International Journal of Science Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

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INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2022.2089366

Embodying science: the role of the body in supporting young children's meaning making

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ABSTRACT

Primary school science emphasises hands-on interactions, but little is known about how the sensorimotor experiences these interactions provide shape children's science ideas. Early interactions with science need to be engaging as these shape children's developing attitudes towards science and themselves as science learners; however, these activities need to go beyond engagement to set children up with the resources they need to develop and deepen their learning. Findings demonstrate that designing science activities and the discourse they are situated within through an embodied lens can support children's meaning making by providing them with sensorimotor experiences to draw upon, valuing their lived experiences and being open to their multiple modes of communication. Such body-based activities offer alternative routes into learning which are playful, engaging, and dynamic, whilst making concrete connections between children's interactions and the development of complex science ideas.

ARTICLE HISTORY
Received 8 October 2021
Accepted 9 June 2022

KEYWORDS
Embodied learning; primary science; air resistance; multimodal discourse

Introduction

While STEM pedagogies, particularly for young children, value the role of doing and place emphasis on children's active processes of meaning making, the specific ways in which these sensorimotor experiences can effectively shape and support young children's science learning is less understood. According to Bianchi et al., (2021) 'Children experience 'fun' science activities that fail to deepen or develop new learning' (p. 6). While 'fun' is centrally important to learning, and critical for fostering motivation, engagement and continuing interest (e.g. Leonard, 1987; Ryan & Deci, 2009; Willis, 2007), it is imperative that we deliver positive and engaging science activities which also provide children with cognitive resources to extend their science meaning making. This paper draws on theories of embodied cognition to speak to this, by examining the role of purposefully designed embodied activities in young children's meaning making and discourse around a science topic (air resistance). Activity designs grounded in embodied learning theory (informed by embodied cognition) can provide meaningful and engaging

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interactions with STEM, by creating learning activities which make concrete connections between children's embodied actions and the underlying science ideas. This approach fosters children's STEM 'knowledge' development and engages them in STEM processes, such as critical thinking, inquiry and problem-solving, whilst also broadening what science looks like and positively impacting their perception of and disposition towards STEM (Evangelou et al., 2010).

This paper focuses on the implementation and analysis of a set of purposely designed outdoor science activities to support young children's meaning making around air resistance, that drew on three core principles from embodied learning (lived experience, meaning congruency and integrated physical learning tasks) (Thomas Jha et al., 2020). It considers how different sensorimotor experiences supported children's engagement, embodied meaning making and discourse around the topic of air resistance. Specifically, we address two questions:

(1) How do different embodied experiences of air resistance shape the way children think about this concept?
(2) How does this shape the way children use their bodies to communicate ideas of air resistance?

This paper demonstrates how interactions grounded in embodied learning can better leverage the role of the body to effectively support children to both acquire and communicate science ideas. Activities designed through an embodied lens importantly maintain 'fun' interactions whilst also providing children with body-based resources which support in-the-moment and ongoing science knowledge development and process skills.

Background

Embodied cognition

Within the embodied cognition paradigm, the notion of enactive cognition proposes that understanding is actively constructed through dynamic interaction between body, environment and others (Gallagher & Lindgren, 2015; Varela et al., 1991). This theoretical perspective is grounded in research from both neuro-anatomical and biological processes; and sensorimotor (or physical) experience (Garbarini & Adenzato, 2004). Neuroscientific research shows evidence for direct links between action and perception at the neural level (e.g. Gallese 2005), for example, through direct perceptual coupling between object shape and function via mirror and canonical neurons, while our interrelated multi-modal sensory systems (vision, hearing, touch, and action) contribute to our understanding and perception of the world (Smith and Gasser, 2005).

From an enactive cognition perspective, active participation in developing meaning around interaction is emphasised: 'The softness of a sponge is not to be found 'in it' but in how it responds to the active probing and squeezing of our appropriate bodily movements (e.g. with the fingers or the palms of the hand)' (De Jaegher & Di Paolo, 2007, p. 489). Embodied learning argues for the importance of meaningful sensorimotor experiences in providing children with an embodied toolkit of resources (independent of language skills or subject specific vocabulary) which they can draw upon to develop and express ideas through gesture (e.g. Barsalou, 2008; Goldin-Meadow et al., 2001; Alibali & Nathan, 2012; Gallagher & Lindgren, 2015). The specific sensorimotoric experiences are important in shaping the kinds of gesture (sensorimotoric representations) children use in explaining their understanding (e.g. Thomas Jha et al., 2021). With this in mind, three core principles from embodied cognition informed the iterative design of science activities for young children from an embodied learning perspective: '*lived experience*', *meaning congruency*, and *integrated physical learning tasks* (see Thomas Jha et al., 2020 for activity design process). The notion of '*lived experience*' argues that we make sense of the world based on our sensory experience, which is modified and shaped through ongoing experiences. Activities grounded in 'lived' experiences are likely to have greater resonance for children (Archer, 2018), and more likely to lead to positive attitudes towards STEM. *Meaning congruency* (Hald et al., 2016) identifies the important role of motor and perceptual experiences in meaning making. Research suggests that bodily movement that is semantically related to the learning content and *integral* to the task (rather than incidental to it) (Skulmowski and Rey, 2018; Wilson & Golonka, 2013) better supports children's meaning making and discourse.

The design of the learning tasks aimed to develop integrated physical learning tasks, foregrounding 'felt' experience that fostered movement and wider perceptual experiences in meaning congruency. This paper examines how the different activities provided embodied experiences and how they differently shaped children's scientific meaning making and communication.

Primary school science

An early foundation in science education is essential to nurture 'curiosity and teach essential skills, including enquiry, observation, prediction, analysis, reasoning and explanation' (Wellcome Trust, 2014). Attitudes towards science and self-attitudes around capabilities for learning science are established early (Hachey, 2020). Primary science needs to not only offer fun and engaging activities, it also needs to provide children with opportunities to develop and deepen their learning (Bianchi et al., 2021).

Recent work on students' attitudes toward science (Andersson & Gullberg, 2014; Archer, 2018) places emphasis on the importance of eliciting students' knowledge and experience, valuing these, and linking them to science content. Using an embodied lens speaks to this, by foregrounding movement and felt experience as new processes for engaging with science. It places the child at the centre of the discourse and supports them to make meaning through reflection on their own experiences.

The multimodal nature of sensorimotor experiences offers alternative modes of knowing from verbal or written transmission, influencing how students make sense of, and thus construct, different forms of knowledge (Vosniadou et al., 2004). Different disciplinary research (e.g. neuroscience, psychophysics, psychology) highlights how different (sensory) modalities influence children's learning. For example, children typically use haptic information to perceive object the size, and visual information for understanding orientation (e.g. Gori et al., 2012; Gori et al., 2014).

Science teaching and learning is inherently multimodal (Kress et al., 2001; Yeo & Nielsen, 2020) through the use of drawings, pictures, tables graphs etc … Science education research also suggests that students use body motions to make and revise predictions, make visible the invisible parts of a physical situation, and convey ideas they cannot yet describe in words (Crowder, 1996; Roth & Welzel, 2001). Other research foregrounds the role of the hands through interaction with physical apparatus in fostering science thinking about balance (Metz, 1993), bridge building (Thornton, 1999) and more broadly to think through and develop their ideas (Papert, 1991).

Given developing understanding of the role of gesture in children's reasoning and communication (e.g. Clark & Lindsey, 2015; Roth & Lawless, 2002), gestures themselves become ways of continuing to think with objects, even in their absence. Roth and Welzel (2001) argue that: 'gestures arise from the experiences in the phenomenal world, most frequently express scientific context before students master discourse, and allow students to construct complex explanations by lowering the cognitive load' and 'provide the material that 'glues' layers of perceptually accessible entities to abstract concepts' (p.111).

This paper examines the role that particular sensorimotor experiences play in young children's meaning making in situ and in later reflection. We frame science as doing – emerging from physical processes and experiences as well as through multimodal discourse around these practices (Siry et al., 2012).

Air resistance

Any object in motion through air is subjected to a resistive force to that motion termed *air resistance*. This force is affected by variables including the surface area of the object, its volume and its speed of motion. The unseen nature of air brings challenges to science learning, particularly around how we make this 'visible' and salient, and foreground key relevant ideas. Smith & Peacock (1992) found that primary school teachers themselves retain misconceptions of the effects of gravity and air resistance on falling objects. We expected that this experience would be children's first structured introduction to the concept of air resistance, as the topic is not addressed by the curriculum until Year 5. We hoped that this experience might act as a foundational experience which children could build on when this topic was delivered formally. Given their age, we did not expect children to emerge from the tasks with a fully formed concept of *air resistance*, but rather that these activities would provide complementary experiences which drew attention to relationships/factors which underpin this concept, such as: when an object moves through air its movement is slowed by the air around it; the shape and size of the object will influence the extent of this slowing 'force'; you can feel the effect of this 'force' by moving objects through air, or observing objects being moved by air.

Air resistance is introduced in primary school from Year 5 onwards through activities like observing falling skydiver toys (outlined in the English National Curriculum). However, research suggests that such activities can support misconceptions, with children tending to believe that heavier objects will fall faster. Bar et al. (1994) found that between 7 and 12 years of age the majority of children predicted that a heavier object would hit the earth faster than a light object, whilst younger children considered weight to be a less relevant factor in an object's fall. Baker et al. (2009) found that six and eight-year-old children thought that heavy objects would fall faster. They concluded that older children were more likely to have persistent incorrect ideas about the weight-speed interaction. In this paper we explore activities that offer different physical ways of engaging with air resistance. Noble (2007) suggests that embodied experience of air resistance may indeed support children's meaning making. They found that body motion, sensory feedback and speech collectively support children's developing ideas around how parachutes work, and 9- and 10-year-olds used object manipulations and gesture to support their discourse around parachutes. This study builds on this, comparing how the standard skydiver activity supported children's developing notions of air resistance, with three other activities which provided different body-based ways to experience air resistance.

Methodology

The study took a qualitative case study approach since it sought to explore and better understand the complexity of children's in situ meaning making.

> Qualitative research is a situated activity that locates the observer in the world . . . qualitative researchers study things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them. (Denzin & Lincoln, 2000, p. 3)

As such, it lends itself to exploring and examining how experience is created and given meaning through participant observation and semi-structured interviews. This paper focuses on the evaluation of five purposefully designed activities to bodily engage children with concepts related to air resistance (see Thomas Jha et al., 2020 for design process).

Participants

Twenty-six children aged 5–6 years participated in an in-situ constructive dyad interaction design (Benedikte et al., 2005), to promote discussion, collaboration and interaction. The research was approved by UCL ethics committee; number REC 957. All participants had informed parental consent and each assented to take part. The study took place in the outdoor playground of a UK primary school during school hours.

Suite of activities

The activities were designed to provide children with an opportunity to feel and see the effects of air resistance on different materials and through different actions. Children were offered opportunities to make links between size, force and effort in relation to air resistance, through their felt and observed experiences. As an introduction to the session children were asked to observe and describe the effect of wind on the motion of a ribbon. They then took part in four activities in a prescribed order.

Running with different sized cardboard sails

The aim of this activity was to give children a different felt sensation of resistance to their motion when running with two differently sized cardboard 'sails' (one large and one small), and under different states of motion (stationary vs. in motion). Children were asked to hold one of the sheets at the edges, with the cardboard in front of their bodies (Figure 1(a)). They took turns to run to a designated end point, enabling them to observe their peer's motion. Children completed two runs before swapping 'sail' sizes. The activity was designed to give children an opportunity to link their felt bodily

Figure 1. From left to right: (a) Running with Cardboard Sails; (b) Running with Wearable Parachutes (small size pictured); (c) Dropping Toy Skydivers; (d) Pulling Toy Skydivers.

experience (e.g. the push force experienced on the sail) to the material size (surface area), and to observe the impact of their motion on the shape of the sails during the activity. Between each run children were encouraged to reflect on their experience and consider how the previous or next run might differ.

Running with different sized wearable parachutes

The aim of this activity was to give children a felt sensation of resistance to their motion given different sizes of parachutes, and different states of motion (stationary vs. in motion). The activity was designed to give children an opportunity to link their felt bodily experience to the variable (parachute size) which influenced this felt sensation, for example linking the size of the parachute to the amount of effort needed for them to run. Children wore child-sized resistance parachutes adjusted to have two different surface areas (large/small) (Figure 1(b)). They ran individually from a designated start to end point twice, before switching parachutes (start and end points were the same as for the cardboard sails). When stationary, children observed their peer running. Between each run children were encouraged to reflect on their experience and to consider how the previous or next run might differ.

Dropping toy skydivers

This activity is traditionally used to introduce the concept of air resistance, but does not give children a felt experience of air resistance. Here children could observe the motion of two differently sized toy skydivers as they travelled through air, allowing them to explore the impact of size on motion/speed, and the impact that motion has on parachute shape. Children had two toy skydivers matched for colour but differing in size, as well as a weight (plastic skydiver figure) without any parachute attached (Figure 1(c)). Children initially dropped the parachutes and weight sequentially, and then dropped pairs of skydivers simultaneously. The relationship between surface area, shape and air resistance was only available through observed motion. Children were encouraged to reflect on their experiences between each release and consider how the motion of the skydiver differed and the factors which might contribute to this.

Pulling toy skydivers

Using the same skydivers, children explored ways of moving them through air when holding the plastic figure attached to the parachute cord (Figure 1(d)). The aim here was to enable children to simultaneously feel the resistive force generated by differently sized parachutes in motion, and to observe how these forces and the shape of the parachutes changed as they moved through the air. Children were asked to reflect on their felt and observed experience and were encouraged to explore ways of moving e.g. running, jumping, rotating their arms/ bodies, pulling simultaneously or sequentially, leading to a range of potential sensorimotor experiences. Table 1 shows each activity linked to key sensory experiences and potential learning outcomes.

Procedure

The activities were led by a researcher-practitioner pair who structured the tasks, provided practical support and prompted conversation around the activities. One pair of children at a time completed all four activities in a prescribed order; however, each activity allowed children room to explore and investigate. Total activity sessions varied from 15 to 20 min.

Following their interaction each pair were interviewed in a separate classroom by a researcher who had not been involved in the activity session. Children were seated adjacent to one another, with floor space in front of them to allow for bodily movement and expression. The semi-structured interview aimed to elicit children's thinking around air resistance, drawing on their felt experience and their observations. Questions were structured around each of the activities and children were encouraged to describe what they did, what they could feel, what they observed and how these sensations and observations differed across the activities. Interviews lasted between 10 and 15 min.

Data collection and analysis

All interaction sessions were video recorded using one static camera, and a roaming video camera to capture the overall activity including children's body positioning and

Table 1. Each activity linked to the sensorimotor experience and potential learning outcomes.

Activity	Key sensory experience	Potential learning outcomes
Running with cardboard 'sails'	Whole body felt experience of air resistance Observable change in shape of sail during motion	Relationship between size (surface area) and effort/speed Relationship between shape of 'sail' and its motion through air Relationship between direction of motion and direction of resistive force
Running with wearable parachutes	Whole body felt experience of air resistance Observable change in shape and position of parachute as another child runs	Relationship between size (surface area) and effort/speed Relationship between shape of parachute and its motion through air Relationship between direction of motion and direction of resistive force
Dropping toy skydivers	Observe skydivers falling at different speeds, through different trajectories and changing shape	Relationship between size (surface area) and speed Shape of skydivers influenced by motion through air Influence of wind speed and direction on skydiver motion
Pulling toy skydivers	Felt experience of moving skydivers through air allowing for comparison across sizes Observe skydivers changing shape as they moved through air	Relationship between size (surface area) and speed Shape of skydivers influenced by motion through air

movements and closer recording of interactions between child pairs and between children and researcher/practitioner. Interviews were video recorded using a static camera that captured the space around the children, to record any bodily movement during communication. Multimodal transcripts were generated for all interactions and interviews, capturing children's speech, gestures, gaze, and action.

Analysis of eight hours of video data of interaction and post-interviews focused on how children used their bodies to explore and make meaning, whilst supported by the designed physical environment, and how children communicated ideas about their felt and wider perceptual experiences during the subsequent semi-structured interviews. Given this, analysis drew on a multimodal analytical approach (Jewitt, 2009) to focus on action, gesture, gaze and speech, bringing the body into the centre of the analytical frame. This approach is beneficial in identifying how bodily experience is brought into dialogue with science ideas, noting the relationship between embodied action and language, and identifying the use of spontaneous representational gesture (Hostetter et al., 2007; Thelen et al., 2001). Two researchers analysed the data through a repeated and iterative process. Firstly, all video data was transcribed using multimodal descriptions of interaction and communication (gesture, action and speech, including screen shots of relevant action or gesture). Secondly, patterns of interaction and communication across participants were identified and formed the basis of the key themes emerging in children's conceptualisation and communication around air resistance (e.g. air flow, shape, size, effort, weight, flying*)*. Finally, key thematic episodes were identified from the video and were collated to provide evidence for the findings.

Findings

In this section we describe the children's experiences and their reflections on these experiences for each activity. We consider how these activities supported children's embodied interactions with science in terms of fostering engagement, developing learning and supporting communication. Quotes are reported from particular children (using pseudonyms) but are illustrative of children's discourse more broadly.

Running with cardboard 'sails'

Children were keen to interact with the activity and explore ways of moving with the cardboard sails. During interviews, children were animated in their recollections and needed little prompting. The activity drew children's attention to the way that air flowed around and onto the sail and their own bodies, the shape of the sail and the different resistive forces generated.

The majority of children reported a felt sensation of **air flowing** between the edge of the sail and their hands. For example, '*the big one felt like only the air was coming through the side. And when I was running, I felt like the air was going past me*'. (James). They expressed both a felt, embodied experience of air flow generated by their own motion through air, and observed the effect of this air flow on the changing **shape** of the sail as they ran with it, curving or bending towards their bodies. For example, '*The cardboard was like blowing and it was like nearly folding*' (Monique). The experience of air flowing around their body occurs whenever they move; however, running with the sail made the relationship between the size of the material and the resistive force encountered more apparent, enabling children to develop understanding of the causal link between these variables.

Children readily compared their experience of running with the large versus the small sail and the difference in resistive force that this generated. The way in which they collectively discussed this force drew on multiple notions of effort, weight and push. Children talked about the difference in **effort** required to run with the sails, for example, '*The small one was kind of easy because it caught less air than the big*' (Benjamin). Children also mentioned the **effort** required to keep hold of the large sail, for example, '*I was holding it really, really tight*' (Freddie). Some children suggested one sail was '**heavier**' than the other, for example, Asha said '*the wind like … like … . Slams it in, like the wind gets much more bigger and bigger and then it gets much more heavier and heavier to hold*'. When probed children elaborated that this 'heaviness' was not simply a difference in weight between the two pieces of cardboard but related to the force they experienced when running with the sails as can been seen above and from Monique; '*I mean the small one would be even heavier if it was windy and, if it wasn't windy, it would be even lighter*'. Some children talked about the sail **pushing** them, e.g. '*then the air pushes you back*' (James). These ideas all link to children's observations and felt experiences of resistance against their movement, caused by trying to run with the differently sized sails, and provide different ways for children to engage with and communicate their developing understanding of the causal relationship between the size of the sail and the amount of resistance generated.

This (and the wearable parachute) activity purposely minimised any conflicting influence of wind direction, by asking children to only run into the wind rather than against or across it. This design choice was motivated by; ensuring the key variable of size of sail/parachute was salient (as suggested in previous research, e.g. Kloos et al., 2012) and the additional variable of wind direction and to some extent wind speed minimised; and safety concerns about children becoming entangled in the wearable parachutes. While the wind speed in the playground was variable across children's runs, they did not report noticing a difference in felt or observed experience due to this, and instead attributed any difference to the sails. Children appeared to interchange the words 'air' and 'wind' to refer to similar ideas of air flow and resistance. Despite not observing or reporting a felt difference in resistance due to wind variance, children were able to combine their prior experiences with their experience in the task to make suggestions of what might happen on a windier day. Generally, children conceived of increased wind speed as increased 'air', which would lead to the feelings and observations they reported being enhanced. Children used the sensorimotor resources they gained from this experience to support this theorising, drawing on their bodies through gesture and re-enaction, for example, from Aaron's interview (Figures 2 and 3).

Aaron:	With the red square thingies it was like really hard, 'cause I was like urrgghhh … . And with the little one I was like this pfft pfft pfft pfft.
Researcher:	So what were you having to do when you were running with that big one?
Benjamin:	We were trying to, we were having to run to see if it was harder or slower

Later Aaron uses this process of re-enaction to help him think through and express his ideas about a hypothetical scenario.

Figure 2. Aaron re-enactes running with the large sail. He creates a similar space between his hands as in the task. He then leans his body forwards and positions his hands as if they are pressing against an invisible surface. He moves forward slowly keeping his hands and body in a similar posture while emphasising the effort required to move through action, facial expression and vocalisations.

Figure 3. Aaron positions his hands as if holding onto the edges of the 'big' cardboard sail, he leans his body forward and makes slow plodding steps to emphasise the effort needed to move forwards against the opposing force generated by the sail on this theoretical 'super windy' day.

Researcher: What do you think would happen if there had been much more wind today?
Aaron: Well if there was a big one and it was like super windy, it would be like … . [Aaron accompanies this with a re-enaction as shown in Figure 3].

Through a combination of speech and whole-bodied re-enaction (Figure 3), Aaron captures the notion that less effort was required to run with the smaller sail, enabling him to run faster. This lived experience was so visceral and body-based that it seemed almost impossible for him to express his experiences without re-engaging his whole body. He seamlessly interweaves modes of communication (bodily, verbal language and verbal sounds) to compare and contrast the sensation of resistive force on his body, impeding his motion. With minimal use of 'science' vocabulary, Aaron depicts the key causal relationship between the size of the sail and the air resistance it generated. This allows him to engage in ongoing discourse around the notion of air resistance, helping to develop his understanding. He uses his body to both engage with and communicate his thinking around a hypothetical scenario, allowing him to go beyond his experience of the activity, and combine this with his prior experience (e.g. of wind).

Overall, this experience promoted discourse around the concept of air resistance and supported children's causal reasoning; however, there were instances where children expressed some confusion. Monique described the large sail as '*pushing us where we had to go*' and accompanied this with a forward moving push gesture. This activity provided children with felt and observed experiences which could support them to identify and discuss key factors around air resistance, but for children to develop farther it would need to be situated within an ongoing discourse, introducing children to the associated vocabulary and addressing any arising confusion.

Running with resistance parachutes

This activity was particularly engaging and created a lot of excitement and discussion. As with the cardboard sails, children readily compared the experience of running with the large versus the small parachute and the difference in resistive force that this generated. They approached this using similar language (e.g. heaviness, effort, pushing/pulling and changing shape), often drawing on several of these notions.

Children reported that more **effort** was required to run with the large parachute, for example, 'The big one felt like its holding you, stopping you from running and the small one was more easier so you could run actually with it, it wasn't holding you' (Jacob). And that they had a felt sensation of being **pulled** or held back by the larger parachute in particular, for example Katy reflected on running with the larger parachute, 'It feeled like it was harder. Something was pulling me'. They often connected this sensation with the idea that the larger parachute 'caught more air'.

Again, a number of children described the larger parachute as feeling **heavier**, and when probed clarified that this heaviness was only experienced whilst in motion:

Shweta:	'cause the big one it was so heavy, you had to kind of run for it. It was so heavy
Researcher:	Did it feel heavy when you stood still?
Shweta:	no it was like light
Researcher:	So if you were running it felt heavy?
Shweta:	yes, from the wind

Children also noted how the shape of the parachute changed when they were in motion (Asha's gestures in Figure 4 and accompanying speech below):

Asha:	and when I looked back the small one was like … .not puffing … it was a bit small
James:	but the big one was puffing out

Motions behind her

Turns her body as if looking upwards to the parachute

Uses her hands to create a curved shape – emphasizing “puffing”

Jumps from her seat and gestures upwards to demonstrate how the big one puffed out “like”

Figure 4. Asha describes how the small parachute changed shape as she ran. She turns her body as if to look at the parachute and then back to the interviewer to demonstrate how the small parachute did not ‘puff’ as much as the big one. Finally, she jumps up from her seat, showing how the large parachute ‘puffed’ and rose higher.

Asha: Yeah like

A number of children reported a felt sensation of ‘**flying**’ or feeling like they were about to ‘fly’, ‘*It felt like … like we were flying!*’ (Monique). This felt sensation was unique to this activity, and more frequently reported for the large parachute:

Lily: the little parachute just had a little bit of air and, the big parachute felt like I was flying.
Lily: Yes, and the little one had less air than the big one.
Lily: The air go … the air went under the parachutes and, then, we was about to fly.
Lily: And I was like … it was like so hard to run I was like, oof, I need to stop.

Lily’s accompanying gestures demonstrated the air flowing up inside the parachute from underneath.

Children drew comparisons across the two sizes of parachutes and suggested why the experience differed between the two; often referring to the amount of wind/air and occasionally to area, for example, ‘*Because it’s like the wind has … it has more area and it pushes like the air balloon (wearable parachute)*’ (Katy). This statement was accompanied by gestures (Figure 5), in which Katy used her hands to represent the wind ‘pushing’ on the parachute. She spread her hands apart to emphasise ‘more area’ and brought them centrally to emphasise the air pushing, as she also moved her hands back and forth as if pushing against an invisible material.

The felt experiences generated by this activity were qualitatively different from those experienced during the sail activity, with children reporting unique sensations of flight and of being pulled. However, there were threads of connection in the way that children discussed their felt experience and observations from the parachute and the sail activity,

Figure 5. Katy spreads her hands apart to emphasise 'more area', then positions her hands centrally and emphasies the air 'pushing' by moving her hands back and forth as if pushing against an invisible material.

with children drawing on ideas like heaviness and effort, as well as observing changes in the shape of the materials during motion. Together these activities supported children to develop a coherent notion of air resistance and drew out key causal relationship between size of material and force generated, as well as highlighting that air resistance is a resistive force against motion, which is not experienced when stationary.

Pulling toy skydivers

This activity allowed children to explore, experiment and simultaneously compare the felt and observed effects of air resistance generated by the small and large toy skydivers. Some children explored a wide range of movements including spinning, running, jumping, and jerking. This task elicited similar discussion of the relative '**heaviness**' of the parachutes and the amount of **effort** required to move them, as well as increased resistance to **pulling,** as captured in the vignette below. This activity elicited the least discourse during the interview, with children giving succinct answers and rarely expanding beyond the question posed to them without prompting.

> Benjamin: I felt like the big one was catching more wind so it was harder to pull it towards me … .. It was so hard because it was like, well I think, ermmm, well it was kind of like that you were trying to pull something really heavy towards you … .and it was catching lots of air

During the activity itself children simultaneously compared the felt sensations associated with each parachute enabling some children to iteratively explore these sensations, whilst engaging in discourse comparing the two parachutes. For these children this led to moments of focused exploration (e.g. Figure 6); however this activity was not as accessible to all children; being open-ended gave space to explore, but placed expectation on children to know *how* best to explore.

Dropping skydivers

Typical activities for learning air resistance in primary school centre around dropping toy parachutes, despite research demonstrating that this can support misconceptions

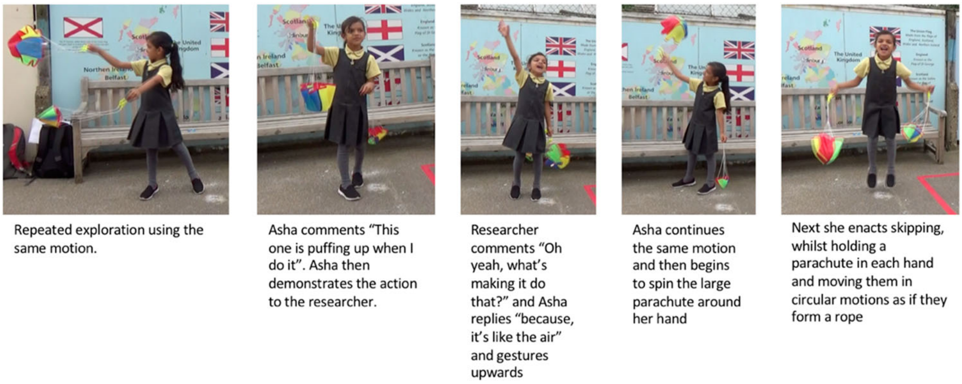

Figure 6. Asha holds the large skydiver in her right hand and the small one in her left. She explores the same motion with both objects, flicking them upwards, then dragging them towards her body. She observes that the large parachute is 'puffing up when I do it'. When prompted she raises to her tiptoes and gestures upwards to signal 'air'. She then spins the large parachute and observes the effects. Finally, she jumps and rotates her hands holding the parachutes as if skipping.

(Bar et al., 1994; Baker et al., 2009). This activity allowed children to simultaneously observe the effect of air resistance on falling skydivers, but did not provide them with a 'lived experience' of this force. While having both skydivers fall at the same time potentially enables comparison across the two sizes, this actually introduced complexity; the direction of the wind was perpendicular to the falling parachutes, causing them to travel horizontally as well as vertically. The larger parachutes travelled farther horizontally than the smaller parachutes, so although they tended to take more time to travel to the ground, children typically focused on this horizontal motion (Figure 7 and vignette below). Nevertheless, children described this as having '*caught more air*' and still drew comparisons between parachute size and the way they travelled, but the direction of this relationship was less clear than for other activities.

Rahul: Um, it, the air moves it where it's gonna land

Rahul: So, if, not like this falling to the ground. Like this.

Rahul: If it just fell, it would've gone there but, if it fell with the air moving it, it would've felled, felled somewhere else or maybe the air would push it back to where it goes.

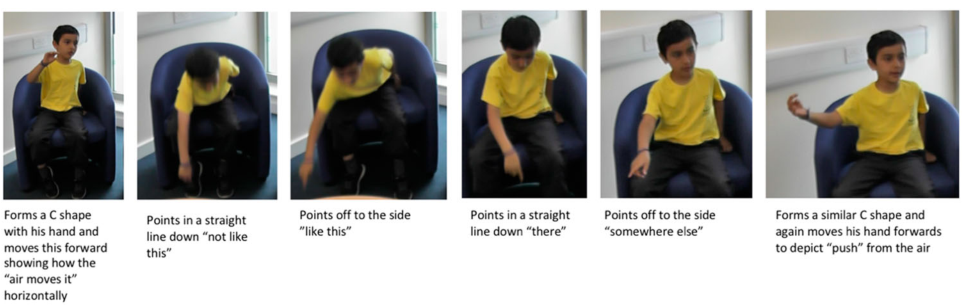

Figure 7. Rahul's gestures focus on depicting how the large parachute moved horizontally before landing.

Children still referred to the larger parachute being heavier and catching more air but appeared more confused about which parachute reached the ground first/fell fastest, and how the relative size might influence the parachutes' descent. This is not surprising given previous research that demonstrates a common misconception that the speed at which an object falls is linked to its weight (Baker et al., 2009; Bar et al., 1994), rather than its volume. Interestingly, in the other activities children discussed both weight and volume (area) with relatively little confusion. This further supports the benefit of providing a range of body-based activities, which give children different ways to engage with the same concept. In particular, here, it was important to give children experiences which drew attention to the concept of air resistance using trajectories other than falling.

As children in our study frequently discussed the various apparatus in terms of relative weight, we might expect them to suggest that the 'weightier' object (larger parachute) would fall faster. However, children all recognised that the skydiver without any parachute at all would fall the fastest, and that the parachutes would slow the rate of fall to some extent. Of particular interest is that even immediately after observing the parachutes falling, children sometimes struggled to describe what they had observed (as in Baker et al., 2009). In this sense the task failed to effectively provide children with an experience which they could use to further develop their notion of air resistance.

Discussion

This paper explores how activities and the subsequent semi-structured conversations designed through the lens of embodied learning influenced young children's science learning. This approach has the potential to promote new modes of engaging with and communicating about science, by making concrete links between children's lived and felt experience and science themes, as well as addressing concerns about valuing children's experiences (Archer, 2018) and giving children early exposure to science which is both engaging and supports meaning making (Bianchi et al., 2021). In this section, we draw together our empirical observations to address our two key research questions.

Firstly, we asked, how do different experiences of air resistance shape the way children think about this concept? Activities designed from an embodied perspective engendered *specific 'lived' sensations* of air resistance which were drawn upon during discourse to help children determine and express key causal relationships. The embodied and personal nature of these experiences provided children with a way of interacting with and communicating about air resistance, which did not rely on subject specific vocabulary. The complementary nature of the experiences allowed children to draw on different scenarios to build a coherent notion of air resistance.

In the semi-structured interview, we encouraged children to describe what they had seen and felt during each activity, eliciting, attending to and valuing their experiences (Andersson & Gullberg, 2014; Archer, 2018). Both the activities themselves and the discourse around these activities were informed by an embodied perspective, that enabled children to draw and build upon these experiences beyond their initial interactions. Each activity presented children with materials in two sizes (large and small); through their descriptions children assigned felt sensations and observations to these materials, in particular their size, and began to make comparisons and identify relationships between them. The discourse, thus, complemented the embodied experience. Because their actions were semantically related to the science content (air resistance) and integral to the task (Skulmowski & Rey, 2018), as children engaged in multimodal discourse around their feelings and observations, they also developed and deepened their skills and knowledge. For example, by describing how it felt to run with the small and large parachutes they classified the parachutes (as large or small), communicated their observations, and made implicit inferences about the relationship between size and felt experiences. This then allowed them to develop explicit inferences about these relationships and in some cases to posit a prediction of what might happen given x (e.g. more wind or a larger parachute). This provides additional evidence of how interactions grounded in embodied learning can extend children's meaning making, by providing them with sensorimotor experiences which can be used as resources for further science 'think' and 'talk' (Lindgren et al., 2014; Thomas Jha et al., 2021).

As previously demonstrated (e.g. Siry et al., 2012) we found that children's understandings and processes both emerged from, and were demonstrated through, their multimodal discourse. Particular ways of talking about air resistance emerged across the tasks, with children drawing on similar language and themes to express their experiences and observations. Although the tasks were qualitatively different, children generated some cohesive discourse around air resistance drawing on consistent themes of felt sensations of pulling/pushing, or relative heaviness or amount of effort to pull/push/run, and observed changes in the shape of the parachute/sail. Across the tasks children used these notions to draw out causal relationship between size and resistive force.

These ways of talking were encouraged since children were prompted to talk about their felt experiences and the observations they made. However, the particular felt experience which children reported emerged from their embodied interactions, which successfully promoted sensations of push and pull forces. An unexpected phenomenon was children describing a sensation of 'heaviness', which appeared to link to the extent of force they experienced. This notion of 'heaviness' emerged across activities, suggesting that the felt experience underpinning this descriptor was in some way similar, and linked to the relative effort required to run with the different materials. Again, this descriptor places emphasis on the felt experience of trying to run against an opposing force and supported children's developing understanding that air resistance is an opposing force to motion. These ways of engaging with the experience provide important foundations for ongoing conversations in the classroom which link children's experiences to more conventional ways of talking about air resistance.

Given the potential to compare action experience with large and small surface areas, as children engaged in multimodal discourse around their felt and observed experiences, they engaged in a process of scientific reasoning – observing similarities and differences and inferring which variables might be responsible, and how. This highlights the importance of considering the role of the body, not only in the activities presented to children, but also in encouraging and supporting later discourse around these activities.

Secondly, we asked, how do different experiences of air resistance shape the way children use their bodies to communicate ideas of air resistance? As noted above children used their bodies to support and elaborate upon their verbal communication during discourse. They demonstrated this through traditional gestures where the hands were used to depict ideas alongside speech (e.g. Roth & Lawless, 2002), but also through whole-body re-enaction

(Thomas Jha et al., 2021). In this section we explore how children used their embodied experiences and their bodies to communicate their felt sensations and observations, and discuss the specific function the body played in supporting this communication.

Children needed little prompting to share their observations and readily elaborated on these (especially for the whole-body activities). The activities and the discourse they were situated in being focused on action as a lived experience (Clark, 2013; Sheets-Johnson, 1982) seemed to empower children with the confidence to engage with and express their felt experiences and observations.

Children used representational gesture – or gestures acting as referents and being aligned with or expanding on the information being presented verbally – to communicate their observations and represent forces not directly experienced by them. Children frequently used their hands to represent the invisible phenomenon of air. For example, representing air being trapped by the parachutes/sails and depicting this 'trapping' by pressing their hands (representing the air) against an invisible barrier (the sail/parachute). This gesture represents both the invisible phenomenon of air and their observations about how the materials changed under its influence. Through such gestures, they explored the relationship between the size of the material and the felt sensations they experienced. Children expanded the space between their hands and repeated this same gesture when expressing how the larger sail/parachute trapped more wind and this meant (for example) that it was harder to run. Children also used their hands to depict the invisible and ungraspable concept of forces – in particular the pull and push forces which they experienced in the various activities.

However, re-enaction – recreating movements from the activities – of lived experiences *more directly* related to air resistance (e.g. sensations of heaviness and effort) provided richer expressions of children's understanding. For example, children enacted running in slow-motion versus full speed to depict the difference between running with the large compared with small materials (Figures 3 and 4). They used facial expressions, body-posture and sounds to bring to life the sensation of the effort required to run against the force of air resistance generated by the larger materials. Children drew on their visceral whole-bodied experiences and used this same mode to help them express their ideas. They repositioned themselves within the context of the activities and continued to use the felt sensations generated by the activities to help them engage in meaning making and communication. This allowed them to draw out explicit connections between the sensations they felt and how these related to the size of the material they were trying to run with; often communicating understanding beyond that conveyed verbally. This provides further evidence that this process of re-enaction allows children to re-engage with experiences and draw out causal relationships underpinning them (Thomas Jha et al., 2021). Skulmowski and Rey (2018) and Lindgren and Johnson-Glenberg (2013) amongst others, propose that movements which involve the body to a greater extent are more likely to support embodied learning. This aligns with our suggestion that whole-body experiences extended children's engagement and discourse beyond that of the other activities. However, these whole-body activities are also likely to be the most novel for children, which might contribute to their success. Future research should explore how these activities support longer-term exploration around the ideas of air resistance and how effective these activities are at supporting older children's meaning making.

Children also used enaction to depict their observations and experiences during the toy skydiver tasks. This re-enaction drew on their bodies to the same extent as in the original activities. For example, children used their hands to demonstrate releasing the skydivers from a height or pulling the skydivers. When children engaged in discourse around these activities, they also used their hands to depict their observations, including the relative motion of the skydivers as they fell and the way the shape of the parachutes changed as they moved. Again, these enactions allowed children to compare their observations for the differently sized parachutes and to engage in discourse about how the size of the parachute might have affected its shape and motion. However, this task did not provide children with a direct embodied experience of air resistance, and their observations often failed to accurately reflect what had happened. As their reasoning was shaped by their own observations, sometimes this led to confusion. This highlights the importance of offering children complementary embodied experiences which allow them to develop a broader understanding of the concept at hand and to confront misconceptions in different contexts.

Across the examples discussed above, the embodied nature of the activities extended the discourse from science 'talk' to doing, with children building on their in-place meaning making and continuing to draw out connections and ideas through their movements. Further work would be needed to explore how best capitalise on the foundational experiences which these interactions engender, to support children's continuing development around this complex topic.

Conclusion

This paper explored how four science activities designed from an embodied learning perspective supported young children's meaning making around the notion of air resistance both during interactions and in later discourse. The paper makes the following key contributions:

Firstly, we show that activities, which involve movement which is integral to the task and semantically related to a science topic engaged and excited young children and allowed them to engage with key causal relationships and ideas underpinning this phenomenon, beyond that offered by the conventional skydiver dropping task. Secondly, we show that both hands-on and whole-body activities designed from an embodied perspective engendered *specific 'lived' sensations* of air resistance which were drawn upon during discourse to both express and develop children's notions of air resistance. The embodied and personal nature of these experiences supported children by providing them with a way of interacting with and communicating about a complex topic, which did not rely on subject specific vocabulary or pre-existing confidence in science. Thirdly, we show that children used gestures to communicate their '*lived experiences*' of air resistance and their developing ideas of this phenomenon, for example by using their hands to make the invisible visible and their bodies to depict felt sensations of effort and resistance and link this to material size. This provides further evidence that children create sensorimotoric representations during interactions that they then use to support discourse around science, and the complementary role of discourse in developing embodied science understanding.

These findings have important implications for science pedagogy as they propose a perspective through which we can provide science interactions which value children's experiences (Andersson & Gullberg, 2014; Archer, 2018), give children early exposure to science which is not only engaging, but which also helps children develop and deepen their learning (Bianchi et al., 2021), and provide new routes into science which value children's other modes of knowing and communication.

Acknowledgements

This material is based upon work supported under a collaboration between the National Science Foundation (NSF), the Wellcome Trust, and the Economic and Social Research Council (ESRC) via a grant from the NSF (NSF grant no. 1646940) and a grant from the Wellcome Trust with ESRC (Wellcome Trust grant no. 206205/Z/17/Z). Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the view of NSF, the Wellcome Trust, or ESRC. We would also like to thank Alison Motion, Mizuki Choi and Minna Nygren, the children who participated in the study, and teachers who made this research possible.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by National Science Foundation (NSF) [Grant Number 1646940]; Wellcome Trust [Grant Number 206205/Z/17/Z].

Ethical statement

This research was approved by the Institute of Education, University College London's ethics committee: approval number REC 957. All participants had informed parental consent and each assented to take part.

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