adapted by the children in supplying electricity to other components, including a motor/propeller.

Figure 3. Light Board.

A 'turbine generator' (Figure 4) was provided, which lit a small LED lamp when spun quickly by hand or when it was turned by wind or water flow. Small electric motors generate electricity when they are spun so that the operation of a turbine like this may be improvised. This also provides a potentially valuable practical application of a 'transducer' (a device that changes energy from one form to another), and the more general (and

Figure 4a. Turbine generator.

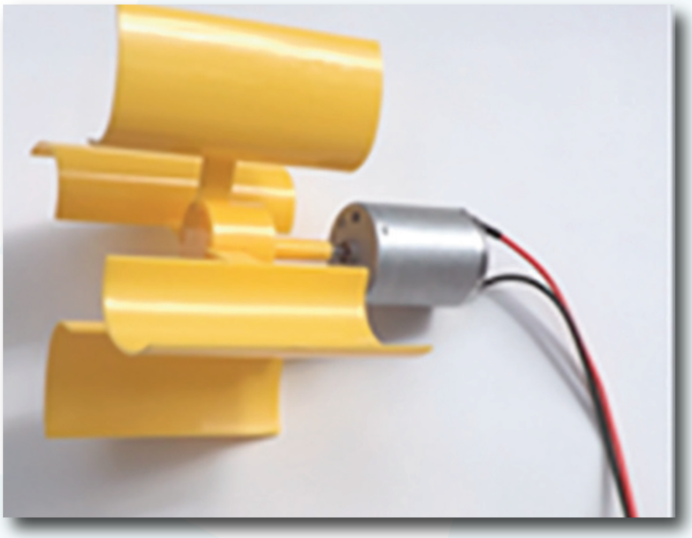


Figure 4b. Motor/propellor.

reversible) energy principle of movement energy producing electrical energy and electrical energy producing movement. The children found playing with these motor/generators particularly fascinating and they also provided a useful challenge for many in terms of their development of fine motor skills and their 'pincer grip'.

Whenever possible, the activities were used to provide an opportunity for the adults to apply appropriate language and terminology, and to talk about safety and also about electricity generations, expense, consumption and conservation.

Each of the resources was first presented to each child in a controlled (Montessori-inspired) manner, on a tray, in a room with which they were familiar and by an adult whom they knew.

The materials also needed to provide what Montessorians refer to as a 'control of error' – a means by which the child was able to self-correct. While both of these considerations were taken into account in developing the electricity resources, it was found that, in the practical realities of the children's free play, the resources were combined in unforeseen ways that will have served to undermine their didactic intentions. The children discovered in their play, for example, that the light board provided an energy source that could be applied to the motor (fan) when this was connected in parallel with the lamp. This split in the current distracted their attention from the 'circular' pathway required in the simple (one battery and one transducer) circuit.

Data collection

The case study took the form of a collaborative action research project. The project began with a short stimulus questionnaire, discussion, and a brainstorm with the five staff on how they understood electricity, how they spoke about electricity and what cognitive *schemes* they might be applying metaphorically in the process.

We shared our understandings of how a light circuit works, experimented with the Buzz Box and brainstormed suggestions on what we might try to do with the children to teach them about electricity and sustainability. All parents were informed of the project and permission to take part was sought, including from those who were selected to take part in the evaluation of the activities to be photographed and/or videoed.

These children were given pseudonyms for the purposes of the research exercise. All the children were in the pre-school group in the nursery and considered to be of a similar ability. The children were asked if they would like to participate in the study, and they were asked verbally for permission to film them. Two children did choose not to participate in the teacher-directed activities, but they did participate in the activities when they were offered as free play opportunities.

Table 1. Data collection.

Name	Age	Dominant schemes (repeated actions observed in free play)	Observed play schemes (key person notes)
Amy	53 months	Trajectory, Rotation, Transformational	Strong rotation scheme, loves stirring 'potions'
Harry	54 months	Trajectory, Rotation, Transporting, Enveloping, Positioning, Connecting	Harry was particularly interested and focused on the task [making a tower], and was keen to have a go
Lexi	53 months	Trajectory, Transporting, Containing	Enjoys role play. Loves containing and transporting when playing upstairs where they love to pretend to go on holiday to Butlins
Jack	48 months	Trajectory, Rotation, Enveloping	Jack is very interested in how things work and why. He enjoyed finding out about electricity and how we use it in different ways. Jack likes to monitor the lights in the nursery and to turn them off when they are not being used
James	54 months	Trajectory, Transporting, Containing. Rotation, Positioning, Connecting	James told us initially that he did not know what electricity was or what made the lights work

Results

Data were collected on the response of five children, and the schemes that had been identified by their key person in their unrelated play (Table 1).

The first surprise was regarding the children's knowledge of materials; while it was assumed that they would all be aware of the difference between plastic and metal, some children had not yet understood this. The discovery reminded us that we should use 'materials' words more often in our day-to-day interactions with artefacts in the nursery. We also identified the mistake that we made in including two spoons; the similarity in function, appearance and name of these all distracted from the intention of focusing the children's attention on the difference in material.

We found that the children could *easily sort electric appliances from battery appliances.* Children have now taken ownership of recycling activities and are persistent in reminding adults to switch off lights, both in the nursery and, we have been informed, at home as well. The learning objectives related to sustainable energy conservation had therefore been met to some degree.

The staff questionnaire that stimulated our initial discussions asked:
'I want you to think about when it's getting dark in the evening and you need more light to read or do something – and you ask your partner or someone else to do something about it – what do you say to them? What actual words do you use?'

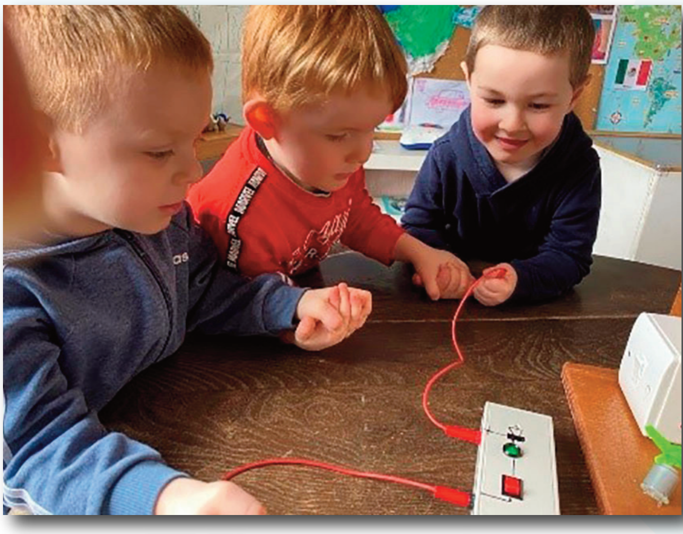
The staff responses were split between 'putting', 'turning' and 'switching'. There was general agreement that the most helpful way to say this to the children would be to 'switch the lights on'. Most of the staff also felt that this was the most accurate way of saying it, although a minority preferred 'turn it on', e.g: *'Electric comes from outside so turning the switch on lets the energy/electric in to **turn** the light on'*. Alternatives were suggested, such as *'Could you **push (or press)** the light switch, please?'* or *'click the switch'* with older children.

It is not clear where the idea of 'turning' came from, but almost half felt that it was appropriate. It may be that this is a term strongly applied in our culture because the very first switches did need to be turned (see Figure 5). Yet it seems unlikely that respondents would consider it appropriate to refer to 'cranking' the car, as opposed to 'starting' it or 'turning' the ignition. The majority (7/9) did answer by saying that 'switch' was the most appropriate term, which suggests that they felt the children should learn the proper name of the device that is used to achieve the lighting result.

When the Buzz Box circuit was completed by attaching a wire between the terminals, the children were given an audible and visual indication of the quantity of electricity passing through the circuit. When the children were given the 'hands-on' experience of sorting materials according to how well the electricity went through them, the evidence of their experiments showed that both water and they *themselves* were conductors. It provided a strong illustration of the reasons why all electrical appliances should be kept away from bathrooms, and why it is that we will experience an electric shock if a large current passes through our body.

Figure 5. Antique General Electric rotary light switch.

Figure 6. A human electric circuit.



The nursery is not a Montessori setting, and the children were therefore less familiar with the idea of trays providing dedicated self-select activities for their free-play time, and it was recognised that this would significantly influence the process and potentially limit the time spent repeating the activity in free play. However, Figure 6 shows the children having the electricity flowing through themselves in a circle during their free play with the Buzz Box. The preferred 'on/off switching' was achieved by joining hands or, even more enjoyably, by having a finger pressing the nose as a button.

Conclusions

Although this sample of children is very small, there is no doubt that teaching children to make circuits, helping them to understand different kinds of energy, consumption, etc. is not only valuable in terms of emergent learning but, more importantly, offers interesting and exciting opportunities in the early years. These were activities with meaning, the children really enjoyed them and could play with them independently – they definitely offered a new dimension to the 'classroom' – they were exciting and interactive.

While any correlation between the children's identified schemes and their developing understanding of electricity can be little more than speculative with such a small sample, it may be significant that the only child who had not been identified as applying a 'rotating' scheme in their play showed the least capability in making the circuits. Harry and James, by contrast, both having been previously identified as having 'rotating', 'positioning' and 'connecting' schemes, both took a strong interest and developed a good deal of confidence in the activities. Further research on this is warranted.

There were some physical problems with the apparatus that some of the children found difficult to overcome, and the materials need to be adapted with this in mind. For example, for many of the children, opening the crocodile clips was demanding and it was beyond the capability of some of the children to 'blow' the wind generator into action. But these challenges often provide opportunities as well as limitations. For example, the crocodile clips provided a very motivating context for the development of the children's strength in the 'pincer grip' that will support their writing.

Overall, the staff saw the activities as a positive experience that they themselves had learnt from, as well as the children:

*'The children have been interested in the electricity devices and working out how they can get them to work. One child recalled [that] if you put wood into water it conducts electricity, which I found interesting as I didn't know this' (*Practitioner Report).

For the children and the adults involved, the project has progressed very much as Sorin (2005) has described:

'Curriculum for the agentic child is co-constructed through adult-child collaboration. Adults guide the learning process, based on their own learning, life experiences and resources, and both children and adults strive to augment their understandings of issues important to them' (Woodrow, 1999, p.18).

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Pre-schoolers as systems thinkers: Testing the water

● Şebnem Feriver ● Emre Göktepe

Abstract

Systems thinking (ST) is a potential game-changer in terms of helping children and adults to understand the complexity of sustainability, so that they can develop sustainable and just societies in harmony with the planet. In this study, a learning framework was developed for 32 children aged 5-6 and it was implemented over the course of four weeks with children in a pre-school in Turkey. The children were pre- and post-tested with assessment instruments using a mixed method approach. The results revealed a significant development in the ST skills of the children. The children defined system elements related to water more effectively, came to see invisible elements as parts of the system and established high quality causal relations between some of the system elements. In this paper, we provide a summary of the Concept Mapping (CM) findings of this study (for full study, see Feriver, 2021)

Introduction

A growing number of scholars in the field of *Education for Sustainability (EfS)* argue that equipping children to address complexity, which is at the core of systems thinking (ST), will contribute to the goal of sustainable education (Rieckmann, 2012; Bosch & Cavana, 2013; Lewis *et al*, 2014). A system has been described as *'an arrangement of parts or elements that together exhibit behaviour or meaning that the individual constituents do not'* (Dori *et al*, 2020, p.2) and, in this edition of *JES*, Siraj-Blatchford (2022) identifies these behaviours and meanings as 'emergent'.

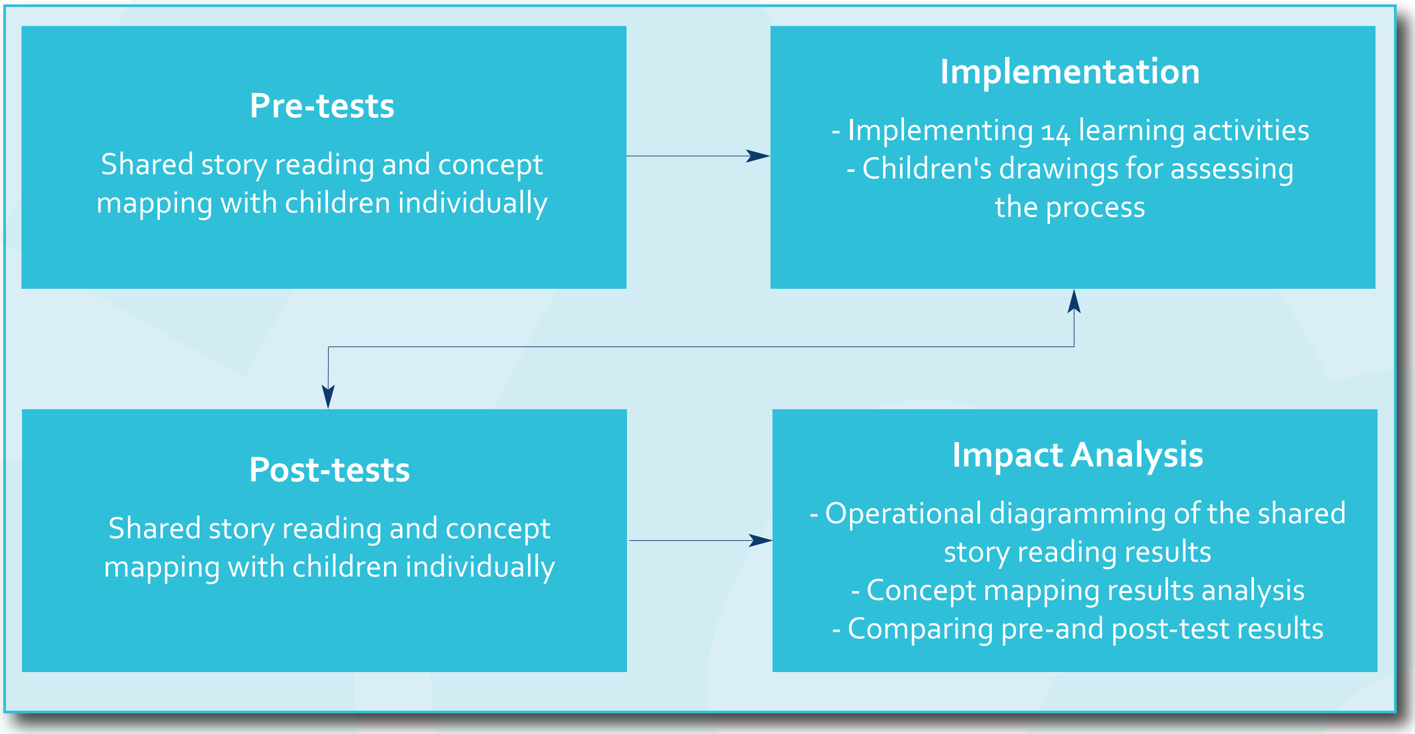
Although the systems approach has been used for more than 50 years, the focus on the primary and early years phases of education is a relatively recent development. Educational research has so far been largely restricted to higher education and workplace studies, which have highlighted the limited ST skills of adults (Jacobson & Wilensky, 2006). Based on the findings of research conducted with adults, ST researchers have suggested that children should be introduced to ST at the earliest age possible (Peppler *et al*, 2020). Indeed, studies with primary school students (e.g. Hokayem & Gotwalz, 2016) and pre-schoolers (Gillmeister, 2017) have demonstrated improvements in the children's ST skills and their progress in the degree and accuracy with which they recognise system elements and the interactions between the elements. Despite these promising results, there is still an important gap in the implementation of systems education for pre-schoolers.

We know that people, especially children (Perkins & Grotzer, 2000), tend to simplify complexities and apply reasoning that assumes a linear causal relationship (Hung, 2008). In the present study, in order to eliminate this tendency, a project-based learning framework with deep learning experiences was developed and implemented, which incorporated sustainability and ST as core components into the pre-schoolers' learning experiences.

Method

The study employed a mixed methods design and the research procedure is summarised in Figure 1. Further details of the overall aims of the study and its methodological and procedural rationale can be found in the full research article published by *Environmental Education Research* (Feriver, 2021). Two assessment tools for Shared Story Reading (SSR) and Concept Mapping (CM) were developed and implemented in the study. The SSR procedures and results have not been dwelt upon in this article in order to focus more closely upon the pedagogic practice and its relevance for practitioners.

Figure 1. Procedure of the study.



The study was conducted following ethical guidelines over four weeks in a small, three-classroom pre-school in a middle-class urban neighbourhood in Ankara, Turkey.

The number of children who took part was 32 ($_{n}$girls = 19, $_{n}$boys = 13, $_{mean}$age = 69 months).

The learning framework provided 14 integrated play-based pre-school learning activities on the theme of 'water' (See Appendix A). These activities were drawn from a guidebook designed to enable children to develop their broad understandings of water (its nature and importance, and interrelated features of its behaviour and use) in the framework of ST principles.

Overall, a comparison of the SSR pre- and post-test results showed that there were notable changes in the children's recognition of system elements and processes. During post-test assessments, invisible elements were added to the children's repertoire, and they established more qualified causal connections between things that change and possible causes of the change.

Concept Mapping (CM)

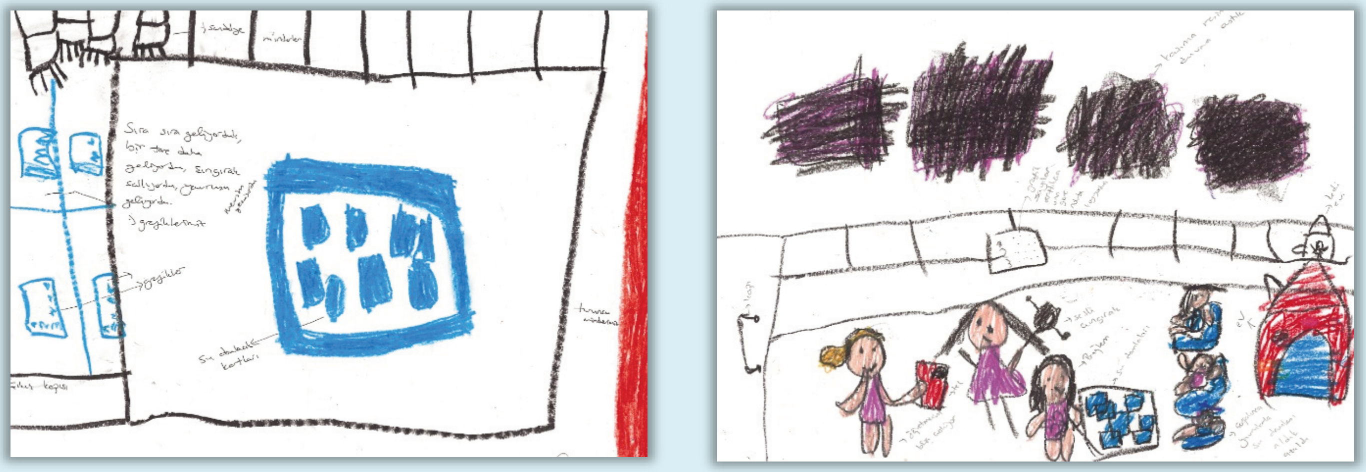
Concept maps may be considered the expression of mental models (Yin *et al*, 2005), and it is an approach that makes it possible to display concepts in a visual and non-linear manner, to address the relations between concepts, and they may be applied in this way to broaden the limits of conceptualisation (Novak & Cañas, 2006). In this study, the CM activity was devised as the second assessment instrument due to its capacity to measure systems thinking ability (Watson *et al*, 2016). A recent study had shown that CM reduces neurocognitive effort and results in better-quality concept generation on sustainability-related issues (Hu *et al*, 2019). CM was also included in the study for the purpose of triangulation, and was implemented, like the SSR, in the form of a pre- and a post-test. CM can be highly-directed, in which case concepts and linking words are provided, or non-directed, when the concepts and linking words are generated by the participants (Ruiz-Primo, 2004). Highly-directed CM has advantages when it comes to validating the accuracy of propositions (Brandstädter, Harms & Großschedl, 2012). The CM in this study was medium-directed, as the children could not be presented with linking words due to literacy limitations and the activities were structured around water and eight different concepts that might be related to water, which were visualised on cards. The set of concepts applied by the children were then identified by four experts and compiled of both obvious and non-obvious concepts related to water. The CM activity was also kept simple in view of the levels of development of the children taking part in the study. Simple concept maps involve fewer components, and they do not aim to create a hierarchy (Ruiz-Primo *et al*, 2001). First, the water card was placed in the middle of a piece of paper and the children were asked which cards might have a relationship with water. As the children placed their chosen cards around the water card, they were asked how the cards were related to one another, to get them to explain the relationship between the concepts on the cards. The links that the children made between the concepts were noted down by the investigator on the piece of paper to elicit links among concepts. The children's reasoning was recorded in the form of CM-linking words. The activities lasted for 10–15 minutes and were videotaped.

Implementation

A typical learning activity (Appendix A, Day 7) inspired by the *Fish Banks Ltd.* game created by Dennis Meadows (co-author of *Limits to Growth in 1972*) involved a structured dramatisation demonstrating the relationship between population growth and water supply, where children acted as antelopes sharing a forest lake. Figure 2 shows the drawings made about the process by two of the children who took part in the learning experience detailed above, together with their narratives about the drawings.

Analysis and results

The CM data was analysed by counting the valid connections constructed by the children. If the connection between two concepts was formulated using a valid proposition, one point was assigned but, if it was formulated using an irrelevant or invalid proposition, no point was assigned. The pre-test and post-test frequencies for each code were calculated in accordance with the standards for inter-coder agreement and content-level comparisons were made (Feriver, 2021). Figure 3 presents the CM interview conducted with Child 14, and it demonstrates how the interviews were visually created.

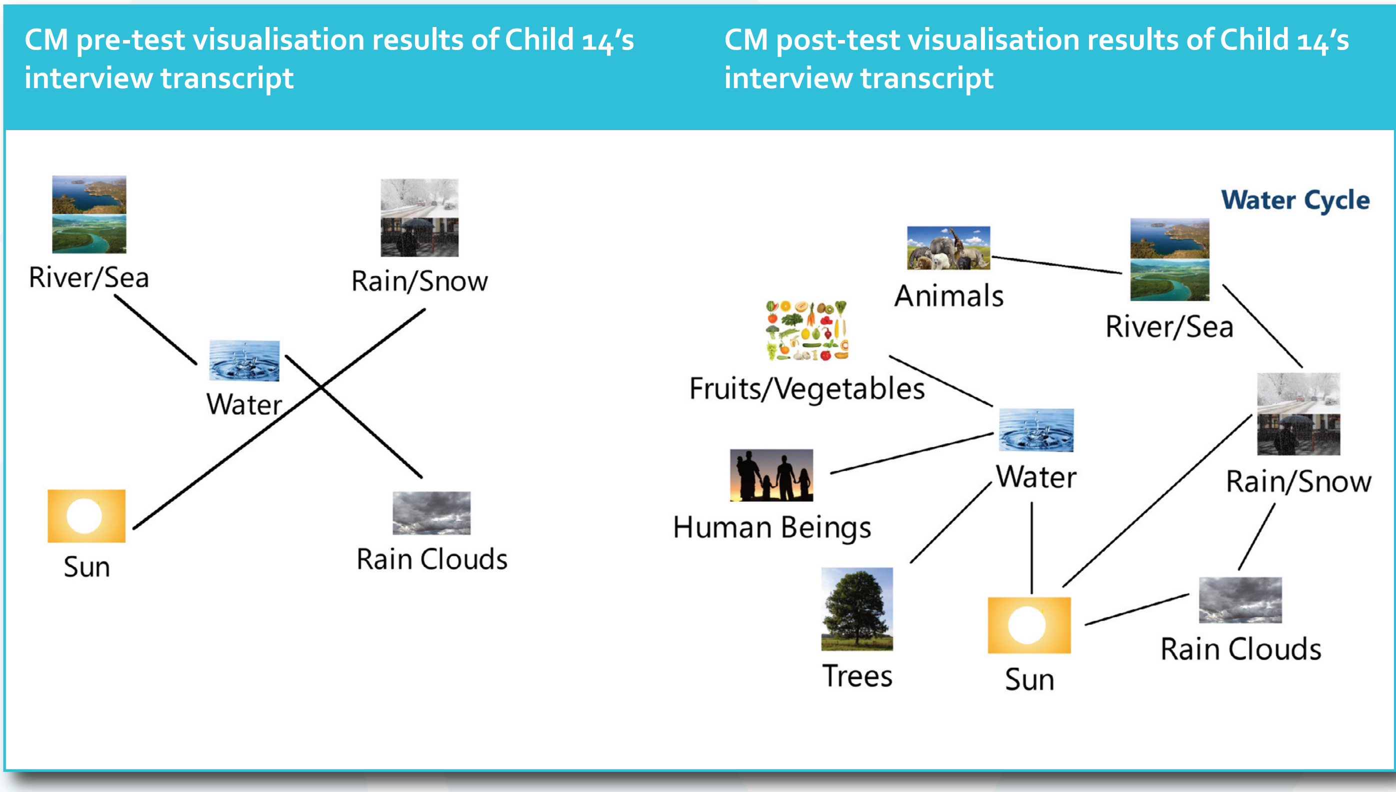


'We were multiplying more and more. With our babies, our numbers were increasing. We showed this on the graph. After a while, our water ran out very quickly. We put this on the graph too. After the water has run out and there is no room left in the forest, the baby and mother antelopes have to migrate somewhere else.'

'When we rang the bell, a season went by, it rained and the antelopes had babies. We put our increased number on the graph. Every season, the baby and mother antelopes took a water card from the lake and we put the reduced number on the graph. After a while we had no water left and we were very crowded in the forest.'

Figure 2. Children's drawings with narratives.

Figure 3. Concept mapping results of Child 14.



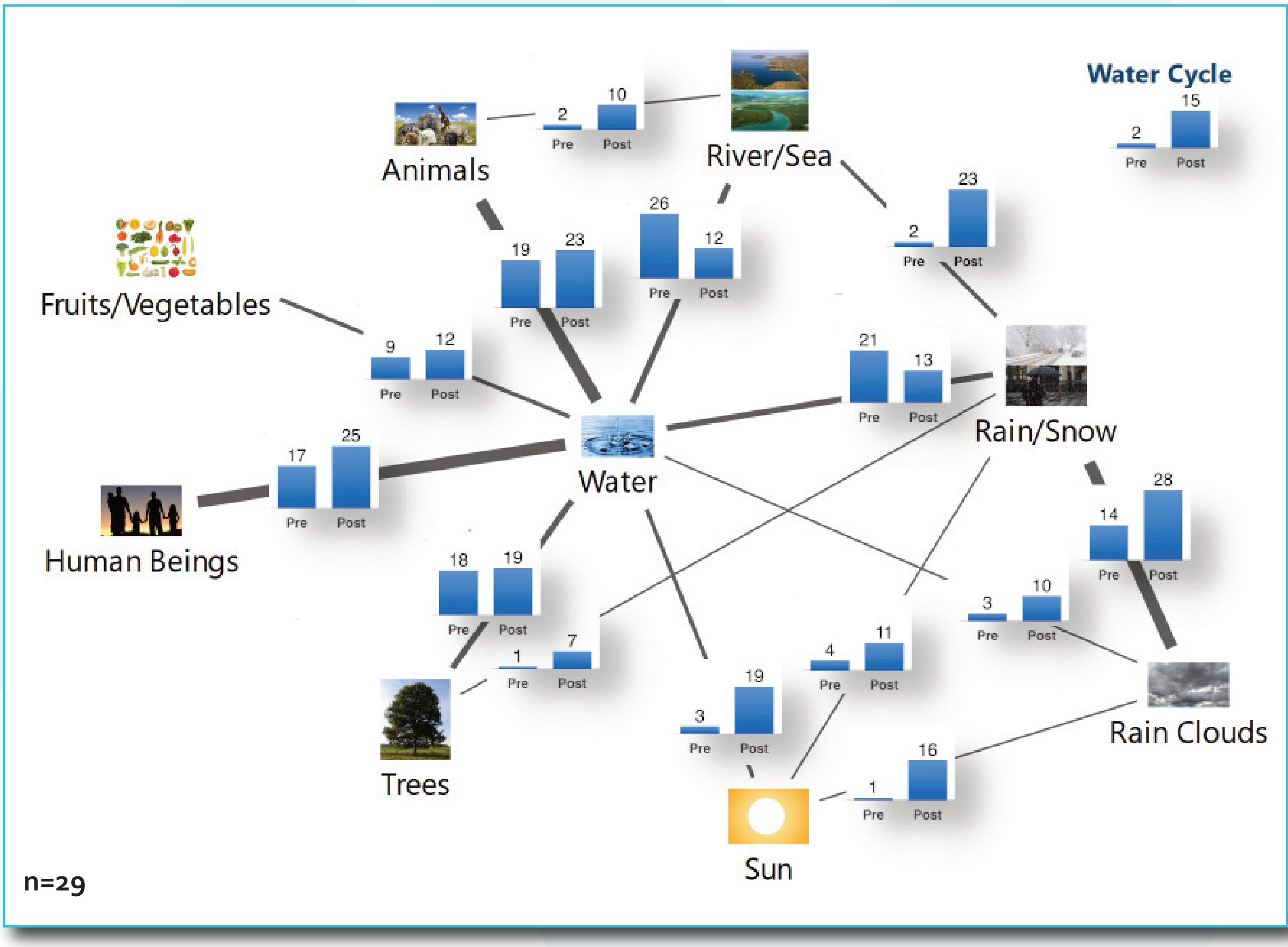


Figure 4. Concept mapping overall results.

For the CM data analysis process, consensus was reached on 16 codes related to the content of the implementation framework. The codes were placed on the concept map as shown in Figure 3, in much the same way as the cards were placed during the child assessment process. The visuals in this figure are, in fact, the cards used in the assessments of the children.

The thickness of the connecting lines in the Figure 4 combined CM (see page 22) reflect the total frequencies obtained from both the CM pre- and post-tests, with the thickest line representing the highest frequency and the thinnest line the lowest. The post-CM analysis process revealed that the children established consecutive connections between the elements *water-sun* (sun evaporates water), *sun-rain cloud* (evaporated water gathers in the rain cloud) and *rain cloud-rain/snow* (rain/snow falls from the rain cloud and, for some children, it rains/snows on the river/sea). The occurrence of this three-stage consecutive connection was coded as the 'water cycle' and the frequencies for this code were presented in the upper right corner of the concept map.

For an overall appreciation of the extent to which the comparison of the CM pre-test and post-test results showed that there were notable changes in the children's recognition of connected elements and processes, and higher occurrence regarding more sophisticated connections, reference should be made to Feriver (2021).

Implications and conclusion

This study has shown that learning experiences that expand children's causal structure development in a complex context, and help them to structure this knowledge holistically, yield positive results.

Further studies are recommended in order to develop the validity and credibility of this approach further. Children are known to create well-structured, coherent and cohesive narratives starting from at least the age of five (Schick & Melzi, 2010). The concept maturity, causal reasoning and narrative abilities displayed by the children in this study at the age of around five suggest that a shift in the focus of systems research towards children in this age group is possible.

Understanding complex systems involves more than recognising elements; it requires reasoning about causal connections (Grotzer *et al*, 2017). This in turn can be supported by mechanism knowledge – i.e. an understanding of the patterns of relationships within which systems work. Expansion of the mechanism repertoire leads to significant achievements in terms of causal complexity (Grotzer, 2012). Like other pieces of research (i.e. Grotzer & Basca, 2003; Perkins & Grotzer, 2000), this study also indicates that learning experiences have the potential to expand children's causal structure development in a complex context.

Another educational implication of this study is that it illustrates the value of educational experiences directed towards deep learning, which widen children's experiences through a project-based approach that aims to extend learning over time. The study shows that children may be engaged in explicit discussions on causality, not only to focus on the visible but also on invisible system elements and mechanisms. As leverage in the course of these processes, asking children high-demand questions, guiding them to develop a more complex explicit understanding by drawing out their implicit understandings, and helping them to understand 'why' by linking direct experience and vocabulary to learning, have the potential to create the systems thinkers needed by our planet (Spratling, 2015). In order to provide these opportunities, there is a crucial need to improve the capacities of teachers for ST and EfS, as their capacity has the potential to positively affect sustainability competences of their students (Murphy *et al*, 2021).

During early childhood, children are known to face certain constraints in their expressive language development (Kuhn *et al*, 2016). This study has shown that CM can be useful for grasping the implicit understandings of children and supporting them in creating narratives with the help of visual images. In the CM exercise, the children were observed to be able to create links between the systems elements more easily and more frequently, and even to develop a consecutive narrative in such a way as to form a cycle.

Research has shown that humankind has limitations in terms of demonstrating ST skills (e.g. Cox *et al*, 2019). As a matter of fact, what we have done to our planet is the most obvious proof of these limitations. ST is not a perspective that will come to the fore unless we intervene deeply in the mental models that we use to make sense of the world. It is therefore essential for the wellbeing of our planet that we integrate with this discipline at an early age and allow it to guide us in forming our mental models. Based on these premises, this study was intended to pioneer the development of an integrated approach to the curriculum and assessment that incorporates ST with Education for Sustainability, using the theme of 'water', and so to offer inspiration to education policy makers, researchers and educators.

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Appendix A

Flow	Learning Activities	Learning Outcomes
Day 1	Warm-up activity: Introducing the Water-Drop hand puppet to children	Exploring children's knowledge of water
Day 2	Interactive storytelling activity: *'Could a Dinosaur Have Drunk from the Same Water?'* Creation of a water web	Understanding that water does not disappear in its cycle Discovering that water use creates webs
Day 3	Science activity on the three states of water Preparation of water bags to observe evaporation, condensation and precipitation	Understanding that water is in a permanent cyclic system in three states Exploring the stages of the water cycle
Day 4	Short animated video about the water cycle and water resources Play activity describing the interconnections among water resources	Discovering different water resources on Earth Recognising that different water resources on Earth feed into each other in a connected system
Day 5	Art activity: Individual drawing activity displaying learning about water resources	Describing the learning experience by individual drawing and verbal expression
Day 6	Water Talks: Why is the Earth called the Blue Planet? Science activity on limits to accessing fresh water	Recognising that while the Earth contains plenty of water, freshwater is a very limited natural resource Exploring adverse impacts of excessive consumption of fresh water resources on people, animals and plants
Day 7	Play activity demonstrating limits to growth with limited water resources and a growing population	Discovering the causal relationship between population growth and fresh water resources Understanding exponential growth conceptually
Day 8	A short movie on Africa's great Serengeti wildebeest migration Illustration of different animals' migration cycles	Discovering the migration cycles of different animals Understanding the causal relationship between animal migration and water
Day 9	A drama activity representing animals looking for food and water in a cyclical pattern	Recognising that some animals also migrate in a cyclical pattern to survive
Day 10	Art activity: Individual drawing activity displaying learning about water Photo exhibition summarising the learning experiences of children	Describing the learning experience by individual drawing and verbal expression Summarising the learning experience by browsing and discussing the activity photo exhibition
Day 11	Book exploration activity	Exploring different stories told about water
Day 12	Drama activity representing exponential growth in terms of water contamination	Exploring how water pollution can be transmitted rapidly to different sources within the connected system
Day 13	Interactive storytelling activity: *Where is the Starfish?*	Understanding the causality between water pollution and the loss of biodiversity in marine ecosystems Creating a behaviour over time graph about marine pollution
Day 14	Bar graph drawing activity to demonstrate hidden water use for products such as jeans, bars of chocolate and water bottles	Exploring the concept of 'hidden water usage' by understanding that the production of food/goods also requires water consumption Recognising the relations between water consumption and our daily consumption habits Creating a bar graph demonstrating hidden water consumption

Table 1. Implementation of the learning framework.

Embedding sustainability in primary science education

● Amy Strachan

Abstract

As a provider of primary science CPD and lecturer in primary science Initial Teacher Education (ITE), I consider how a primary science curriculum can provide an opportunity to embed climate change and sustainability education. Using a global learning approach and the UN Sustainable Development Goals, this article suggests that science education is central to the preparation and empowerment of young people to help reduce climate change and manage its consequences. Based upon my experience working with primary schools and my research in this area, I offer an approach to incorporating education on climate change and sustainability.

Keywords: Sustainability, disciplinary knowledge, substantive knowledge, purpose, global citizenship

A high quality science education fit for our future global citizens

'We are facing a global crisis in which the natural systems on which we depend are on the verge of breakdown' (Dasgupta, 2021:1). In agreement with the Sustainability and Climate Change Strategy for Education (DfE, 2022), educators have both the responsibility for and privilege of educating and preparing young people for a changing world, ensuring that they are equipped with the right knowledge, understanding and skills to meet the challenges they will face. UNESCO (2021) highlights the importance of rethinking education, emphasising the importance of education as the foundation for sustainable development. In this article, I argue that primary science education provides *'the foundation for understanding the world'* (DfE, 2013) and, as such, it is central to the development of such knowledge, understanding and skills.

In England, an Ofsted Research Review for Science published in April 2021 highlights factors that could contribute to 'high quality' science education, based on a wide range of research evidence (Ofsted, 2021). Whilst this Ofsted review is not phase-specific, Turner *et al* (2022) have developed a useful guidance document for primary schools, considering how the review relates to primary science practice. Whilst a renewed urgency to reconsider the important role of science education in sustainable development is paramount, drawing on this guidance can be considered in parallel.

The weakened status of primary science education as a core subject in England due to the focus on high-stakes accountability testing in English and maths motivated my research to explore how a global learning pedagogical approach to science could reignite its core status (Strachan, 2020). My mixed-methods research design collected quantitative data to measure stakeholder (senior leaders, leaders of science, teachers, advisers and pre-service teachers) attitudes towards global learning in primary science, whilst qualitative data, in the form of semi-structured interviews and case studies, explored how professional development could support the implementation of the approach. (This perspective article focuses on describing the approach, rather than presenting the data.)

The research described above highlighted that high quality science can be supported by sustainability education, giving it purpose and relevance. However, as Walsh (2021) suggests, the majority of teachers feel under-prepared for the task of putting climate change and sustainability at the heart of their teaching. I will therefore outline, from a practitioner's perspective, how we can embed sustainability in the primary science curriculum in a manageable way, contributing to a high quality science education fit for our future global citizens.

Figure 1. Key definitions.

Global Learning: 'A pedagogical approach that puts (science) learning in a global context, fostering critical and creative thinking, self-awareness and open-mindedness towards difference, understanding of global issues and action and optimism for a better world' (Bourn, 2016).

Sustainable Development Goals (SDGs): 'A collection of 17 interlinked global goals designed to be a blueprint to achieve a better and more sustainable future for all' (UN, 2015).

Five emerging issues for primary science teachers

Turner *et al* (2022) have helpfully identified five key issues from the Ofsted Research Review that are particularly relevant to primary science. These were: the importance of subject leadership and teacher expertise in science; the need to develop both children's substantive and disciplinary knowledge; carefully sequenced science learning to ensure that ideas are learned and applied; a purposeful selection of teaching approaches; and ensuring that teachers have sufficient subject knowledge to assess effectively. These five key issues will be used to frame my research-informed recommendations on how global learning and the Sustainable Development Goals (SDG) (Figure 1) can add purpose and value to primary science education.

1. Subject leadership and developing teacher expertise in science

Research findings from primary schools that trialled a global learning approach to primary science revealed that having a shared understanding of the value and purpose of the science ensured that it was given the '*planning time, recognition and support'* it deserves (Strachan, 2021). These findings are supported by the Primary Science Quality Mark (PSQM, 2020), who identified that having a clear vision and 'principles' for science learning enables the school's leadership to monitor, support and improve teaching, learning and assessment in relation to these principles.

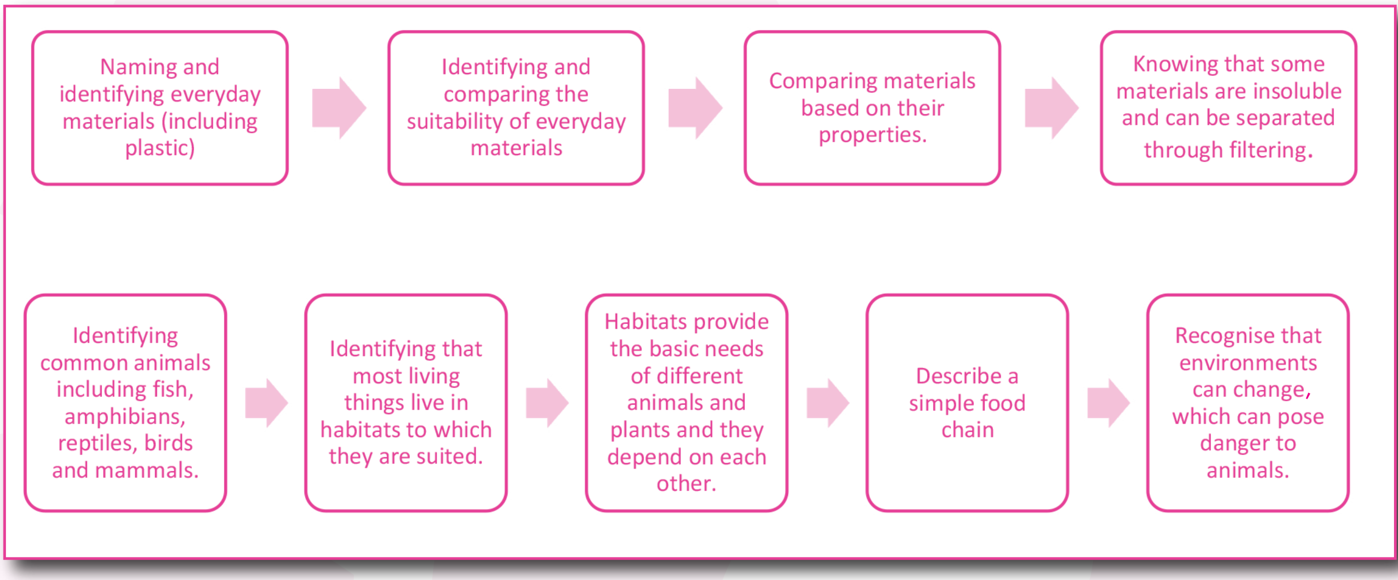
The science vision and principles from one such primary school (Figure 2) is underpinned by the wider school ethos of ensuring that all members of the school community are respectful, resilient and responsible global citizens. This includes the importance of equipping children with the knowledge and skills to solve problems with innovative solutions. For this school, supporting teachers to give real purpose to their science teaching has become a key area of development. This has included professional development on the integration of the SDGs in relation to each science programme of study.

2. Substantive and disciplinary knowledge

Considering global learning in relation to primary science education is based on the premise that enabling children to be global citizens of the future,

Figure 2. An example of a primary school's science vision and principles.

Figure 3. A progression of science concepts informing an understanding of the negative impact of micro-plastics on ocean biodiversity.



empowered to make responsible decisions and actions, requires a secure foundation of substantive knowledge (science content) as well as disciplinary knowledge (working scientifically). For example, we cannot expect children to make informed decisions about avoiding the use of plastic-based glitter so that it does not impact on ocean biodiversity, unless they have a secure foundational knowledge in relation to both materials and animals in their habitats developed across the years of their science curriculum (DfE, 2013). An example of such a progression can be seen in Figure 3.

Only with secure foundational knowledge can children begin to care about the effect of glitter going down the sink and how this might enter the food chain of ocean organisms. Schools who trialled the global learning approach were able to link science learning to real issues, global contexts and purposeful enquiries, ensuring that children were able to draw upon their prior knowledge of key concepts when considering responsible action, innovation and solutions. Findings showed that security of foundation knowledge in science enabled children to consider the consequences of their actions, e.g. the link between glitter in the oceans and animal survival.

Equally, empowering children to be agents of change (Bourn, 2021) enables them to develop an understanding of how to answer problems that can be solved using a range of enquiry approaches and through secure development of working scientifically skills. For example, 'how can we prevent plastic-based glitter and other micro-plastics entering ocean food chains?' can be supported through a range of enquiry approaches such as:

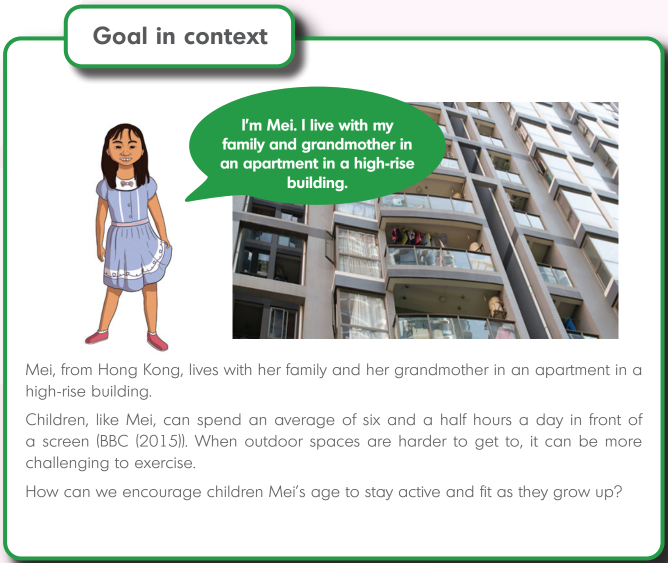
- **Grouping and classifying**: Which glitters/packaging are soluble and which are insoluble?
- **Comparative testing**: Will the type of material used as a sieve affect how much glitter is separated?
- **Secondary research**: Which alternative materials make the best plastic-free shiny glitter?

The Ofsted Review (2021) asserts that, when young people develop their disciplinary knowledge, they learn about the diverse ways that science generates and grows the knowledge through scientific enquiry. This can inform decisions (such as the choice to avoid using plastic-based glitter) as well as innovative action (such as the development of plant-based glitter or effective filtration inventions). Using purposeful science enquiries based on real-life issues meant that children were more engaged and findings were more meaningful (Strachan, 2020).

3. Curriculum-led and sequenced learning

Embedding global issues into science learning can provide context and purpose (Strachan, 2020); however, it is important that the core science knowledge and skills are not lost, something that

Figure 4. SDG 3 Good Health and Wellbeing Goal in context, from *Saving The Planet One Science Lesson At A Time* (Strachan & Davey, 2022).



can be an issue with theme-based learning (Barnes, 2015). Turner *et al* (2022) argue that developing a curriculum that is meaningful does not mean replanning the whole curriculum, but focuses on both 'what' is taught as well as 'how' it is taught, ensuring that key ideas are understood and applied.

As a result of my research conducted with case study schools, I offer a framework sharing 'how' SDGs can provide a context and purpose for science learning, as part of a sequenced, cohesive curriculum. An example of this is shown in Figure 4, where a learning experience draws on the 'good health and wellbeing' Sustainable Development Goal Three (SDG 3), to show the SDG in context (Strachan & Davey, 2022).

Strachan (2020), along with Nag Chowdhuri, King and Archer (2021), support the importance of providing relatable contexts for learning that link science learning to children's own interests and concerns. As Figure 5 demonstrates, the framework shows how the SDG can support children to develop a deeper understanding of core knowledge through connecting, critical thinking, purposeful enquiry and application.

As part of the continuity between and within topics in this example, children build on their knowledge of animals, including humans, from previous topics, such as their knowledge related to the human circulatory system in relation to SDG 3.

CORE (Planned curriculum knowledge and skill objectives)	- Recognise the impact of exercise and lifestyle on the way our bodies function. - Planning different types of enquiries to answer scientific questions. - Recording results with increasing complexity (taking repeats)
CONNECT (Explore different perspectives, different examples and ideas around the world)	Develop science capital by exploring sports and exercises practised by families and friends around the world. Exploring global issues: Why do some children not get enough exercise?
CRITICAL THINKING (Activities designed to elicit prior knowledge, retrieve and consider different ideas)	Which sport is best for our health? This is helping to develop children's argumentation skills.
CURIOUS (Purposeful enquiry drawing on planned development of working scientifically skills)	Comparative testing: Which exercises can increase our heart rate the most?
CREATE (Application of knowledge to responsible actions and problem-solving)	Design a new health game that can be accessed by all (applying findings from purposeful enquiry and developing understanding of the benefits of exercise on our heart, lungs and muscles).

Figure 5. Framework with SDG 3 example.

Figure 6. A global learning approach to 'Uses of Materials'.

Critical thinking: *'Do we need to wrap presents?'*
As highlighted in *Saving The Planet One Science Lesson At A Time* (Strachan & Davey, 2022), a vital component of being a global citizen is the development of critical thinking and questioning our own understanding and assumptions. Within science learning, offering opportunities for children to reflect on their own perspectives and recognise the possibility of multiple viewpoints will not only support a better understanding of the nature of science, but will also enable teachers to consider prior learning and experiences on which disciplinary and substantive knowledge can be developed further. The question above, for example, can help children to think about the materials that we use to wrap presents, where those materials come from, their properties, and how we could conduct enquiries to find more suitable, sustainable materials.

Creative thinking: *'How can we wrap presents without using plastic sticky tape and newly made paper?'*
Whether children have developed their knowledge and skills through direct teaching or enquiry-based learning, having the opportunity to apply these within problem-solving contexts not only allows teachers to assess understanding of knowledge and skills, but also empowers children to see how their science learning has purpose in relation to everyday decisions and global issues.

Connecting ideas: *'How do you wrap presents for celebrations in your community?'*
In relation to the Primary Science Capital Approach (Nag Chowdhuri *et al*, 2021), making sure that, as teachers, we start with the child, their backgrounds and experiences ensures that they see the relevance of science learning to their local and global perspectives.

Outdoor learning: *'Let's look at the trees that our wrapping paper comes from.'*
As recommended in the Dasgupta review (2021), enabling people to understand and connect with nature will empower them to make informed choices and demand the change that is needed.

4. Purposeful selection of a range of teaching approaches

Teaching approaches such as direct instruction and purposeful enquiry-based teaching can support knowledge and skills to be effectively developed. Alongside this, an approach to science learning that promotes an understanding of global issues and action and optimism for a better world, a range of critical and creative pedagogical approaches should be interwoven into science topics. Hoath (2020) and Willingham (2020) both encourage the promotion of opportunities for children to develop critical thinking skills, allowing them to draw on substantive knowledge to solve problems and raise new questions and discoveries. Figure 6 provides a suggestion for how a topic on 'materials' might use a global learning approach, incorporating different teaching approaches.

5. Teachers' knowledge and assessment

One of the key findings of my research with teachers, which involved supporting them to plan their science programmes of study using a global learning pedagogical approach, was their lack of confidence when making links between global issues and science programmes of study.
Supporting teachers to consider how they would assess science knowledge and skills within a global learning approach is important. This requires teachers to have secure science subject knowledge as well as an understanding of global issues.
A global learning approach to primary science education (Strachan & Davey, 2022) suggests that science learning experiences could include four learning outcomes:

- *A knowledge outcome*: I can identify suitable properties for a wrapping material.
- *A skill-based outcome*: I can plan an enquiry to find out which material is the strongest.

- *An attitude-based outcome*: I can choose a material that has less impact on the environment.
- *A reflection*: One way I think differently about present wrapping than I did before is…

Final thoughts

Both the research outlined in this article and my work as a lecturer and teacher educator of primary science have highlighted that, as a discipline, science has the potential to be central to the development of global citizens and their sustainable future. Teachers need leadership support and time to explore different ways of working and to bring real meaning to the curriculum that they deliver. A supportive community of practice can enable us to enrich science learning through sharing resources and activities that are both relatable and relevant. Using the UN Sustainable Development Goals gives us an opportunity to develop young people's scientific literacy, supporting children to use knowledge about the natural world and knowledge about science (OECD, 2013) when faced with real-life decisions and actions. We have the opportunity to support teachers as agents of change, developing a 'high quality' primary science education that can support children in an unpredictable world.

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The Primary Science Capital Teaching Approach: Building science engagement for social justice

● Meghna Nag Chowdhuri ● Heather King ● Louise Archer

Abstract

Although many children enjoy school science, not all of them feel that science is 'for them', especially those belonging to minoritised communities. This paper showcases the Primary Science Capital Teaching Approach (PSCTA), developed by researchers in partnership with primary teachers to support every child's engagement and identification with science. The PSCTA is a reflective framework, which provides practical ideas about how to embed an equitable approach in everyday science teaching in primary schools. The social justice framework supports children's voice, agency and active participation in the issues that matter to them – including climate injustice, racial injustices etc. Over the course of two years (2019-21), with the support of the Primary Science Teaching Trust (PSTT) and The Ogden Trust, the reflective framework of PSCTA was developed in partnership with 20 primary teachers across England. This article presents the framework alongside illustrative examples, insights and testimonials from participating teachers.

Keywords: Social justice, primary science teachers, science capital, professional development, science engagement

Introduction

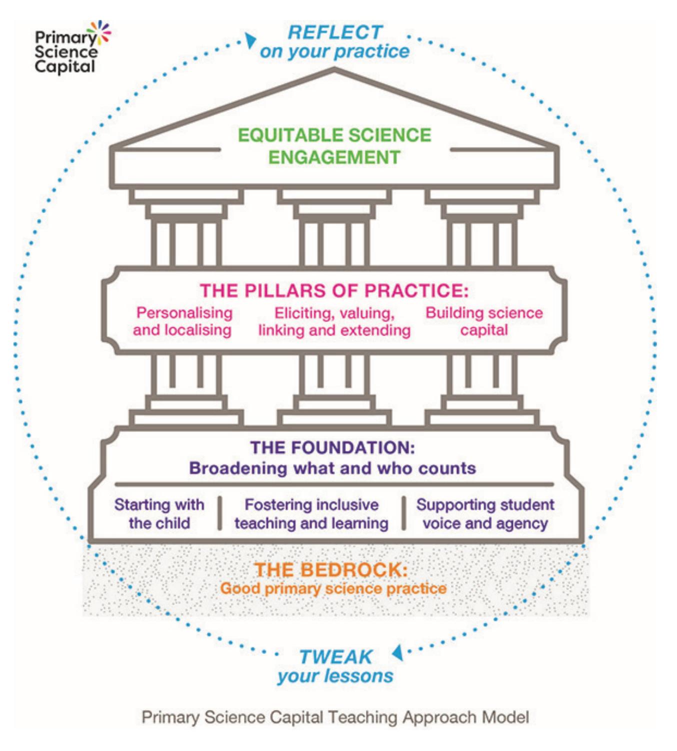
Studies show that despite increasing emphasis on making science more accessible, there continues to be marginalisation of children from underserved communities who feel science is not 'for me' (Archer *et al*, 2010). Social justice-oriented pedagogies, which acknowledge systemic inequalities, are powerful in redressing this imbalance (Ladson-Billings, 2013). This article introduces The Primary Science Capital Teaching Approach (PSCTA) – a social justice-oriented teaching approach that focuses on supporting underserved and minoritised children in developing their science engagement and identity (Archer *et al*, 2013, 2015, 2017). By focusing on children's assets (rather than viewing them from a deficit lens), it supports children's voice, agency and active participation in science (Barton & Tan, 2010). School science lessons thus become an opportunity for young people, and their teachers, to be empowered to act on all sorts of societal issues, from local environmental concerns to climate injustice and global sustainable living. Over the course of two years (2019-21), with the support of the Primary Science Teaching Trust (PSTT) and The Ogden Trust, the reflective framework of PSCTA was developed in partnership with 20 primary teachers across England. This article outlines the core elements of the approach, along with examples from teachers' practice.

The PSCTA

The Primary Science Capital Teaching Approach (PSCTA) is based on cycles of critical professional reflection and intentional action, in which teachers make small changes to their pedagogy aimed at challenging and redressing imbalances in power and privilege. The PSCTA is a culmination of work that started in 2013 with secondary schools (Godec, King & Archer, 2017), and has since been developed with primary schools in England between 2019-2021 (Nag Chowdhuri, King & Archer, 2021).

As detailed in Figure 1, the PSCTA model consists of three core components: *bedrock of good science teaching*, the *foundation*, and three related *pillars of practice*. The approach is then enacted through iterative processes of professional reflection in which teachers '*reflect and tweak*' their practice. The following sections detail each of these elements and present examples from teacher practice.

Figure 1. Primary Science Capital Teaching Approach Model.



Bedrock of good science teaching

The approach is based on a bedrock of good primary science teaching, as informed by the contemporary science education research literature, including elements such as learner-centred learning (Dole *et al*, 2016; Weimer, 2013), play-based learning (Fleer, 2019; Jahreie *et al*, 2011), enquiry and investigation-based teaching and learning (Minner *et al*, 2010). Our approach builds on and extends these elements through a specific focus on equitable science engagement.

The foundation: broadening what and who counts

The foundation is based on broadening what we value in science teaching and learning, and challenging (rather than reproducing) traditional representations of science as white, male, hierarchical, elite, etc. (Carlone *et al*, 2015; Chaffee & Gupta, 2018; Dawson, 2019). This foundation seeks to value all students and focuses on changing the way that we teach science in order to better engage and support all children, but particularly those from under-represented communities. The approach suggests three practical ways of achieving this: starting with the child, fostering inclusive teaching and learning, and supporting student voice and agency.

- ***Starting with the child*** critically reorients the lens of science pedagogy by centring the child. This simple shift in lensing supports shifts in teachers' thinking by focusing on what children already know and care about, rather than what they ought to know. For example, the following extract describes how Mr. Collins reorientated his lessons based on what he actively noticed about the needs and experiences of children in his Year 4 class (age 8-9):

'Mr Collins explains that the original un-tweaked lesson was on puddles, but he tweaked to personalise more. He had noticed that lots of children were missing school in the morning recently when it was wet (it had been very wet recently with several days of torrential downpours) because their clothes hadn't dried out properly. So, he changed the lesson plans for this series of 3 lessons to start with an experiment in which the class wetted shirts in water and then hung them up in different places in the school, then went back to see how much liquid was left (how much they could squeeze out and measure) to work out how much had evaporated. The children really seemed to respond to and engage with this and enthusiastically recall it in class. Children enthusiastically and knowledgeably shared their experiences – they knew how to disperse steam and dry clothes and could connect with the science behind it' (Field notes, October 2019).

- ***Fostering inclusive teaching and learning*** encourages teachers to reflect critically on power dynamics within their classrooms and identify pedagogical ways of disrupting these. This aspect of the foundation challenges the reproduction of social disadvantage (e.g. by gender, race, class, disability and so on) that permeates science classrooms. For instance, Ms O'Connors recognised that some girls in her Year 4 class preferred to have more time to respond to questions, rather than being expected to put up their hands and answer questions immediately. By broadening the ways in which she encouraged children to contribute, Ms O'Connors challenged the dominant masculine ways in which science is often performed (Archer *et al*, 2016):

'Ms O'Connors paid attention to two girls in her class, who she believes do not engage in science lessons. By providing multiple ways of student expression (providing time for all children to write their answers/responses on Post-its) she encouraged all children to contribute. She then focused on the

responses of the chosen girls. One of the girls used a metaphor for understanding canine teeth as 'vampire teeth'. Ms O'Connors appreciated the contribution and referred back to it and linked it to the teaching' (Field notes, January 2020).

■ ***Supporting student voice and agency*** recognises that the goal of science learning is not just the acquisition of knowledge, but also to empower children to be able to use science more widely in their lives, for example, as critical thinkers and active citizens. This is particularly important in climate education, where students' agentic approaches to climate change can empower them to take action (Trott, 2020). This form of agency-based pedagogy can support children's critical understanding of their own and their communities' needs, struggles and injustices (Schenkel & Barton, 2020). The following example shows how Ms Lessing helped Year 3 children (age 7-8) to develop ownership of their learning and use their expertise to help others and take action:

'Ms Lessing goes to the children's local park and takes a photo of the puddles on the field. It generates spontaneous contributions from a range of children. Children then write letters to their local council to share their knowledge about what sort of soils would work best for a new all-weather football pitch. This enables them to see that they do have agency and can be recognised as knowledgeable producers of science' (Field notes, January 2020).

Pillars of the PSCTA

Learners' engagement, experiences, aspirations and identification with science are shaped by the extent to which a given setting recognises, values and legitimises who students are and what they bring with them (Archer *et al,* 2015). Thus, the purpose of the pillars of the approach (which often overlap) is to strengthen students' relationship, identity and agency in relation to science. The pillars provide practical ways of connecting science with individual students' lives: personalising and localising; meaningful eliciting, valuing, linking and extending; and building science capital dimensions.

■ ***Personalising and localising*** is a technique to help teachers connect science content to students' own lives, experiences and understandings. Context-based science learning has been important to science education, but it often focuses on application, comprehension and utility of science in everyday life, rather than foregrounding cultural, personal and political aspects of children and schooling (Sevian *et al,* 2018). Accordingly, this pillar prompts teachers to tailor science content specifically to the children in their class and develop a critical understanding of the cultural and political aspects of children's personal lives and their communities.

For example, the following extract involves Ms Wilson reflecting on a Year 3 lesson on soils, in which she wanted to make sure that children who did not have access to a garden were not disadvantaged by this, or seen as 'lacking'. She decided that accessing soil for the lesson would not be linked to this privilege. She also tried to personalise the task in an inclusive way:
'...asking them to bring in a soil sample in a little bag...was effective but also because I talked them through the fact that I wanted them to get it from near their house...we wanted to sample it near their house but not their own garden. Thinking about the children's circumstances is really important and making sure that what you're asking of them is not going to be a barrier' (Ms Wilson).

■ ***Meaningful eliciting, valuing, linking and extending*** takes personalising a step further by supporting children to bring their own knowledge and understanding into the classrooms. Teachers develop techniques to elicit responses (meaningfully) from children and then value them and link these to the curriculum, extending where appropriate. For example, Ms Rizwan was teaching the classification of animals and wanted to explore the scientific method of classification. She elicited responses from students, valued these respectfully and used that knowledge to talk about the topic:

'Children in Ms Rizwan's Year 6 class were from various different cultural backgrounds and the teacher wanted to value and celebrate their cultural experiences. During a lesson on 'classification of animals', she began by asking students about the different types of sweets that they eat in their families to highlight how these can be sub-classified. Gulizar named her favourite sweet as halva. Ms Rizwan valued Gulizar's contribution by giving recognition and importance to what she was sharing. She then linked this to the topic of classification and

*asked if she knew of different types of halva (e.g. red/white, sticky/hard). The teacher drew up a classification chart on the board using Gulizar's example. As the lesson proceeded to cover the classification of animals, the teacher referred back to Gulizar's example to help the children understand the topic' (*Field notes, November 2019).

- ***Building science capital dimensions*** focuses on the dimensions developed by Archer *et al* (2015) based on sociological conceptions of capital (Bourdieu, 1986). These dimensions determine to what extent learners find science is 'for me'. The components of science capital include: scientific literacy, science-related dispositions/preferences, knowledge about transferability of science in the labour market, science-related behaviours and practices (consumption of science-related media), participation in out-of-school science learning contexts), science-related social capital (knowing someone who works in a science job, parental science qualification, talking to others about science, future science aspirations, science identity). Through this third pillar, teachers are encouraged to explicitly ensure that their teaching supports and builds scientific engagement through these dimensions. For example, Ms Wilson showcased diversity among scientists by linking science to the jobs that children in her class could see around them:

'During the lesson on "What Is Soil?", we did a little survey of children's parents' occupations. One child's father is a builder and that connected him to the lesson and it seemed to boost his confidence. When I presented different jobs related to soils to the class, I made an effort to put lots of pictures of diverse people and those images really helped children see that soil scientists can be different types of people from different backgrounds' (Ms Wilson).

Implications

The PSCTA supports teachers' critical professional reflection about inequities and injustices that are prevalent in science education, and provides a model that can be applied to any curriculum. It is enacted through an iterative, ongoing process of reflection and tweaking, which over time can lead to shifts towards a social justice-oriented pedagogical mindset. By valuing children's identities, experiences, histories and changing how school science is represented, taught and experienced, the practice supports teachers to change their science practice. PSCTA supports teachers to use science as a vehicle for supporting children's voice, agency and active citizenship, rather than seeing the value of learning science as being only the acquisition of knowledge and/or the supply of future scientists. In other words, the approach supports teachers in critically reflecting on children's lives, their social conditions and linking those with the science being taught. When embedded into the teachers' practice, this has the potential to become a powerful tool for raising critical social issues that are meaningful for students – including climate injustices, racial inequalities and socio-economic issues. PSCTA can be a powerful way of bringing about change in science-related practices in primary schools across the UK.

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- Use UK spelling and single 'quotes' for quotations.
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- Include information about yourself (e.g. job title, email) at the end of the article.
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- For in-text references, use (Author, Date) e.g. (Johnston, 2012). If there are three or more authors, the first surname and '*et al*' can be used.
- Include a reference list (examples below), set out in alphabetical order.

Referencing examples:

Book

Russell, T. & McGuigan, L. (2016) *Exploring science with young children.* London: Sage.

Chapter in book

Johnston, J. (2012) 'Planning for research'. In Oversby, J. (Ed) *ASE Guide to Research in Science Education.* Hatfield: Association for Science Education.

Journal article

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