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# Semiotic Resources in the Mathematics Classroom: The Use of Gesture in the Development of Spatial Reasoning

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This paper sets out to clarify the role gesture has in creating meaning when learning mathematics. General characteristics of gesture and the mathematical concept of spatial reasoning are discussed. Features of the theoretical basis of that concepts are then explored, primarily to outline how the modern embodied form of knowledge was developed and how it applies to mathematical learning. Features of one aspect of embodied knowledge, gesture, is then examined and deconstructed to highlight specific ways it can be understood in order to contribute to mathematical learning.

## Introduction

*Mathematics is seen as the epitome of precision, manifested in the use of symbols in calculation and in formal proofs. Symbols are, of course, just symbols, not ideas. The intellectual content of mathematics lies not in its ideas, not in the symbols themselves... the intellectual content of mathematics does not lie where the mathematical rigor can be most easily seen – namely, in the symbols. Rather, it lies in human ideas (Lakoff & Nunez, 2000, p. xi).*

Teachers must be able to utilise all forms of communication to ensure their learners are being given the best chance to succeed in their education. The Australian Professional Standards for Teachers

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emphasise that accomplished teachers are expected to be conscious of where they want student learning to go and how they want students to get there (AITSL, 2011). Moreover, the Australian Association of Mathematics Teachers developed a set of standards for excellence that require excellent teachers of mathematics to "have a strong knowledge base of… how mathematics is learned, what affects students' opportunities to learn mathematics and how the learning of mathematics can be enhanced" (AAMA, 2006, p. 2).

Over the last several decades, the concept of learning has undergone a dramatic process of change (Radford et al., 2011). The established concept of learning as the ability to reproduce given theoretical content gave way to a more contemporary concept that emphasises the critical and creative inclusion of students (Radford et al., 2011). Currently, school mathematics continues to be primarily oriented by perspectives on cognition that focus on abstract mental operations, which often reduce, and occasionally dismiss, the importance of embodied interactions in shaping not only personal understandings, but also the person (Thom et al,. 2015). In order to try to contribute to overcoming aspects of this rationalistic orientation to learning, this paper sets out to explore discourse in the mathematics classroom. By adopting a transdisciplinary approach, multiple research perspectives are brought together to understand new ways of reconceptualising mathematics learning. The emphasis on the exploration of the use of gesture in the development of spatial reasoning aims to provide more coherence about how to understand and promote mathematical thinking within the broader education community.

The notion that mathematics can simply be taught through language and symbols alone is outdated. In mathematics classrooms around the world, multi-modal elements of learning, such as gesture, along with linguistic, symbolic and visual elements, combine to contextualise and communicate the mathematical concepts that are being learnt. These multi-modal elements of mathematics learning are often unknown to mathematics educators, however, understanding these elements; how the theory meets the reality, and the role they have in the ways they make meaning in the learning of mathematics, is vital to ensure the success of students as they develop mathematical proficiency. This paper seeks to detail the way gestures can be used to reveal what a learner knows and who

## Contextual Matters

When people talk they gesture. Revealed within those gestures is information that cannot be found in speech alone (Novack & Goldin-Meadow, 2015). Gesture involves more than just illustrating or enriching the message of a lesson. It can be an insightful device for learners, promoting conceptual development while simultaneously providing feedback both in the learning opportunity and on the way future gestures are used to convey meaning (Novack & Goldin-Meadow, 2015). To illustrate this, Harun and Williams (2011, p. 176) suggested engaging in the following activity:

*Part 1*
*With closed eyes, imagine two overlapping triangles in a six-pointed Star of David, with a bead placed on each node (i.e., each point of intersection of the edges);*
*Count the beads, without verbalising and without gesturing, that is, no moving your hands or fingers*

*Part 2*
*Open your eyes;*
*Try to describe your experiences – what did you 'see' in your mind's eye? How did you count the beads? Did you move your head at all as you counted?*

*Part 3*
*Repeat the activity a second time, but this time you may use your hand in whatever way you want.... Does it help you to count to yourself?*

Harun and Williams (2011) suggest that after completing this one could use a 'pointer' such as an imaginary finger to allows people to help them to mentally frame the two triangles within their visual spatial field and to point to each of the beads as they are counted off using inner speech, while nodding the head in rhythm with the counting to help solidify the thought. This activity can be used to help define the two broad classes of gesture: representational gesture and beat gesture.

Representational gestures are movements likes the one described above that convey or indicate meaning; they depict “a spatial or motor referent by pantomiming a particular action, by demonstrating a spatial property, or by creating such a referent for an abstract idea” (Hostetter, 2011, p. 298). In contrast, beat gestures are small, rhythmic movements that do not convey any obvious meaning, but are vital in contributing towards the development of meaning (Hostetter, 2011). The term gesture for the purpose of this essay refers to representational gestures, or those that convey meaning. Moreover, gesture is additionally taken to describe all types of body activity that play a role in a given communicative transaction, including such multimodal aspects facial expression, body poise, eye motion and gaze, along with movements of the hands and arms that are produced when engaged in effortful cognitive activity, such as those seen when speaking and problem solving (Alibali, 2005).

With regard to the impact of gesture on developing students’ understanding of mathematical concepts, the paper will largely focus on how gesture has an impact on the learning of concepts within spatial reasoning. To address the needs of learners who are ever increasingly in need of the ability to innovatively think in a technological world, spatial reasoning is of critical importance, especially for those seeking careers associated with sciences, technology, engineering and mathematics (the STEM disciplines) (Mulligan et al., 2018).

Spatial ability is linked to mathematical competence (Wai et al., 2009), and particular spatial competencies are predictive of mathematical achievement, are malleable, and are able to be developed from an early age (Hawes et al., 2015). Spatial reasoning comprises a complex, interconnected web of processes, but can more specifically be defined as the "ability to perform mental manipulations of visual stimuli, the ability to transform spatial forms into other visual arrangements, an awareness of the structural features of spatial forms and the analytical thinking required to find relationships and solve problems" (Mulligan et al,. 2018, p. 78). A new related overarching theme is emerging in mathematics education, namely, that mathematics learning is a complex, dynamic system of interconnected components, fundamentally dependent on spatial reasoning, rather than on the initial development of number concepts and arithmetic, as if habitually assumed (Davis et al., 2015). However, spatial reasoning has yet to penetrate the traditional mindset of 'school mathematics'. Thus, it is imperative that those associated with mathematical learning in schools understand the ways in which they are able to lead the way towards a broader collective understanding of pragmatic ways to develop spatial reasoning in schools: through that of gestures.

## Mathematics: An Embodied Form of Knowledge

Being a relatively young discipline, the study of mathematical thinking has been subject to a number of major shifts since its birth in the first half of the 20th century (Sfard, 2001). Historically, the learning of mathematics has been almost exclusively understood to be a rational cognitive process of procuring the skill and knowledge mathematics presents in a somewhat linear structure (Seeger, 2011). Consider, for example, common metaphors that are currently used in education to describe learning: humans 'build,' 'scaffold,' 'absorb,' 'give,' 'acquire,' 'process,' 'transfer,' 'store,' and 'access' this tangible thing called 'knowledge.' (Thom et al., 2015). This knowing continues to be described as an attribute of the mind that transcends the bodies that are seen to contain knowledge, whereby the body is simply the conduit through which knowledge passes and is the container though which it accumulates (Thom et al., 2015). Because of thatt, it was viewed that knowledge

> … originates from and circles back to higher out-of-body places. The highest human quest is therefore to seek knowledge's revelation though empirical inquiry into the world's secrets (i.e. do 'science')

> and then to refine that knowledge by attaining body-transcending, body-bracketing rationality (do ‘mathematics’) (Thom et al., 2015, p. 67).

Thus, modern schools had no place for the body in sense-making in the world. The assumption has been one of a mind-body split. That belief in a dualism that separates the mind from the body, that knowledge continues to be positioned out in the world, awaiting proper transfer into learners’ minds, has had a strong influence on both mathematics and mathematics education for some time (Radford et al., 2009). However, the rise of cognitive science is helping to rethink these assumptions about the human mind and the body, seeking to understand the mind as embodied and the body as minded (Thom et al., 2015).

In the field of mathematics education research, there has been growing interest over the past 20 years in identifying and understanding the varied ways that the body is central to and included in learners’ mathematical cognitive development. The inclusion of the body in the act of knowing can be traced back to the work of several social theorists, epistemologists and phenomenologists such as Husserl (1931), Gelhen (1988) and Merleau-Ponty (1945) (Radford et al., 2009). While their respective theoretical perspectives differed, they all agreed on one point: knowledge is more than the product of abstract deductive mechanisms (Radford et al., 2009).

Knowledge is produced by the individual’s experience in the act of knowing. This experience is mediated by ones’ own body. This return of the body indicates an awareness that, in our act of knowing, different sensorial modalities (tactile, perceptual, kinaesthetic etc.) become fundamental parts of our cognitive processes. That is known as the multimodal nature of cognition (Radford et al., 2009). From this viewpoint, mathematics is considered to be a powerful and stable product of human imagination, with its origins in physical experience:

> While modulated by shifts of attention, awareness, and emotional states, understanding and thinking are perceptuo-motor activities; furthermore, these activities are distributed across different areas of perception and motor action based on how we have learned and used the subject itself. [As a consequence,] the understanding of a mathematical concept, rather than having a definitional essence, spans diverse perceptuo-motor activities, which become more or less active depending on the context (Nemirovsky & Borba, 2003, p. 108).

This description of the cognitive and epistemic nature of multimodality was elaborated on by Gallese and Lakoff (2005), who emphasised that mathematical understanding which has been studied from perspectives informed by embodied cognition "is mapped within our sensory-motor system… providing structure to conceptual content, [and] characterises the semantic content of concepts in terms of the way that we function with our bodies in the world" (p. 455 – 456). This consideration of gesture and the body does not exclude the fact that mathematics and other forms of knowledge are conjoined to symbolic tools and that cognition is a culturally shaped phenomenon (Sfard & McClain, 2002). However, the symbolic tool described here, namely gesture, is to be seen as a part of the resources that are available within the context of multiple semiotic modalities.

> Multimodal integration has been found in many different locations in the brain... it is the norm that sensory modalities like vision, touch, hearing, and so on are actually integrated with each other and with motor control and planning. This suggests there are no pure 'association areas' whose only job is to link supposedly septate brain areas (or modules) for distinct sensory modalities (Gallese & Lakoff, 2005, p. 459).

Studies on learning are dedicating attention to gesture in the multimodal sense described above (Nemirovsky & Ferrara, 2009). Gestures can be taken as the physical evidence that the body is involved in thinking and speaking, and as such are an "embodied form of knowledge" (Alibali & Nathan, 2012, p. 248). While this concept of embodied knowledge has yet to be developed into a unified theory, it is generally agreed that mental thought processes are facilitated by body-based systems, such as movement and scale, along with motor systems such as sensation and perception (Glenberg, 2010).

With regard to mathematical learning, the notion of embodied cognition challenges the idea that mathematics is disconnected from the body, action and perception (Lakoff & Nunez, 2000). This embodied perspective on cognition embraces the notion that “all cognitive activities are ultimately grounded in actions of the body, and as such, explicit bodily actions can contribute to and shape ongoing cognitive activity, so activities that are accompanied by actions may unfold in different ways that activities that do not involve actions” (Alibali, 2005, p. 309). Because gestures are bodily movements, and because they often occur when speakers talk, the embodied perspective suggests that gestures may affect speakers’ thinking (Alibali, 2005). These theories of embodiment have significant implications for school mathematics. With regard to spatial reasoning, the very phrase itself juxtaposes reason and space, suggesting a central role of the body for reasoning (Thom et al., 2015).

## Assessing Knowledge Conveyed in Gesture

The gestures produced by learners while they are explaining their reasoning can provide distinctive insight into their thought processes. Often, learners will produce information in gesture that is different to what they produce in speech. Melinger and Levelt (2004) found that speakers who were asked to communicate multiple pieces of information, such as the size and shape, about a stimulus to their listeners often conveyed one of the pieces in their gestures without also declaring it in their speech. The following excerpt from Novack and Goldin-Meadow’s (2015, p.406) work is an example of how the gestures that learners produce while explaining their reasoning can provide insight into their thought processes:

> Imagine a child who does not yet understand the concept of conservation of liquid quantity and believes that the amount of water

> changes when it is poured from a tall, thin container into a short, fat container. When asked to justify this belief, the child might say, ‘this one is taller than that one,’ while at the same time, producing a C-shaped gesture indicating the narrow width of the tall container. The child is highlighting one dimension of the containers in speech (height), but his hands make it clear that he is beginning to think about a second dimension (width). His gesture is conveying different information than his words.

Referred to as a gesture-speech mismatch, it occurs when the gesture delivers information that is different from (although not always contradictory to) the information conveyed in the speech it complements (Singer & Goldin-Meadow, 2005). The following example of a simple gesture-speech mismatch was described as follows:

> *When giving a child instruction in how to solve the problem 7 + 6 + 5 = __ + 5, a teacher articulated the equaliser problem-solving strategy in speech: “We need to make this side equal to this side.” At the same time, she conveyed a grouping strategy in gesture: She pointed at the 7 and the 6 on the left hand side of the equation and then at the blank on the right side (7 and 6 are the two numbers that, if grouped and added, give the correct answer). (Singer & Goldin-Meadow, 2005, p. 85).*

The two strategies described above add to correct solutions, yet do so via alternative methods. Thus, they comprise a ‘mismatch’ (Singer & Goldin-Meadow, 2005).

Gesture-speech mismatches are frequently found in teaching situations, to the point that it has been found that teachers spontaneously increase the number of mismatches in their instruction when teaching children who are on the verge of mastering the task (Singer & Goldin-Meadow, 2005). On a broad note, it is considered to be evidence that the speakers intended for their gestures to communicate, as they chose to distribute necessary information across both gesture and speech modalities, rather than conveying it in speech alone (Hostetter, 2011). More specifically, children whose gestures express alternate ideas from their speech when they explain a task are more likely to gain deeper understanding in that task than children whose gestures are superfluous with their speech (Novack & Goldin-Meadow, 2015).

The unique information that is conveyed through gesture, however, is often implicitly understood. Therefore, it is not yet accessible for explicit understanding (Alibali & Nathan, 2012). Consequently, as gesture is not bound by the conventions of spoken language, it can be used, both by the learner and the teacher, as a signal that the learner is in a transitional state, ready to make use of relevant input (Goldin-Meadow, 2003). This notion of readiness to learn exists in several theories of developmental change. For example, when using the Piagetian lens of the 'teachable moment', children are characterised by instability of knowledge, or periods of disequilibrium, whereby they are particularly receptive to input from the environment that allows them to resolve discrepancies in their knowledge structures in order to move them toward a more stable state (Alibali et al., 1997). While this interpretation does not take into account the social origins of new knowledge, it does illustrate theoretically how a teacher who identifies a student in a state of disequilibrium could offer appropriate experiences to facilitate the students' advance to a more correct knowledge state (Alibali et al., 1997). Thus, gesture can be seen as an indication that the student is in a prime state for learning. However, this then begs the question of whether these subtle cues are accessible and identifiable to those primarily involved in mathematics education: teachers.

## *Gesture as a tool to improve communication*

Delving into the meaning of gesture, this dynamic dimension of language allows insight into how gestures fuel thought and speech. Gestures, language and thought are often seen as different sides of a single mental/action process. However, McNeill (2005) argued that gestures are active participants in speaking and thinking; linguistic forms and gestures participate in real-time reasoning and are integrated on actional, cognitive and biological levels, and thus activate and shape speech and thought as they occur moment to moment. At the same time, different types of gestures are often distinguished within the research.

Gesture can be referred to with regard to its everyday occurrence; the spontaneous, involuntary and regular accompaniments to speech we often see when people move their fingers, hands and arms (McNeill, 2005). This type of gesture is so ubiquitous that even congenitally blind people who have never witnessed anyone gesture move their hands when they talk (Novack & Goldin-Meadow, 2015).

Similar to the adage that ‘a picture is worth a thousand words,’ gesture has specific communicative power when conveying information about spatial ideas and spatial relations. Speakers tend to produce gestures when they speak about topics that contain spatial information, and gesture more when talking about spatial themes than when talking about nonspatial themes (Alibali, 2005). In contrast, gestures that accompany speech about nonspatial topics add very little to the communicative exchange as the gestures cannot explain the nonspatial descriptors any more clearly than the accompanying speech (Hostetter, 2011). This was reiterated by Driskell and Radtke (2003), who found that listeners were able to deduct the identity of spatial words (e.g. under, square) in fewer attempts when the speaker gestured, as opposed to when the speaker did not gesture. In addition, they found no gesture advantage when the speaker described nonspatial works (e.g. colour, warm). Thus, the comprehension was enhanced when the listener had access to both gesture and speech, and the gesture had a significant positive impact on speech production (Driskell & Radke, 2003).

### *Gesture as an alternative source of information*

Children’s gestures have the ability to reveal important information about their problem-solving abilities. However, initial research outlining this illustrated concern that this information would only be accessible to researchers trained in gesture coding (Novack & Goldin-Meadow, 2015). On that, teachers, including undergraduate graduates, have been found to be sensitive to the content that is uniquely conveyed in students’ gestures (Alibali et al., 1997). Additionally, even when a gesture is completely redundant with the associated speech, listeners may refer to the gesture as another source of information when they cannot comprehend the speech (Hostetter, 2011). As such, gestures are communicative because they are able to provide additional cues when speech comprehension is difficult, as might be seen in classroom situations where learners have verbal skills that are not yet fully developed, be it through age or for individuals who are developmentally delayed or neurologically impaired, or are non-native speakers of the language being spoken (Hostetter, 2011).

With regard to bilingual learners, Sueyoshi and Hardison (2005) found that the use of gestures improved the comprehension of those who were considered to have low proficiency in their second language. However, the same gestures did not improve the comprehension of bilinguals who were of high proficiency. Similarly, Ng (2016) found that bilingual learners in a high-school calculus class utilised a variety of resources, such as language, gestures and visual mediators, in their mathematical communication. Gestures, however, had a prevalent role in the bilingual learners’ mathematical communicational acts. Conversely, it was noted that the ways in which those students used gestures, namely dragging actions, were not only to imply the static increasing/decreasing amounts and slope/tangent with regard to derivative graphing. Equally, these dragging gestures were used to communicate dynamic features and properties of the derivative sketch, for example, to communicate ‘as x varies along this graph’ (Ng, 2016, p. 292).

Similar findings were reported by Chen and Herbst (2013), who studied the gestural and linguistic resources used with students making reasoned geometric conjectures. In that instance, it was noted that when provided with geometric diagrams that are lacking in labels or drawn elements, students were able to make use of particular gestures that both reported known facts and allowed hypothetical claims to be made about certain diagrams:

> … gestures, as well as modality expressions can be mediation tools available to compensate the semiotic limitations of diagrams and could be especially important in enabling students to engage in such conjecturing (Chen & Herbst, 2013, p. 304).

This aligns with Sfard’s (2009) claim that gestures take on different roles in mathematical communications, and consequently require that those involved in mathematical education require some form of examination of the kinds of gestures and their interplay within a students’ repertoire of communicative resources that are situated within mathematical activities.

## *Considerations*

As previously discussed, a meta-analysis conducted by Hostetter (2011) confirmed that speakers’ gestures benefit listeners’ comprehension. However, understanding this causal link between gesture and learning has been complicated by the confounding of gesture with other communicative cues. To determine causal links between gesture and learning outcomes, pure experimental manipulations of gesture are required (Cook et al., 2017). For example, the research previously mentioned by Singer and Goldin-Meadow (2005) used controlled instructions, conveyed by an experimenter who gestures in one condition, but did not involve gesture in the comparison condition. This instruction delivered by the experimenter introduced confounding factors, such as the impossibility for the instructor to be blind to condition, and consequently allow the possibility of experimenter bias and observer-expectancy bias, whereby the experimenter might prompt exactly the expected behaviours being monitored (Cook et al., 2017). Additionally, controlled live instructions can be considered unnatural as they are rehearsed and therefore do not include the hesitations, false starts and other characteristics of spontaneous communications (Cook et al., 2017). Thus, while much research to date has found that gesture can increase learning, methodological issues (such as those raised above) in studying gesture can limit the conclusions that can be drawn from such research.

## Recommendations

In recent years, mathematics educators have increasingly paid attention to the social context of mathematical classroom discourse. Known as social semiotics, this framework draws on a wide range of theoretical traditions to explain the ways in which people use semiotic resources to make and exchange meanings (Van Leeuwen, 2005). Social semiotics is

> ….a framework that focuses on the function of multiple semiotic systems (symbolic notation, oral and written language, graphs and visual displays, gestures and the use of material objects) and grammatical patterns (technical vocabulary, dense noun phrases, ‘being’ and ‘having’ verbs, logical conjunctions, visual codes, canonical gestures) in spoken, written, and performed mathematical texts (de Freitas & Zolkower, 2011, p. 229).

The ‘social’ aspect of social semiotics signifies that theoretical sign use is noted as a part of social practice, reflected as a part of socio-cultural norms and conventions. That is, it is a framing of the definition that is essential for studying the situated code-switching habits of students and teachers and how they approach specific characteristics of school mathematics discourse in a variety of contexts (de Frietas & Zolkower, 2011). In order to propel mathematics education into the next era, while simultaneously supporting the Australian Professional Standards for Teachers and other relevant policies, mathematical practitioners should be given opportunities to use the social semiotic framework to help illuminate the complexities of mathematics teaching. By analysing student classroom communication through the social semiotic lens, mathematics teachers may be better placed to solve the kinds of problems the system as a whole is having with engagement (both student and teacher), curriculum and the challenges associated with teaching in these increasingly complex environments (de Frietas & Zolkower, 2011).

Taking this approach into account, it would be useful for teachers to have the opportunity to collaborate in planning, trying out and documenting, discussing and revising problem-centred lessons and units, with the idea to concentrate on the linguistic, gestural and diagrammatic challenges of mathematics teaching and learning. With regard to this, research conducted by de Freitas and Zolkower (2011) suggests the use of 'non-routine problems' with the students for the lessons that are to be reflected upon. The use of these styles of questions allows a student to be challenged intellectually, while their interpretation of the question does not get confused with direct methods, procedures or algorithms that may be used by the student to answer the more traditional style of mathematical problems (de Frietas & Zolkower, 2011). How are mathematics teachers expected to make this monumental shift from looking at mathematics as an abstract acquisition of skill, to one which understands both an embodied approach learners' mathematical cognitive development, and identifies the aspects of teaching that require the use of socially semiotic resources?

One way to consider meeting this need for professional development of all mathematics teachers is through that of the development of communities of inquiry. Essentially, school-based and organised by teachers themselves, this form of professional development allows teachers to examine their own practice in school-based communities of inquiry (Doig & Groves, 2011). Research in the literature often states that the professional development offered to teachers is ineffective, as it tends to focus only on updating teachers' knowledge and lacks connection with developmental learning (Ingvarson et al., 2004). However, professional development that provides teachers with an opportunity for sustained learning about issues to do with curriculum, students or teaching tends to promote teacher agency and understanding (Ingvarson et al., 2004). One type of professional development noted that provides a basis for large-scale, sustainable learning is that modelled from Lesson Study in Japan (Doig & Groves, 2011). This practice extends and renews teacher practice, skills and beliefs in order to improve outcomes for students, whether they are focused on skills, attitudes, understandings or engagement, and provides opportunities for teachers to experiment with classroom practice and analyse it in detail (Doig & Groves, 2011); “the more successfully students learn, the more likely it is that the teacher will adopt practices that encourage further successful learning’’ (Ingvarson et al., 2004, p. 23).

On the surface, Japanese Lesson Study appears to be a simple model; teachers with a common goal meet and plan lessons together (Doig & Groves, 2011). The general format for a Lesson Study has been outlined by Doig and Groves (2011). A lesson, known as the ‘research lesson’ is taught by an individual within the group, and observed by all the teachers involved in the planning, and may include other observers within the school or from another school. After the lesson, a debriefing session is held, where the lesson is dissected and discussed in detail, whereby modifications are often suggested by the observers, of which is usually an ‘expert’ teacher.

This Lesson Study Cycle has been identified by Lewis (2002) as having four phases:

1. Goal setting and planning, including the development of the study lesson;
2. Teaching the research lesson, to facilitate the lesson observation;
3. Discussion of the lesson after it has occurred;
4. The consequential consolidation of learning, with the intent to impact teachers’ understandings of the lesson

While these points are stated simply, a great deal of unpacking of each phase is required to understand the concepts and processes this model offers in practice. As such, it has been included as a consideration for mathematics teachers to explore the ways they can improve their understanding of social semiotics and how it can enhance student knowledge; “Even more basic is the whole idea of instruction as something that can and should be improved through consultation with colleagues, trial in the classroom and critique” (Lewis, 2000, p. 32-33).

However, it should be noted that this method of learning requires a degree of openness on the teachers’ behalf; if teachers are to pose challenging questions to the class in order to learn from them, they must be able to embrace the fear of making mistakes in front of their class (Sullivan, 2018). This may in part be overcome by developing a rationale for such openness that is connected to the ways it may also enhance the students' learning, for example by using the student solutions and strategies as a basis for classroom discussions (Sullivan, 2018).

## Conclusion

The learning of mathematics has become problematic. A visible gulf between research and practice exists, with issues varying from the most general questions regarding basic assumptions about everyday mathematical learning, to specific, everyday queries elicited by classroom situations. Those involved in mathematics education, ranging from teachers to students, parents, mathematicians, and ordinary citizens concerned about the well-being of children and their society, have begun to question the current approach to both the theory and practice of mathematics education. The lack of significant, lasting improvement to mathematics teaching and learning has motivated researchers, both theoretical and practising teachers, to begin the appropriate task of considering other aspects of learning mathematics, in order to reincarnate the ways in which we think about mathematics education.

A brief examination of embodied theories of mind and school mathematics in relation to spatial reasoning has been discussed with the purpose to help us understand that embodied perspectives on knowing and learning represent a powerful place of convergence for mathematics education. One specific aspect was considered through this lens of embodied knowledge, that of gesture, with the purpose to appreciate how this knowledge can aid teachers to work towards evolving their pedagogical practice, part of which requires that students themselves understand and identify how the use of gesture is part of a multi-modal approach to construct mathematical knowledge. Although much research to date has found that gesture can increase mathematical learning, fundamental methodological issues in studying gesture have limitations regarding the conclusions that can be drawn, and consequently requires renewed attention in the multidisciplinary realm of human cognition.

This discussion on the emergence of a contemporary approach to school mathematics has been presented and developed, drawing from embodied theories of cognition, with a hope to link spatial reasoning and its development through gesture as a vital and central part of moving school mathematics curricula out of its current rut and into a rich future. Recent attention within the Australian Curriculum, particularly in the area of Mathematics, may be well timely to prompt rethinking not only about mathematics curriculum, but also the whole curriculum. In the long term, the impact of developing and refining teachers' understanding of the use of semiotic resources in mathematics education may contribute to a shift towards the progression of new mathematical skills and thinking processes required by students to thrive in a spatially-orientated technological society.

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