RESEARCH PAPER

A Call for Translational Research in Embodied Learning in Early Mathematics and Science Education: The ELEMS Project

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Previous psychological, neuroscientific, and educational research indicates that a focus on individual haptic modes of learning (touch, body movement, gesture, tracing), and on the development of emerging mathematical and scientific drawing, can enhance children's learning in mathematics and science. However, most of these studies have focused on one embodied mode and one piece of content, and many have been laboratory studies with limited ecological validity Though less numerous, educational studies in classroom settings have confirmed the potential of particular haptic-mode strategies to improve learning outcomes. Missing from the body of research are studies that take an integrated approach to developing embodiment-rich pedagogy with teachers in authentic classroom settings. This paper argues that translational research is needed to develop evidence-based, curriculum-connected advice for teachers.

Finding ways to improve engagement and outcomes in the STEM disciplines is an ongoing goal in education (Office of the Chief Scientisit, 2014), though less attention has been given to developing educational strategies for the early years than to later stages of schooling. In recent years, research from the fields of neuroscience and psychology has been accumulating knowledge of the brain and the body's roles in children's processing of mathematics and science concepts (Ibrahim-Didi et al., 2017; Kinnear et al., 2019). Although some advances have been made in arts-based embodied learning (e.g., Garrett et al., 2018), little of the embodied learning research has been translated into pedagogical knowledge through STEM-oriented educational research.

The aim of this paper is to present some background to a call for research and development projects that collaborate with teachers in naturalistic classroom settings to translate previous research findings into curriculum-connected pedagogy to enhance children's learning and cater for diversity in learning needs. The focus is on the age range of four to eight years (spanning Pre-school to Year 2), a developmental period when foundational concepts, skills and dispositions in mathematics and science are emerging. The paper begins by presenting a theoretical stance that connects representation theory and embodied learning theory in the context of mathematics and science education. The second part of the paper draws on an analysis of research literature about each haptic mode to identify some of the key findings of potential relevance to classroom practice for the early years. Space limitations necessitate an indicative rather than comprehensive approach to the review of available literature. The paper concludes with a proposed approach for translational research that has the potential to build an evidence base for effective classroom pedagogy utilising embodied learning techniques.

Theoretical Stance

The growth in the field of embodied cognition research has, to some extent, led to a broader acceptance of closer relationships between the roles of mind and body in learning (Hutto et al., 2015; Kersting et al., 2021). In the disciplines of mathematics and science, a representational view of knowledge and learning allows researchers to describe variation in children's current achievement levels in terms of the development of each child's 'cognitive architecture' or sets of interrelated *internal* representational systems, such as language, imagery, and symbols and touch/kinaesthetic (Goldin & Shteingold, 2001). To some extent researchers (and teachers) can infer the development of particular *internal* representation systems through a child's self-

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created *external* representations (e.g., spoken words, drawings, modelling and actions) and their interactions with more formal representations created by others (e.g., symbols, diagrams) (Bobis & Way, 2018). Under-developed representational systems, or mismatches between internal representations and externally imposed representations, potentially create barriers to learning (Goldin & Shteingold, 2001). Incomplete representational systems are particularly noticeable in the disciplines of mathematics and science which place high demand on the formation and connection of multiple representation systems. The interplay between internal and external representations should therefore be of primary concern to teachers (Goldin & Shteingold, 2001). This view of representational theory acknowledges that the internal-external 'interplay' is dynamic and two-way, meaning that external representations are more than *communication tools*, but are also *thinking tools* which can cause cognitive change (Goldin & Kaput, 1996; Prain & Tytler, 2013; Tytler et al., 2013). Hence the need to consider 'representation' as an act or process, not just a product or reflection of existing internal mental images.

Sensorimotor learning is accepted as an essential form of development for infants and toddlers (Gerber et al., 2010; Piaget & Inhelder, 1969), but it has been largely ignored as an important ingredient in the learning of school-age children in the disciplines of mathematics and science. Embodied cognition theories capture enactive types of knowing and learning that cannot be well explained in terms of the 'within brain' processing of sensory inputs as information, as advocated by traditional Cognitivism. In the field of education, the term 'embodied learning' is often preferred, rather than 'embodied cognition', as it better reflects the learning intention behind applying embodied approaches in educational settings (Skulmowski & Rey, 2018). Embodied learning in mathematics and science places emphasis on representation through the haptic mode which includes tactile and kinaesthetic actions (gesture, pointing, touching, tracing, and larger body movements). A critical point is that the origins of embodied representation lay in the movement of the body itself and/or in the interactions between the body and the external environment (Hutto et al., 2015). The active engagement with a variety of movements assists the child to notice and attend to the essential properties, structures and relationships of the mathematical and scientific ideas, beyond what 'looking', 'talking' and retrieving mental images can achieve alone (Alibali & Nathan, 2012; Ginns et al., 2016).

Although most research has found that embodied learning approaches enhance learning, there is less agreement on how much engagement with the haptic modes is needed to achieve learning gains. Although classroom-based research is still relatively limited, positive learning effects have been found with low, moderate and high levels of engagement with embodied-based learning, apparently depending on the type of embodiment and the type of engagement (Skulmowski & Rey, 2018). Different types of embodiment influence learning in different ways. The next section of the paper groups together key research findings into two broad categories of embodiment: the hands used in gesture and tracing, and larger body movement. A third category of 'drawing' is proposed as a further area of embodied learning that is not often considered in the context of embodied-cognition literature. The review is intended to demonstrate how various modes of embodiment can potentially support learning in different ways, rather than provide a comprehensive review of literature.

How Modes of Embodiment Can Enhance Learning

Gesture and Tracing

Humans are genetically predisposed to attend to nonverbal behaviours including gestures and so gesture can be used to focus student attention and enhance engagement (Paas & Sweller, 2012). While basic gestures come naturally and do not need to be taught, science and mathematics knowledge that requires explicit instruction can be supported by using accompanying gestures (Martinez-Lincoln et al., 2019).

Co-speech gestures can be deliberately planned to help connect concepts and mental images to the words that are spoken by the teacher (Alibali et al., 2013), and can take the form of non-representational gestures (beat gestures and pointing gestures) or representational gestures (iconic or metaphoric). Non-representational gestures do not actually depict a concept, object or process, but are used to direct attention while talking. Representational gestures depict a tangible object or dynamic scenario (Alibali & Nathan, 2012). Students will often mirror the teacher's gestures when talking about the topic themselves (Elia et al., 2014). The use of gestures in a *pantomime* way can assist young learners of second-language vocabulary (Mavilidi et al., 2015), and so may support acquisition of key terms and concepts from the science and mathematics syllabi and meaning-making during learning experiences.

While children's learning can be enhanced by observing various types of teacher's gestures, they also learn through their own spontaneous or prompted gesturing. Children's own use of gesture can create more robust memories because gesturing while communicating simultaneously activates two different regions of the brain and increases the likelihood of retrieval (Skipper et al., 2009). Gesture is not always directly connected to speech or words. *Co-thought gestures* are produced while silently thinking, visualising and problem-solving and can reflect strategies and enhance performance. Co-thought gesture may enhance learning because of its ability to represent imagistic, spatial and/or motor information that is difficult or even impossible to represent in speech (Alibali, 2005) and can lead to new problem-solving strategies. Therefore, encouraging children to 'think with their hands' and attending carefully to their gestures may be beneficial. Interestingly, mismatch between a spontaneous gesture and the spoken words may signal that a cognitive change is imminent (Goldin-Meadow, 2015). The gesture may be representing an emerging idea or additional thinking, that the words are not expressing. Noticing such a mismatch can alert a teacher to a 'teachable moment' so they can assist the child in further development of the idea.

Touch-pointing (our term) or *tracing*, with the finger contacting a surface, differs from 'in-air' gesturing as it activates further sensorimotor learning opportunities (Gerber et al., 2010; Hu et al., 2015; Montessori, 1912). Therefore, the child's own pointing-tracing actions are likely to be more powerful than only seeing the teacher perform such actions. Unlike the physical manipulation of concrete materials, this form of touching usually involves interacting with graphics such as symbols, photos, drawings or diagrams. Touch-pointing and tracing, when used by either the teacher or the child, serves to focus attention on specific features of the graphic, such as objects to be counted (Alibali & DiRusso, 1999), the parts of an equation (Ginns et al., 2016; Wang et al., 2022), or the structure of a two-dimensional geometric figure or diagram (Ginns et al., 2016; Ginns & King, 2021; Tang et al., 2019). This seems to be particularly useful when the quantity and/or complexity of the information presented in the graphic is difficult to process. The touch actions also appear to support 'chunking' of elements within the information, thus avoiding information-overload and supporting comprehension.

Black et al. (2012) argue an additional stage of *imagination* following embodied learning experiences based on action and gesture can further enhance learning. Glenberg et al. (2004) found 2nd grade students who imagined acted-out stories about farms by manipulating representative toys learned more than students re-reading the equivalent story. More recently, Wang et al. (2022) found students who traced elements of mathematics worked examples first with eyes open, then with eyes closed to encourage imagination, solved more practice problems than students who traced an equivalent number of worked examples with eyes open. The "eyes closed" students were reported to have lower intrinsic cognitive load and to solve more similar test questions than the "eyes open" students.

Body Movement

Conceptual body-movement (movement of limbs or the whole-body in task-specific actions) by learners reflects the dynamic nature of mathematical and scientific phenomena and can enhance learning (Mavilidi et al., 2018). Learning about aspects of the physical environment such as perspective, structures, measurable attributes, sequence, position or geometric properties may be more effectively achieved through experiences that facilitate exploration in relation to the young child's own body; that is, building egocentric spatial frames of reference (Dackermann et al., 2017). Experiences that require making sense of relationships between objects external to the child or from the visual perspectives of others (allocentric frames of reference) are more challenging. For example, a 5-year-old may gain a better understanding of the function of wheel through the sensation of rolling themselves down a hill that just observing a toy car on a ramp.

When exploring physical phenomena, learning can also be enhanced through co-operative action and re-enactment using their bodies, often in conjunction with the materials that model the phenomenon (Shoval, 2011). Such research highlights the social affordances of groups of children in school settings. The socio-kinaesthetic interaction of performing movements with others, joint contact with the physical objects and watching re-enactments by others, have been found to be important factors in maximising the learning benefits by supporting memory of movements and making connections between concepts processes and movements (Shoval, 2011).

Focusing on the notion of *movement memory* leads us to an emerging area of investigation in mathematics and science: touch and hand movement as a form of 'thinking' in exploratory situations that require the creation of new knowledge. For example, feeling an object to explore its characteristics, particularly without seeing the object, triggers a different learning mechanism than visual or verbal stimuli (Roth, 2014). The sense-making and image-building of the object under investigation resides in the hands (Roth, 2014). Exploratory hand movement is different to gesture which often has its origin in the brain, whereas the 'ideation' with touching originates in the hands. The focus instead is on the sense of touch and the *movement memory* of the hands, rather than concrete and visual representation. The possible intersection of this research with the work on the role of imagination following touch experiences (Black et al., 2012; Glenberg et al., 2004) may be a productive avenue for future research.

Drawing

The close relationship between drawing and gesture warrants the inclusion of drawing in discussions of embodied learning (de Freitas & Sinclair, 2012; Robbins, 2009). Like gesture, drawing typically involves the hand, is dynamic, and comes naturally to young humans, but is also culturally contextualised (Pinto et al., 2011). *Natural drawing* is a form of graphic narrative play, often used in combination with gesture and movement, speech, dramatization and expressive sound effects as part of meaning-making. Young children's drawing develops in its purpose and form over several years, moving in stages from playful scribble and exploration of movement and forms, to pictorial and iconic representations of visualisations and real-world objects (Machón, 2013). Until children reach a representational level in their natural drawing development it is unreasonable to expect them to draw actual objects and scenes (Way, 2018) and care is needed when interpreting their personally contextualised drawings (MacDonald, 2013).

The representational mode of *drawing* is significant in the STEM disciplines because of the prevalence of diagrams to depict essential properties, structures and relationships (Mulligan & Mitchelmore, 2009). Drawing is more accurately viewed as a multi-representational mode because the act of drawing captures haptic, visual-spatial and symbolic modes as well as the complexities of transforming three-dimensional phenomena into a two-dimensional representation (Preston et al., 2021). Drawings often represent dynamic events rather than static situations, so children invent, share and borrow techniques and symbols (such as arrows) to express movement or the passage of time, and peer dialogue has been shown to support the development of drawing (Hopperstad, 2008). However, the act of drawing is part of thinking and of exploring emerging ideas, so the process is important, not just a finished representation (Thom & McGarvey, 2015).

Of concern in education, is the conceptual and representational distance between children's own self-created drawings and the conventions and rules of mathematical and scientific diagrams. Frequent use of drawing as a form of assessment of student learning in mathematics and science, without explicit teaching of drawing skills, falsely assumes that all children can naturally use drawing as an effective communication tool (Preston, 2016; Way, 2018). Recent research suggests that valuing drawing as a *thinking tool* in conjunction with haptic modes can support the development of children's mathematical and scientific drawing skills and enhance learning in those disciplines (Brooks, 2009; Preston et al., 2021; Tytler et al., 2013).

Summation

Though brief, the above review of literature relevant to early years mathematics and science has illustrated the variety of ways in which young children's learning can be enhanced through increasing the use of embodied learning modes in their educational experiences. Opportunity to utilise primary biological or instinctive behaviours, for children to physically *be the representation* and to ideate and create representations by dynamically interacting with their environment and with their internal representation systems, has been shown to help focus attention on key concepts and promote understanding of content.

The Need for Translational Research

Previous international research has established that specific embodied learning approaches can enhance children's learning in specific tasks. Much of the published research has been experimental in nature and appears in psychology journals in formats not readily accessible to teachers. Although a growing number of classroom-based studies have produced valuable insights into potential impacts on student engagement and learning, these studies have tended to focus on one mode of embodiment (such as gesture), deal with one content topic (e.g., the number line or the water cycle), and have typically been researcher-directed enquiries. With the accumulation of research findings now pointing towards the learning benefits of embodied learning approaches in education, we argue that the time is right for translational research projects to transform the findings into pedagogical knowledge and practice. To our knowledge, no studies have worked collaboratively with teachers to produce a set of teacher-friendly embodied learning principles supported by evidence of children's progress towards achieving a range of syllabus outcomes in mathematics and science in the early years of schooling.

The *Embodied Learning in Early Mathematics and Science* (ELEMS) project has been designed as step towards addressing the current lack of translational research. The aim of the project is to develop an evidence-based, classroom-ready professional learning resource for teachers that empowers them to implement pedagogy that uses a child's full repertoire of representational modes - emphasising the under-utilised haptic and drawing modes.

Our key objectives are to:

a) translate the findings of embodied cognition research from psychology, neuroscience and education fields into general learning-design principles that can be applied by teachers of early-years mathematics and science.

b) test the impact of these learning design principles on student learning outcomes, developing an evidence base and building on theory in this area of research.
c) produce and evaluate a professional learning package to support teachers to develop pedagogy that includes attention to the haptic and drawing modes in children's learning.

The project seeks to work with early-years teachers (Preschool to Year 2) to collaboratively develop and test teaching approaches and task types that effectively utilise haptic modes, including drawing, to support children's achievement of outcomes. The work will support teachers in curriculum enactment bridging from the national Early Years Learning Framework to the NSW Mathematics, and Science and Technology syllabi (implementing the Australian Curriculum).

Design-based research provides the ideal methodological framework for the project, with its emphasis on improving learning outcomes through authentic collaboration with practising teachers, and the dual goals of theory building and practical products (Reimann, 2010). The iterative nature of design-based research supports a three-phase project structure, with each phase informing the next, over three years. Phase 1 begins in 2022 with intensive work in one school with a diverse student population, before expanding to a larger number of schools in Phases 2 and 3. The initial research schools will be selected from the pool of 100 NSW schools with attached pre-schools. As well as teacher and whole class studies, the selection of focus children will allow case studies of children with a variety of learning needs.

In addition to the psychology-education orientated knowledge-building, we anticipate gaining insights into social-educational perspectives such as improving transition between pre-school and school, and the potential benefits of embodied learning approaches for disadvantaged groups of children. While the ELEMS project is likely to advance our understanding of how embodied learning approaches can benefit mathematics and science education in the early years, we call on other researchers to also consider classroom focused studies to strengthen the evidence base in this field.

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