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An introduction to TWG29: Embodied and material studies of mathematical behaviour

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Starting a new TWG

In the last decades, major paradigmatic shifts across the social sciences have ignited new research on embodied learning and material processes in mathematics education. The embodied turn in cognitive science (e.g., Clark, 1999) and the ontological new materialist turn in cultural studies (Coole & Frost, 2010) bring a renewed attention to bodily-material practices in mathematical behaviour (e.g., de Freitas & Sinclair, 2014; Roth, 2011). Researchers stress the importance of students' and teachers' bodily actions and the use of material artifacts as *constituting* rather than only *representing* mathematical concepts. The insights are often linked to the use of new technologies—such as motion sensors, multitouch screens, eye trackers, and emotion recognition systems. These technologies allow for detailed analysis of mathematical behaviour and also prompt educators to create unique technological and crafting environments that foster students' exploration of mathematics. New developments also draw attention to the production of mathematics dis/ability in and out of classrooms (e.g., Yolcu & Popkewitz, 2018) and raise broad questions about the role of agency and multimodality in mathematical thinking and doing.

At CERME 13, researchers with an interest in embodied and material mathematical activity came together to form a new group. We called for contributions by scholars whose work might explore mathematics education according to the following themes: sensory-motor processes, including gesturing, eye movements, drawing, touch, and speech; aesthetic and material-making processes; group activity and coordination between bodies; affect and emotion as socio-material phenomena; technology, material artifacts, embodied technicity; diversity of racialized, gendered, dis/abled bodies. We invited participants who might be interested in discussing some of the many relevant theoretical perspectives, such as posthuman and neo-materialist perspectives on the body and eco-cognition; complex and functional dynamic systems perspectives on bodily coordination; cultural-historical approaches to sensual cognition; phenomenological and enactivist studies. As a group, we felt committed to unpacking the concrete implications of these theories on the future of mathematics education and welcomed a broad range of studies that share our curiosity.

Structure of the group work and overview of the contributions

After the review process, 11 papers and 8 posters co-authored by 33 researchers were accepted. At the conference, 25 participants from 12 presented 10 papers and 6 posters. The group work started

with an embodied activity that involved moving and chatting with other participants in a speed-dating format, where the conversation prompts were increasingly focused on recollections and accounts of embodied experiences. This introductory activity allowed the group to break the embodied ice and brought the theme of the TWG into shared focus. The final group report also included a set of material and bodily activities that invited listeners to engage with the various mathematical phenomena investigated during the week thus complementing summaries of the group discussions.

The work during the conference week was centered around four thematic panels. Participants were in advance invited to explore how their paper might speak to a set of specific for each panel questions. The first panel, *Static and dynamic aspects of mathematical concepts*, unfolded through the following questions: How are mathematical concepts understood from material and embodied perspectives? What are the roles of dynamic and static entities in learning and doing mathematics? How can (digital) tools be designed and used to explore the processual nature of mathematical concepts? Ferrari and Soldano presented a dynamic approach to the concept of symmetry through the use of educational robots; a case study analysis revealed new dynamic ways of approaching this concept, thus setting the intervention as a diffractive apparatus. Boels and colleagues presented the dialectics of actions and artifacts in their logical-historical analysis of statistical and trigonometric concept development.

The second panel *Dance and metaphors in mathematics learning* explored how metaphors can be understood in an embodied way and what the relations between mathematics, language, and movement are from an embodied perspective. Soto-Andrade and Diaz-Rojas approached the idea of metaphorizing from an enactivist perspective; they showed how bodily exploration of probability concepts reveals theoretical interconnections between Brousseau's TDS and contemporary debates in neo-materialism and agential realism. Efron continued on the topic of exploring probability through dance and brought the affective dimension into the conversation by explicating how confusion and embarrassment can ground probabilistic notions of uncertainty and randomness.

The third panel *Spatial sense and the generative power of the mathematical imagination*, questioned the role and limits of mathematical imagination, explored the ecological dimension of mathematics, and focused specifically on spatial sense as a grounded, embodied, situated, and speculative phenomenon. Gkreka further explored egocentric and allocentric dimensions as their alignment constituted a core difficulty in approaching space, even when supported by GPS technology. de Freitas explored the speculative nature of mathematical imaginations, by studying different scales of mathematical embodiment (from the individual, to the cultural, to the earthly) of spherical forms, including attempts to visualize and capture with gesture the four-dimensional sphere. Ferrara and Ferrari continued the focus on the power and limits of the human imagination, unpacking mathematical imagination as a situated bodily practice involving the materiality of various instruments; their analysis brought an affective dimension again into the conversation.

Finally, the fourth panel *Affect, art, and inclusivity of mathematics* centered around the topic of sensation and affect emerging through art and craft practices consonant with mathematics. We questioned: How is art different from mathematics? What is the agentic power of media in making/doing mathematics? How might embodied mathematics rethink the nature of diverse participation in education? Inspired by Rancière's approach, Nemirovsky, Kathotia, and

Mégrourèche elaborated on *mathematical aesthetics* as they examined how the entanglement of mathematical and craft aesthetics may play a significant role in countering the silencing aesthetics prevalent in mathematics education. Mégrourèche told the story of an interaction between Fibonacci number sequence and a weaving technique called "looping", by tracing the development of a series of pieces created by an artist and collaborator Geraldine. Way, Cartwright and Ginns reported on their translational research, jointly pursued by researchers and teacher volunteers, which strived to develop an evidence-based, curriculum-linked, classroom-ready professional learning resource for embodied learning in early years mathematics.

The TWG sessions also included a poster session. Posters introduced more examples of making and dancing art practices, which prompted students to experience new dimensions for mathematization (Flores and colleagues) and to proof in an embodied way (Rizzo). The topic of implementing embodied and material activities within existent educational practices was raised in the posters, thus signaling that those issues are still at the earlier stage of their exploration. Boonstra and colleagues and Nicolas-Noir and Dias raised the topic of teachers' professional development and creativity in embedding embodied activities and new manipulatives in the classrooms. Lentin brought in the issue of embedding an embodied activity with a digital app (TouchTimes) into a broader teaching-learning practice. Finally, Wagner raised the issue of how we can approach mathematics learning as an issue of mystery: he questioned how new-materialist perspectives can offer insights into the design of mathematical experiences as existentially meaningful and mattering for students.

Main outcomes and further exploration

Group discussions were robust and expansive, tracking the interrelations between three worlds of ideas: (1) movements and actions, (2) materials and manipulatives, and (3) concepts and knowledge. The conversations were seeking to resolve theoretical tensions across different approaches to mathematics, the body, and materiality. For instance, some scholars treat mathematical concepts as the *interiorization* of embodied experiences while others treat formal mathematics as *emerging* from material practices, including manipulation with formulas and definitions. Questions about the existence and nature of internal representations and interiorization were connected to discussing the nature of the mathematical imagination and the ontological status of mathematics. How should notions of imagination, semiotic mediation, thinking, reasoning, and abstraction be re-defined and re-described to match coherently the attention to mathematics as material and embodied practice?

Methodological concerns became a special focus within the group discussions. If a focus on materiality and embodied processes shifts away from theories of cognition as the internal representation of reality, intended research outcomes also turn away from merely representing the reality of mathematics teaching and learning. What kinds of new research methods are consonant to the more complex onto-epistemological realm of mathematics teaching and learning? How can research be both descriptive and transformative? How to study processes that are speculative? The group was very interested in research interventions that create new environments, diffract the mathematical concepts and teaching practices we take for granted, and foster social change. In this work of surfacing previously hidden dimensions of mathematical embodiment, group discussion affirmed the power of personal re-enactments of sensory-motor activities associated with

mathematical reasoning and problem-solving. Such re-enactments can both reveal new aspects of mathematical ideas and habitual material practices that are usually unconsciously performed. Yet, the researchers need to take care of avoiding the limits of their imagination and anticipation when trying to understand and facilitate embodied processes.

At the metalevel, participants reflected that in theorizing mathematics learning, researchers do not aim at providing a full description. Rather, they develop and offer to educators a convenient discourse for discussing previously largely unnoticed phenomena of multimodality, embodied creativity, the affective dimension of movement in mathematics, and others. More research needs to be done to be able to discuss better how the body itself operates in unscripted ways, as we foster embodied processes in mathematics education. Discussing the ethical aspects of our research focuses, the group questioned the choices of the criteria that mark the success of an educational intervention: for example, shall we aim for *effective* mathematics learning or *affective* learning of mathematics?

As a practical outcome, group participants were interested in further expanding connections through the online exchange of working papers and ideas. We also strive to explore alternative formats for communicating research ideas. In publishing practices, we seek to explore ways of better reporting multimodal data by promoting the use of more appropriate digital media such as video abstracts and articles. In conference practices, we seek for formats where participants can experience studied phenomena and thus better recognize them, as we probed already in the report of our group work.

Looking ahead, we will aim to bring teacher and student voices into our discussions to better explore the implications of this work in classrooms. We intend to address embodiment not simply at an individual scale, but across different scales—the intra-individual, the group, the collective—where material and embodied processes are often harder to study. Some participants aim to examine more carefully the ways in which teacher professionalization can involve the body and materiality. Other participants mentioned that in approaching mathematical embodiment we need to include broad human ecologies and non-human learners. Finally, political and ideological aspects were barely in focus this year, while such topics as personal responsibility, inclusivity, and sustainability go hand in hand with conceptual transformations entailed in embodied and material perspectives.

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