



Research paper

Embodied learning in teacher education: Investigating student-teachers' experiences in engaging with embodied cognition theories

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ABSTRACT

This study examines how integrating perceptual, sensorimotor, and reflective processes supports the learning of enactive cognition theory, demonstrating how student-teachers develop competencies for engaging with theory through lived, embodied experiences. We employed between-methods data triangulation, combining the PRISMA method, microgenetic, and thematic analysis of video and text data, revealing students' experiences. Findings describe how concepts of enactive theory become part of student-teachers' bodily experiences and reveal that reflective awareness of these bodily connections coupled with shared dialogue is pivotal for deep learning. This study's approach is a compelling demonstration of how enactive cognition can be operationalized in educational practice.

1. Introduction

In the past decade, advancements in cognitive sciences, particularly under the research program known as 4E cognition – Embodied, Embedded, Enactive, and Extended cognition (see Newen et al., 2018), have renewed and expanded experiential learning theories (Francesconi, 2023). Theories and empirical research within the 4E framework suggest that human cognitive processes, such as reasoning and making sense of the world, are deeply rooted in our perceptual systems and bodily movement during interaction with the environment (Shapiro, 2011). Our bodies, and the ways they engage with the world around us, significantly shape what and how we think. Recognising that cognition is not confined to the brain but depends on extracranial bodily processes, 4E approaches departures from traditional computational and representational models of cognition, which have long dominated learning theories. Within the 4E framework, variations arise in how bodily processes are understood to influence cognition and in what is considered part of these interactions—whether limited to body-brain dynamics or extended to body-brain-environment relationships (Newen et al., 2018).

Briefly, while the Embodied approach emphasises the role of body-brain connections, the Embedded and Extended approaches propose

that cognition is distributed across the environment (e.g., other people, objects, technology, etc), being either partially dependent on or partially constituted by extracorporeal processes. Enactive approach goes further, suggesting that cognition is not only shaped by these external processes between brain-body-environment connections but that action within the environment is the central mechanism underlying cognition. The way individuals engage with materials or other beings in specific contexts affords particular sense-making.

These evolving perspectives in 4E cognition offer new insights into the body's role in complex reasoning during learning, with important implications for pedagogical practices (Castro-Alonso et al., 2024; Schilhab & Groth, 2024). Embodied learning is identified when the design of the pedagogical practice intentionally considers the alignment of students' perceptual and sensorimotor systems and reflective processes¹ in the learning (Bergen & Feldman, 2007). Following this notion, a robust body of empirical work has demonstrated the relevance of embodied practices in education (for a review, see Jusslin et al., 2022), justifying the epistemological convergence of embodied cognition and educational sciences (Agostini & Francesconi, 2021). This includes integrating theoretical developments on embodied cognition into teacher education curricula, both as content (i.e., presenting theoretical

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¹ The term 'mental processes' can also be used in some literature to explain processes related to individuals' mental states, e.g., intentions and desires. We adopt the term reflective processes as it is more aligned with enactive approach to cognition. It is not a detached mental activity but a way the individual reorganizes its ongoing engagement to make sense of its own activity, experiences, and relations.

models that explain learning processes from an embodied perspective) and as a pedagogical approach (i.e., pedagogies that promote embodied learning), and developing methods for assessing the construction of embodied knowledge.

While there is a continuous interest in embodied learning approaches, student-teachers are not necessarily exposed to such embodied practices or encouraged to learn about theories that address embodiment in cognitive processes during their education and training. Current literature indicates that, firstly, most research on embodiment in learning is conducted in school contexts, targeting children and adolescents, and focusing on explicating correlations between movement (e.g., teachers' or students' gesturing) and learning (Hegna and Ørbæk, 2021; Jusslin et al., 2022). Thus, the focus of most the studies is on teachers' embodiment as 'what teachers do and say' and how it affects students' learning outcomes (Goldin-Meadow et al., 2009; Gillies & Rafters, 2020; Congdon et al., 2017; Mitchell & Reid, 2017; Wakefield & Goldin-Meadow, 2021). Less is known about embodied practices from students' perspectives, particularly, how embodied learning experiences promote conceptual and theoretical learning. Secondly, embodied learning is more commonly practised among adult learners in theatre, dance, and outdoor activities (Lawrence, 2012). Reports on embodied learning experiences in traditional classroom environments (e.g., lectures or group activities) that are not focused on teachers' or students' gesturing are scarce.

Hence, considering these gaps, the present study aimed to investigate embodied learning in teacher education, focusing on student-teachers' learning experiences through awareness of their perceptions, sensations, feelings, and bodily engagements. Particularly, we were interested in identifying the connections between student-teachers' experiences and the sense-making of the theory as an intertwined process. For this, we examined the learning processes created in the course 'Embodying Education for the Twenty-first-century Teacher'.² While presenting the theoretical frameworks on embodied cognition, the course also implemented an embodied learning approach (described further in the paper). We aimed to explore how student-teachers come to understand concepts central to enactive cognition theory (one of 4E approaches), as applied to education, by experiencing these concepts through embodied learning practices. To guide our study, we posed the following two research questions: (1) How do embodied learning practices in teacher education influence student-teachers' understanding of enactive approach to cognitive theory? and (2) Which perceptual, sensorimotor, and reflective processes do student-teachers engage in during embodied learning practices?

2. Theoretical background

2.1. Understanding concept learning in higher education: from cognitivist to embodied perspectives

Concepts, as elementary units of reason and linguistic meaning (Gallese & Lakoff, 2005), are foundational in human cognition. They allow the categorisation of entities and facts that organise our experiences, enabling us to understand what we perceive and think (Bruner et al., 1956; Murphy, 2002). Furthermore, our ability to conceptualise forms two-dimensional and dialectical processes, entailing summarising (i.e., grouping things by their similarities) and expanding (i.e., associating new and unknown entities with categories that are already familiar to us) the world, which is crucial for our practical engagements with others and the environment. Concepts are, thus, central to the development of memory, self-regulation, action planning, and various forms of communication, which are critical skills in human life (Oakes, 2008; Oakes & Rakison, 2003; Shanks, 2015). When we refer to concept

learning, we discuss how humans develop and utilise this ability to understand the world, which can be categorised, generalised, and applied to different situations. A constellation of concepts can create a theory of how the world works.

Theoretical accounts on the mechanisms (i.e., how cognitive processes emerge, operate, and are explained) of concept learning vary. The mainstream (cognitivist) models explaining concept learning rely mainly on the understanding that concepts are attributes of words (for a review, see Shanks, 2015) and are traditionally described as mental representations (Margolis & Laurence, 2007) bound by language development and use (Jackendoff, 1992). These models are grounded in a computational notion of cognition, where cognitive processes function like computer processes; situated in the brain and bounded by the mind (Pylyshyn, 1986). They explain the neurological activations of cortical regions in the brain responsible for emotions, feelings, and sensory experiences as a likely side effect of conceptual processing during conceptual thinking, emphasising the representational essence of concept learning (Dove, 2023). This computational perspective raises some criticism regarding the effectiveness of experiential learning practices in higher education, challenging how we can identify the experiential components of learning (Barnes, 2017; Cox, 2010; Nistor & Samarasinghe, 2019). From this perspective, concept learning (and, broadly, theoretical understanding) is assessed by observing and measuring students' ability to reproduce conceptual meaning. This includes qualitative and quantitative examinations of concept comprehension and demonstrations of their implications for problem-solving and practical implementations (Doppelt & Barak, 2021).

While we recognise the contributions of mainstream (cognitivist) theoretical models, in this study, we ground our work on an alternative view brought by embodied cognition theories (4E approach, for an overview see Newen et al., 2018). Cognitive processes involved in learning (i.e., how cognitive processes emerge, operate, and are explained) are not limited to computational and individual brain-operating processes but are spread out (distributed), involving sensory-motor systems, actual bodily movements, and interactions with the world (Kiverstein & Clark, 2009; Lindblom, 2007, p. 1112). Our experiences, perceptions, and possibilities of affordance are partly enabled by our bodies and their specific physiological structures (Uithol & Gallese, 2015). Furthermore, minds are not passive, nor do they exist independently of a person's environment. Instead, the relationship between an individual and the world is brought forth through actual engagement with others and the material environment. Social interactions shape who we are and what we can do, both individually and collectively (De Jaegher & Di Paolo, 2007; Kyselo, 2015). Engagement with material things is consequential for human becoming; it immanently extends our bodily, perceptual, and cognitive faculties (Malaouris, 2018), impacting what and how we learn from an early age (Alessandroni, 2020). Under the embodied framework, the seminal work on metaphors by Lakoff and Johnson (1980, see also Gallese & Lakoff, 2005; Johnson, 1987; Lakoff & Turner, 1989; Lakoff & Johnson, 1999) has shown that concepts are not simply symbolic and abstract representations but grounded in our perceptual and sensorimotor system—our bodily experiences. Thus, if conceptual thinking unavoidably depends on our perceptual and sensorimotor engagements (Bergen & Feldman, 2007), understanding how students make sense of such experiences should provide greater insight into, if and how, concepts are learned. This study adopts the embodied view to explore how these experiences influence concept learning in teacher education.

2.2. Embodying concept learning in teacher higher education

Embodiment in learning is not necessarily a new idea. Theoretical models and research on experiential learning (Dewey, 1963; Emig, 2001; Kolb, 1984) have long shown how bodily engagement in tasks (action) benefits learning processes. Experiences in practical situations enable a specific type of reflection and the construction of tacit

² Contact the first author for the syllabus of the course containing all the pedagogical strategies.

knowledge (Alexander et al., 2011; Rustici, 1997), fostering a meaningful approach to enhance competencies and skills applicable across different fields of knowledge and educational levels (Gross & Rutland, 2017). Reflection plays a crucial role in transforming experience into meaningful understanding. It is part of the dynamic interplay between body, brain, and environment, serving as the connecting tissue between doing (experiencing) and knowing (Laner, 2021). Reflection must also be understood as an embodied process — not merely a cognitive exercise detached from the body, but one that arises through and with bodily experience (Gallagher, 2023; Kinsella, 2007). It serves as the bridge that connects embodied action with conceptual understanding, enabling learners to make sense of their experiences and relate them to broader theoretical frameworks.

This also holds true to learning complex and abstract concepts that build on theoretical frameworks (Abrahamson, 2009; Dove, 2022, 2023). Different types of embodied learning practices that have successfully incorporated experiential practices in mathematics didactics (e.g., Nathan & Walkington, 2017) and sports education (e.g., Paloma & Taruffi, 2017), or gesturing and action observation in science, technology, engineering and mathematics disciplines (STEM) (e.g., Hutto et al., 2015; Kersting et al., 2023) are supportive for developing conceptual thinking. However, most attempts to embody concept learning in teacher education in higher education occur through promoting awareness of embodiment (Hegna and Ørbæk, 2021). This entails examining the correspondence between learning and movements, gestures, or actions (those of teachers' or students') produced in classroom situations (e.g., Beard, 2018; Guerrettaz et al., 2020) or by raising reflection on teachers' positionality in the classroom. In other words, many practices do not necessarily explicitly specify strategies for students to associate perceptual (e.g., something I perceive), sensorimotor (e.g., action that can be performed to engage with), and reflective processes (e.g., intentions, thoughts, desires) in an intelligible and meaningful manner (Barsalou et al., 2003).

Although such studies have contributed significantly to our understanding of the associations between bodily movements and concept learning, fewer studies address learning as a comprehensive sensory and bodily experience, focusing attention on bodily sensations and body awareness, or even on students' experiences (Hegna and Ørbæk, 2021). Students' experiences and perspectives are understudied, especially when methods involving reflectivity are used to assess learning. We agree with Francesconi and Tarozzi (2019) that adopting an embodied learning perspective, particularly that of phenomenological roots, means "taking seriously the idea that cognition is always and necessarily grounded in a bodily dimension and (...) intertwined with emotional, affective, reflexive dimensions" (p. 229). Thus, we argue that to advance embodied teaching practices, the challenge remains in examining embodiment from the perspective of students' experiences and exploring the creation of experiential anchors for concept/theory understanding —bridging corporeal sensations, feelings, movements, actions, and reflective processes (Lakoff, 1994; Gallagher & Lindgren, 2015). Such an approach would allow for a more dynamic and comprehensive clarification of the role of embodiment in the learning process.

3. The present study

The present study was embedded in the implementation of the course 'Embodying Education for the Twenty-first-Century Teacher', which was designed and taught by the authors and funded by a joint initiative of both universities (Tampere University and Brunel University London) through the Seed for Innovation Program. The course aimed to bring the theoretical contributions of embodied cognition theories closer to teachers' practices, including theoretical specificities of embodied, extended, embedded, and enactive approaches, under the umbrella term '4E cognition' (Newen et al., 2018) and their implications for education sciences and teacher education (Castro-Alonso et al., 2024; Kosmas

et al., 2018). Particularly, the course utilised the 21st-century skills framework to discuss how embodied cognition theories can scaffold various discussions regarding enhancing students' social cognition in small-group collaborative learning, understanding ethical engagement with technology and artificial intelligence tools, and improving communication and social interaction among children of different abilities. While building on knowledge of embodied cognition theories, the course was expanded to incorporate embodied learning, with a particular emphasis on the interconnection between perceptual, sensorimotor, and reflective processes.

For this approach, each theoretical body of work under the umbrella of 4E cognition (i.e., Embodied, Embedded, Enactive, Extended; see Newen et al., 2018) was presented to students through specific hands-on tasks designed to prompt experiences that can build on concept/theory learning. The purpose of these hands-on tasks was to provide student-teachers with a learning that would allow them to experience the processes described by the theories through specific concepts (explained in detail in the next section).

The course was offered to all teacher education degree programs at both universities as an optional five-credit summer school course in 2022. The universities were partners in developing the course syllabus and methods, and as part of the bilateral agreement established by the funding program, agreed to host at least one edition of the course. The course was delivered across five days of intensive teaching (6 h per day), each day addressing one of the 4E approaches in this order: Embodied, Embedded/Situated, Enactive, and Extended. In this paper, we describe the pedagogical strategy applied to present the fundamentals of enactive theory and its implications for education, particularly in communication and collaborative learning. Our criterion for selecting the lesson on enactive theory was based on students' feedback, as it was deemed the most applicable approach in learning contexts and the most impactful experience on the hands-on task.

3.1. Concepts in focus: supporting students to understand enactive cognition

Enactive cognition theory (considering specifically the contributions of Francisco Varela and colleagues; see Varela et al., 1991) explains cognition "as an ongoing and situated activity shaped by life processes, self-organisation dynamics, and experience of the animate body" (De Jaegher and Di Paolo, 2007, p.33). To understand this theoretical proposal, students must grasp the concepts of *autonomy*, *dynamic system*, *coupling*, *materiality*, *emergence*, and *coordination* – to mention a few – in the context of an individual's interaction with their surroundings (i.e., including other people and the physical environment). To develop the course, we took these central concepts and created strategies to embody its learning process. Embodying means bringing the phenomenon that is described by each concept to the level of a personal experience, bridging corporeal sensations, feelings, movements, and actions, as well as reflective processes that can lead to or anchor conceptual understanding (Lakoff, 1994). For example, to embody the concept of *coordination* –dynamic and reciprocal regulation of behaviours between people during an interaction, where patterns of mutual responsiveness emerge over time (De Jaegher & Di Paolo, 2007)–, we had to choose an activity that elicited sensations (e.g., the other person's presence in the interaction), feelings (e.g., of attractiveness or repealingness), and thoughts (e.g., of mutual understanding) that lead students to act in accordance with others' actions. Furthermore, our strategy involved exposing students to the combination, in this order, of a hands-on task for introspective reflection on social interactions, a lecture presenting the guiding tenets and concepts of the theory, and a small-group discussion that bridged experience and theory. The hands-on activity afforded students to experience being in a temporary *dynamical system*, *coupled* with another student to *coordinate* a specific action. The action (drawing together) is mediated by different *materialities* (pencil, crayons, pens) that, when changed, create a different sensation for the student,

affording new ways of *coordinating* with the peer.

3.2. The hands-on task ‘Letting it flow’

The embodied task was inspired by the workshop ‘Prisma: Interacting Through Difference’ (De Jaegher, 2022), which is an embodied, intersubjective approach to investigating the interaction experience based on embodied cognitive science and movement practices (for details on the method, see De Jaegher et al., 2017). For this study, we adapted one of the workshop’s tasks, consisting of interacting through drawing, followed by the PRISMA introspective method for annotating one’s sensations, feelings, and thoughts during the interaction (De Jaegher et al., 2017). The task was titled “Letting it Flow” (see Fig. 1). Participants were divided into trios (two drawing partners and one observer) and asked to draw a spontaneous figure together without verbal communication. The drawing started and ended in the same spot in the middle of the page. Participants had 3 min to draw and then changed partners for a new round (this process was repeated three times). While drawing, participants were advised not to lift their pens from the paper and to create a drawing with a single continuous movement. Also, for each drawing round, we purposefully changed drawing materials (ink pens, permanent markers, and wax crayons) to modify the sensations created by the different tools in contact with the paper (A3 white paper).

This task purposefully brings to an experiential level the sensations, feelings, thoughts, and actions described by the concepts (i.e., coupling, coordination, precarity, tension, materiality, etc.) that explain social interaction dynamics in enactive cognition theory. For example, the framework of the task – drawing together – creates a setting for students to understand what *coupling* means: as a temporary engagement with the other that creates an interaction system. The demands of keeping the pencil moving while respecting the boundaries between following/leading or approximating/distancing oneself from the other materialised an experience of *tension*, prompting students to sense and feel how *coordination* occurs. Changing partners and materials during each iteration allows for distinct experiences in negotiating such tensions, as well as intentions, desires, and emotions when producing the drawing. Pens, permanent markers, and wax crayons afford different resistances to the

paper, distinct visual inputs, and sensorial experiences of motion, which reveal the role of *materiality* in social interactions.

While participants engaged in drawing, they were asked to bring awareness to their bodily sensations (e.g., involuntary movements, agitation, muscle relaxation), emerging feelings (e.g., fear, joy, awkwardness), and thoughts (e.g., semantic interpretations of the lived situation, such as “this is difficult,” “I am thinking about what should I do next”), which is also part of the PRISMA introspective method (De Jaegher et al., 2017). Immediately after each drawing session, participants would make notes of their sensations, feelings, and thoughts, creating what we denominated as introspective notes. The introspection notes, then, bring awareness to how these embodied experiences are intertwined and shape thoughts, decisions, and actions within that interaction. We adapted the original version of the PRISMA workshop (De Jaegher, 2022) to use the whole-group discussion (as opposed to participants’ small groups) to construct a configuration of individual shared experiences. This approach allowed the teachers to mediate the experience, bridging the gap between experiential and conceptual development in some moments. When participants share their perspectives on the same experience, they are creating collective agreements on how that concept can be lived, recognising its role in a multitude of dimensions. Through this task, participants discover tendencies in their experience of interacting, which are determined by how the body perceives and engages with the environment (both material and social), and gain insight into their own participation in interactive situations while contributing to the science of experiential interaction dynamics.

3.3. The lecture: understanding social cognition through an enactive approach

Enactive cognition theory was addressed specifically from the point of view of social cognition (i.e., intersubjectivity), introducing participatory sense-making as an alternative to individualistic models of social cognition (Di Paolo et al., 2018). The lecture underlined two important ideas: First, cognition is dependent non-trivially on the body and its means for actions (in)with the environment. The cognitive system is an active, embodied agent and depends on affordances for action in and



Fig. 1. Image of the task “Letting it Flow”.

with the environment to make sense of the world (Gallagher, 2005; Gallagher & Bower, 2014). The material world thus shapes and influences these enactments. Second, cognition is a relational and affect-laden process rooted in biological self-organisation (De Jaegher & Di Paolo, 2007). We make sense of the world through our engagement with and in it, including our interactions with others, guided by what is important to us (De Jaegher, 2013, 2021; Di Paolo et al., 2018; Hutto et al., 2015; Varela et al., 1991). Furthermore, we connected these theoretical insights to educational psychology, especially autism research, exploring how enactive approaches reveal alternative understandings of autistic communication and collaboration (Fantasia et al., 2014; Ferreira & Bottema-Beutel, 2023). This perspective underscores the significance of embodiment in education and underscores the necessity of inclusive pedagogical practices.

3.4. Group discussion: understanding students' learning experiences

After the lecture, we facilitated a group discussion elicited by the materials produced by participants during the hands-on task (see Fig. 2). The discussion followed similar protocols of elicitation processes in focus group interviews (Barton, 2015; Harper, 2002), focusing particularly on exploring students' experiences of interacting and how they engaged in the drawing together. The drawings elicited reflections on their engagement processes, allowing the researcher/teacher to mediate the group discussion and explore specific aspects of the experience directly connected to the theoretical concepts.

4. Materials and methods

In this study, we propose capturing the rich intricacies of the human

experience by employing a qualitative and exploratory study design, which builds on data triangulation methods. Data triangulation has long been widely used in qualitative research (Denzin, 1978; Denzin & Lincoln, 1994), especially among studies involving complex processes such as human learning, development, and social interactions. Here, we employed between-methods data triangulation (Flick, 2004), combining video and text data to enhance the examination of students' experiences during conceptual learning in an embodied way.

4.1. Participants

Participants for this study were recruited through convenience sampling from students enrolled in the course "Embodying Education for the Twenty-first-century Teacher," offered on-site at the university (Tampere University and Brunel University London). It was also possible to participate in the course without participating in the study. However, all enrolled students agreed to participate and provided their written consent for the use of their data and images. In total, 16 students (aged 26 to 46, with 1 male) participated in the study, divided into two groups. Nationalities varied across British (5), Finnish (2), Korean (2), Chinese (2), Indonesian (1), Turkish (1), Thai (1), Brazilian (1), and Mexican (1). Most participants were student-teachers enrolled in teacher education programs (including class and subject teachers), except one from a business school who specifically requested to attend, as they were interested in teaching.

Ethical approval was sought from the relevant authorities (The Ethical Committee of Tampere Region and the Ethical Committee of Brunel University London). This included consideration about the power relations present when students are involved in a programme led by the teacher and researcher (we addressed this by ensuring no student was



Fig. 2. Examples of the drawings produced during the task 'Letting it Flow'. First and second rounds of drawing, respectively.

obliged to be involved), a clear understanding of what the project involved (provided through a participant information sheet and signed consent) and confidentiality and anonymity. To ensure anonymity, we have used pseudonyms in this paper and have intentionally omitted specific details about the characteristics of the students whose data extracts are included.

4.2. Data collection and specific analytical approaches

The data collection respected the organisation and the sequence of activities foreseen for the course. We first collected video recordings of the hands-on task “Letting it flow” (a total of eighteen 3-min-long videos) using a stable camera positioned to capture pairs executing the task together. Subsequently, we collected the materials produced during this task, including drawings and introspective notes elaborated by students (eighteen lengthy annotations, each one page in length and 15 drawings). Lastly, we recorded the group discussions after the task (a 45-min video), which was transcribed verbatim, generating materials for analysis.

4.2.1. Analysing video recordings of the hands-on task “Letting it flow”

The video recordings from the hands-on task were analysed through microgenetic analysis (Siegler & Crowley, 1991), following a specific coding scheme (see Table 1) that reflected the behaviours through which this social interaction of drawing together was constructed. Microgenetic analysis focuses on identifying the moments of change and stability in interactive, learning, or developmental processes and operates under three basic rules (Siegler & Crowley, 1991): a) observation spans from the beginning of change until stability; b) observations are density high; and c) observable behaviours are submitted to trial-to-trial analysis, allowing inferences of how processes emerge and are sustained. We applied microgenetic analysis to identify the moments of change and stability in participants’ movements while drawing together. Particularly, we focused on unfolding eye-gaze, hand movements, and facial expressions (e.g., smiles, laughter, and surprise) to capture observable signs of behavioural regulation between participants. The combination of these behaviours has been widely used for analysing interaction dynamics (Lerner et al., 2013; Streeck et al., 2013) and constitutes the essence of the proposed interaction in this task.

The microgenetic analysis was supported by ELAN software (Brugman & Russel, 2004), which allowed the identification and measurement of individual behaviours across the timeline of the interaction, creating a map of how participants constructed the interactions. Once all coding was complete, we extracted the density plots and the statistics generated by the software to understand how bodily engagements provided opportunities for analysing the emergence of coordinated actions and then analysing behavioural regulations to maintain the task’s goals. This analysis provided a glimpse into how participants constructed the interaction, giving an embodied dimension to the coordination that emerged and was maintained during the task engagement.

Table 1
Coding scheme for social interactions during “Letting it flow” hands-on task.

Type of behaviour	Specificity of the observable behaviour	Description of the behaviour	Code
Gaze behaviour	Gaze on their own work	Eye gaze is identified in a continuum. Eye gaze remains towards the participant’s own hand.	(GOW)
	Gaze on other’s work	Eye gaze is identified in a transition. Eye gaze is on the partner’s hands.	(GOSW)
	Gaze toward the partner	Direct gaze to the partners’ faces.	(GTP)
	Gaze elsewhere	Direct gaze away from drawing or partner.	(GE)
Movements	Movement towards the other	Movement of the hand holding the drawing tool moving toward the partner’s hand. The movement is identified concerning the other person’s hand.	(MTO)
	Movement together	Participants’ hands are synchronised– they follow each other’s rhythms and directions.	(MT)
	Movement away from the other	Movement of the hand holding the drawing tool away from the partner’s hand. The movement is identified concerning the other person’s hand.	(MA)
Facial expressions	Smile	Identified by facial muscles around the mouth moving diagonally up.	S
	Laugh	Smile followed by sound.	L
	Surprise	Identified by the elevation of muscles on the forehead above the eyebrows.	Su

4.2.2. Analysing the introspective notes

The introspective notes consisted of one A4 page of annotation from each participant (18 pages) describing their sensing, feeling, and thinking, collected immediately after each round of the “Letting it flow” task. Participants were prompted to reflect on their bodily sensations during the task and identify their emerging feelings and thoughts. The prompts included a ‘complete the sentence’ exercise inspired by the PRISMA method (De Jaegher, 2022; De Jaegher et al., 2017), such as “As I interacted with my partner, I could sense my body ...”. The annotations made by the participants were freestyle. Participants had 5 min to make annotations on each of the three rounds of iteration.

While the introspective notes offer insights into participants’ experiences interacting and how they perceive the links between sensing (their body), emerging feelings and thoughts, they also allow us to analyse how these different aspects of human experience are understood. For example, how participants differentiate (or not) sensations, feelings, and thoughts and how they guide their actions within the interaction based on such distinctions. Such analytical dimensions are critical when discussing social cognition from the perspective of enactive approaches, as they provide insights into the complexity of the dynamic exchange between partners (see Di Paolo, 2018; Di Paolo et al., 2018). The agents – in this case, two students drawing together – interact in a continuously changing way and simultaneously allow for the continuation of the interaction itself. The analysis of the introspective notes opens a window for understanding each participant’s self-perception (what they sensed, felt, and thought during the interaction) and, based on these individual experiences, understanding what supported the maintenance of the interaction.

When the PRISMA method (De Jaegher, 2022) is applied in its entirety, participants generate and analyse the data, as they are creating configurations of the different perspectives on the interaction experience. However, since we only addressed participants’ self-perception of the interaction in this study, the researchers (authors 1 and 2) conducted the analysis. We distinguished between the first, second, and third-round notations for each participant and identified the most expressive observations among participants’ notations, thereby approximating their experiences. Organising the analysis according to each iteration allowed for the unfolding of conceptual development, revealing differences in what and how participants sensed, felt, and thought during the task from one round to the next. This analysis identified participants’ perceptions of the interaction (see Table 2).

4.2.3. Analysing group discussions

We employed reflexive thematic analysis to analyse the transcripts of group discussions (Braun & Clarke, 2019, 2021), identifying the most relevant ideas of the interaction experience. In reflexive thematic analysis, the conceptualisation of themes is understood “as stories about particular patterns of shared meaning across the dataset” (Braun & Clarke, 2019, p. 591), differing significantly from other types of thematic analysis that treat them as conceptual summaries gathered based

Table 2
Content analysis of the introspective notes.

First round		
Sensing	Feeling	Thinking
Attention	Oneself in the interaction	Attention
Non-attentive, Mind wandering Sensed observer looking at her Heard giggling Saw interaction (from partner) Frustrating Awareness of what picture is becoming	Non-relevant, Individual, Curious Enjoyment Humoured Anxious (mind is blank)	About other things, Non-relevant things This is difficult Desire to communicate How much time left
Materiality	Interaction dependent	Ideas about the task
Bright colours Sound of the pen Movement of the pen Sensing being in a cloud Colour of chalk and paper Position of paper Movement of pencil	Discomfort, Stress, Unsure about the connection, The fun of the activity No pressure Expectant Connecting with partner Conscious of others	Task is not challenging, Task is not about simulating, Doubting doing the task correctly, Expectations about the task No restriction Freedom Wanted it to be meaningful Wanted it to relate to how she was feeling Wanted it to be beautiful Ideas about what was possible No ideas
Bodily sensations	Fluctuating states	Executing the task
Arms resting Bent back Eyes on paper My body moving actively My body still but active Body is relaxed Relaxed motion	Bored/Blank Happy, happy (by end) Calm/Relaxed Peaceful Focused Confused Uneasy More engaged <i>Movement of the interaction</i> Being pulled by the other Flow of the movement Relieved (as picture comes together)	Wanting to collaborate, Painting techniques, Past experiences drawing Needing instruction Wanted to connect with what her partner was drawing. What is my partner thinking Colours trigger ideas Use partner's creation
Second round		
Sensing	Feeling	Thinking
Attention	Oneself in the interaction	Interactive dynamic
Attentive, Concentrated Awareness of the orientation of the paper Observed partner's drawing	Being the coordinator, Being a partner Leading Confident Active Free Anxious about what they'll create	About anticipating other's actions, Giving cues to the partner, Meaning of partner's actions, Ensure my own idea. Wanted to connect with partner Didn't want to cross a line About options to draw Doing something different to partner Wanting communication What will be created What is partner thinking

Table 2 (continued)

First round		
Sensing	Feeling	Thinking
Attention	Oneself in the interaction	Attention
Bodily sensations	Fluctuating states	Materiality of the task
Hands firm, Adjusting eyes to see others work, Light hands, Smells and textures, Partners' hands, Heart beating fast, Active movements Heard laughter Unable to see all the drawing Noise of chalk Unable to move hands as they'd wish Feels rough (not smooth) Restricted in use of hand Itchy finger Sensation of finger touching the chalk	In-tune/Synchronised Confused Happy, Focused Surprised Less enthusiastic Quite free to draw Neutral (not expecting anything particular) Great – by end In suspense Embarrassed, then reassured There was potential Clarity Responsibility Enjoyment Pressure Uneasy	Associations between colours and drawing Looks nice, Pens are not nice to draw with, Looks like a volcano. Chalk was uncomfortable Pens were clumsy (hindered drawing) Doesn't like the chalk <i>Evaluating</i> Presenting the picture well Liked what the other did Funny outcome Able to create something without communicating

on frequencies of code application (Braun et al., 2018). In reflexive thematic analysis, themes evolved through an inductive and deductive process, focusing on both semantic and latent coding. Therefore, themes are generated by examining the data in different ways and multiple times. In this study, we recognise that the key concepts of the enactive theory are embedded in the interpretation of the group discussions and guide the generation of the themes.

The analysis was conducted by a research assistant and the first author, with the second author participating in reflective discussions as the agent responsible for questioning and querying the assumptions made during the interpretation and coding of the data (Braun et al., 2018). The team met to agree upon codes and interpretations, and the two authors conducted the final theme organisation (see Fig. 4 for an example of the coding process).

Code reliability is not a central concern in reflexive thematic analysis (Braun & Clarke, 2021; Braun et al., 2018). However, we were attentive to the importance of aligning ideas and maintaining coherent data interpretation. The analysis resulted in the following four themes: (1) Interaction Dynamics; (2) Task as Guide for Action; (3) Materials Shaping Interaction; and (4) Materials Defining Actions (see Fig. 5).

4.3. Triangulating data analysis

As a final step in the analytical procedure, we triangulated all results to gain a comprehensive understanding of the embodied concept learning process. This data triangulation was purposefully designed to integrate first-, second-, and third-person perspectives on human experience, providing visibility to the association between perceptual, sensorimotor, and reflective processes (see Fig. 3 below). The video data provided behavioural references for the interactive experience, which was purposefully designed to embody specific theoretical concepts of the enactive approach. The text material from students' introspective notes and the group discussion provided insights into how the experience is transformed into concepts. The alignment between the experience and the arrival of abstract notions reveals the path of embodied conceptual

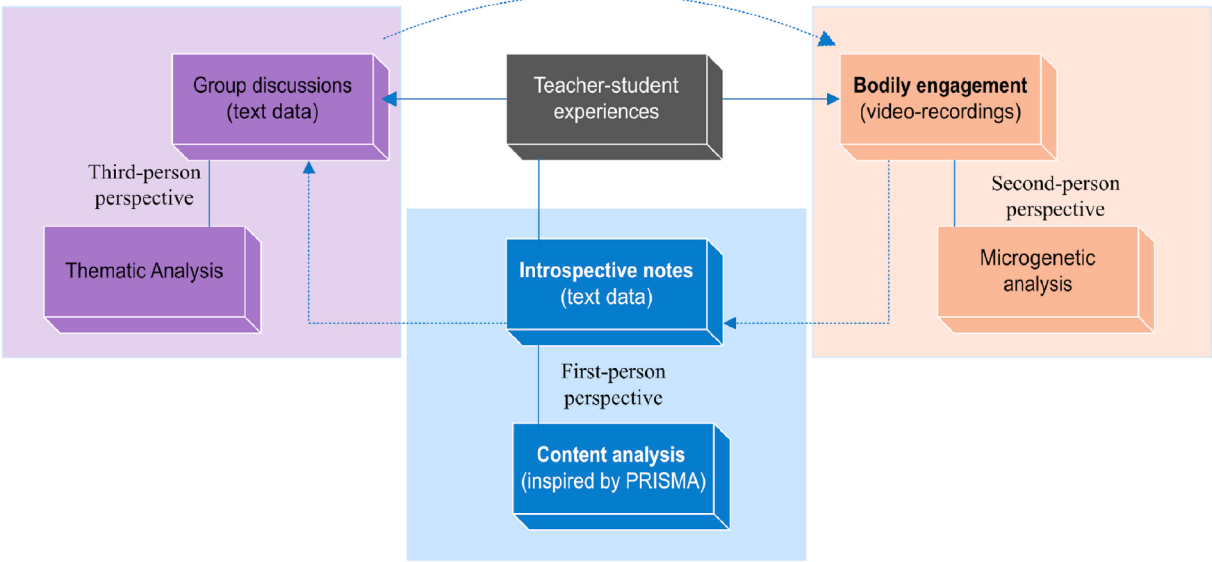


Fig. 3. Diagram of research methods, analysis, and data triangulation.

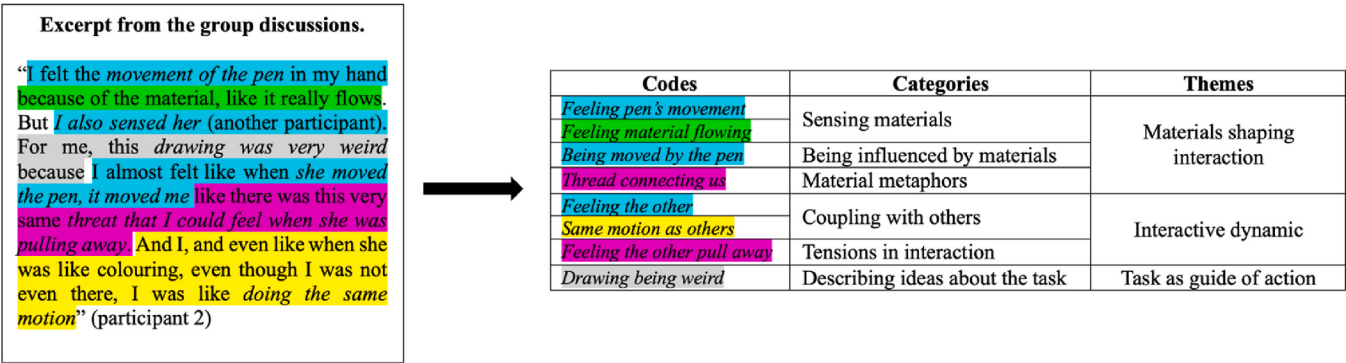


Fig. 4. Example of coding process in reflective thematic analysis.

THE THEMES

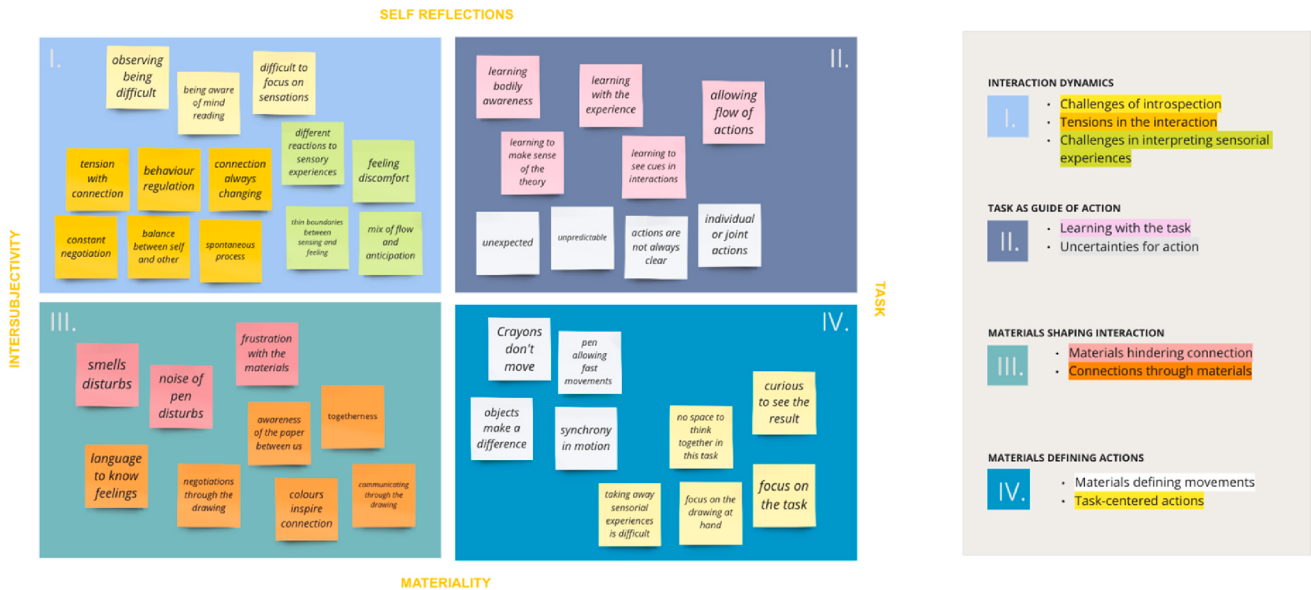


Fig. 5. The construction of themes from group discussions.

learning.

The triangulations included analysing all the concepts and tenets presented during the course and expanding the search for evidence of when the experience provided the grounds for understanding the concept (theory). The starting point of this process could, in theory, be any of the datasets. However, our experience showed that starting from the analysis of group discussions facilitated the identification of core concepts relevant to students. Group discussions allow participants to express what they believe is most relevant to and about their learning process. After identifying the concept, the triangulation integrates observable behaviours (3rd perspective) and reflective processes (1st perspective) to reveal how the embodied experience affords concept understanding. Therefore, aligning experience and concept in all datasets was essential for this analytical procedure.

5. Results and discussion

The results from the data triangulation provided two different insights into how embodied learning practices influence student-teachers' understanding of enactive approach of cognition. The first insight is that experiences created in the practice materialised or brought to a concrete level the abstract concepts explaining enactive cognition theory. Particularly, the meaning and role of foundational concepts in enactive theory, such as *materiality* and *interactional tension*, used to account for the mechanisms of social cognition. This insight answers our first research question – How do embodied learning practices in teacher education influence student-teachers' understanding of enactive approach to cognitive theory? – and is explained in the subsection *Experiences affording concept/theory understanding*.

The second insight relates to learning to improve one's competence in social cognition while learning the theory, revealing the specific perceptual, sensorimotor, and reflective processes involved in the embodied learning. This insight addresses our second research question – Which perceptual, sensorimotor, and reflective processes do student-teachers engage in during embodied learning practices? and is described in the subsection *'Building Competence in Social Cognition within an Embodied Learning Experience.'*

5.1. Experiences affording concept/theory understanding

The first finding relates to how participants interpreted and explored the concepts addressed to explain enactive cognition theory from the perspective of participatory sense-making during the course. Two concepts were particularly significant and appeared across the data of all participants: *materiality*—the unforeseen influence of materials in influencing actions and shaping the dynamic of the interaction—and *interaction tensions*—the combination of different sensations and feelings that emerge during the interaction and guide the continuous negotiation between the two interactors, trying to balance their individual and joint systems. These two concepts are essential to understanding participatory sense-making as the dynamic constituting human social cognition. The hands-on activity provided a concrete venue for participants to experience the role of *materiality*, what and how *tensions* were felt, and what they created in social interactions. The materialisation of a concept through the sensations, feelings and thoughts emerging in the experience allows a direct connection between theory and reality or, in other words, an understanding of how the concept works in practice.

Participants' awareness and understanding of materiality and its implications for the interaction became explicit when we examined the group discussion and traced back the data referring to materials in participants' experiences. For example, participants reported becoming aware of how the texture of a specific material impeded desired actions: "I was just frustrated with the crayons because it was not making the lines I wanted" (Julia, 26 years old, Female), or how the sound of a material affected their mood during the interaction: "they're using the markers, and the markers make a lot of noise like it makes too much

noise for me. It made me annoyed" (Akemi, 23 years old, Female). The combination of bodily experiences and reflective processes about specific aspects of different materials (i.e., textures and sounds) created a sensorial-motor awareness that grounded meaning-making about the concept in the context of social encounters. The abstract notion of materiality gained a concrete dimension anchored in one's sensations, feelings, and thoughts produced within that experience of drawing together.

The embodied practice also allowed participants to concretely experience how materiality shapes the interaction itself, guiding one's actions in the interaction dynamic. For example, in the excerpt below from the group discussion, participant Sofie (26 years old, female) explains how the mere colour of the pen guided their intentions with the drawing and shaped their intentions and expectations with their partners (see Fig. 6):

"(...) I saw that I have blue sharp pen. So I would draw something related to the sea. I hoped that she (Julia) draw the mountain, I guess. So I tried so badly to give her a hint with my movements that I had drawn the fish, which was looking at the birds. So I'm like, this is a fish and the wave's motion; please draw a mountain, and I hoped her drawing was a mountain. So please complete my!" (Sofie, 26 years old, female).

The materials' characteristics or quality are no longer an adornment to a somewhat abstract or conceptual picture, but concrete means through which intentions are shaped in the interaction. The colour and type of pen influenced the participant's creative intentions in drawing, consequently affecting how they positioned themselves in the interaction with the peer. This specific transformation from abstractness to concreteness can be traced in the introspective notes and the micro-analysis. Combinations of descriptions in the dimension of sensing, such as "I became attentive to the bright colours we had" (Sofie's introspective notes after interacting with Julia) and "I was noticing other's active movement" (Julia's introspective notes after interacting with Sofie), provide us with a glimpse of how participants fine-tuned their awareness of the materials and the other in this specific interaction. This awareness builds on the dimension of thinking, as participants' introspective notes reveal how materials are incorporated into sense-making: "I thought of making it look like a volcano. I was thinking all the time about giving cues to my partner" (Sofie's introspective notes after interacting with

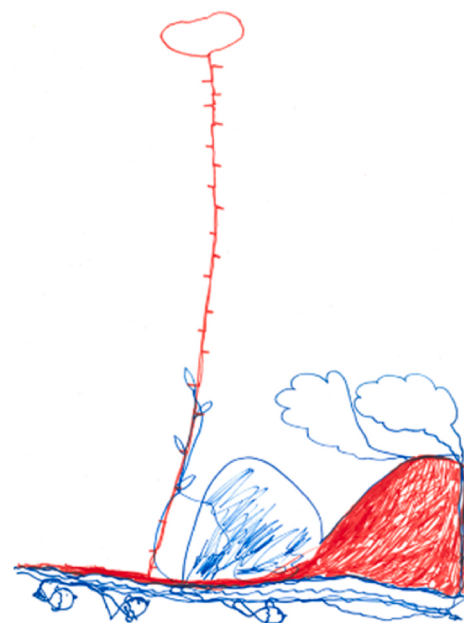


Fig. 6. Drawing together, participants Sofie and Julia.

Julia). The blue colour of the pen directs Sofie to guide the interaction—to show the partner what to do. It shapes participants' thinking and guides their intentions for interacting with others and creating new material products (in this case, the drawing). Thus, we observe that materiality not only contextualises social interaction but also becomes entangled with our lived experiences and thinking (Malaforis, 2018).

At the same time, Julia's notations show us that such intentions were communicated: "I was thinking of associations between colours and drawing" (Julia's introspective notes after interacting with Sofie). This dynamic is confirmed by analysing participants' behaviours captured by the videos. We identified different moments where Sofie actively seeks Julia's movement (moves towards the other rapidly) and then returns to her initial point in the drawing—a dynamic we interpreted as creating movement for attention – and when Julia stops her movements to observe what Sofie is doing. In this example, Sofie starts drawing over Julia's work (see Fig. 5, the blue lines coming from the bottom of the drawing, passing through the red mountain in the bottom right corner and culminating in two steam cloud-shaped drawings). The experience of "giving clues to my peer" appears when the colour's borders are crossed, calling Julia's attention to stop and observe. Sofie concretely integrates 'the sea and the land', creating a specific meaning for her peer's red drawing. This entire dynamic is built and shaped by the colour of the pen.

Another important concept learned through our embodied pedagogy was the concept of *tension*. Similar to materiality, our data triangulation captures different aspects or dimensions of tension. In group discussions, the category 'Tensions in Interaction' in the theme 'Interaction Dynamics' shows how participants recognise the ambiguities and the different feelings provoked during the hands-on task. For example, one participant noted the tensions in the balance between self and others, being torn between what she wanted to do in the task and the need to keep the interaction with the peer: "I realised that the task requires a little bit of cooperation from the other, but I focus on what I need to do in order to make the task easy" (Sofie, 25 years old, female). Another participant explored the notion of tensions from the perspective of her

feelings during the same interaction, recognising how the connection is always changing: "I felt calm, but also some discomfort. Like ... we have that awareness of the other person in the paper, but I also felt it was soothing because I feel that she, herself (referring to Akemi, 23 years old, female), is very soothing, but it still made me a little bit nervous to be so close and dependent" (Telma, 24 years old, female).

Tracing back to the introspective notes and participants' actions during the interaction, tension is evident throughout the entire drawing experience. For example, the researchers noted several instances of synchronisation and movement negotiation during the drawing task, manifesting the "pushes and pulls between individual and interactional autonomies and normativities" (Di Paolo et al., 2018, p. 139), as expected in interaction dynamics. These negotiations are evident in participants' movements towards each other, as they regulate the peer's movement within the boundaries of the drawing or create alternative designs within it. To illustrate, in the interaction between Kate (27, female) and Taylor, we can see how participants constantly negotiate the space in the drawing and build on each other's ideas (see Fig. 7). While the division of space is rather clear in this interaction (the right side is predominantly occupied by Taylor in purple and the left by Kate in light blue), the analysis of their movements reveals several instances when they advance towards each other's side. In response, neither of them retreats, pulling away from the approximation; they move together (e.g., sidelines in both colours) and take the opportunity to build the connections for the drawing (e.g., fishing rod in purple).

The negotiations sustained participants' attention to the joint activity and created boundaries between their individual needs (wishes and interpretations for the drawing) and the collective needs (doing the task together). It reflects the paradoxes, tensions, and unpredictability of social interactions, a key characteristic of social dynamics from an enactive perspective (De Paolo, 2018; Kyselo & Tschacher, 2014). At the same time, individual-level references to feeling "in-tune" or "synchronised" appear in the introspective notes, revealing that what we observe regarding participants' actions aligns with their perception of the experience.

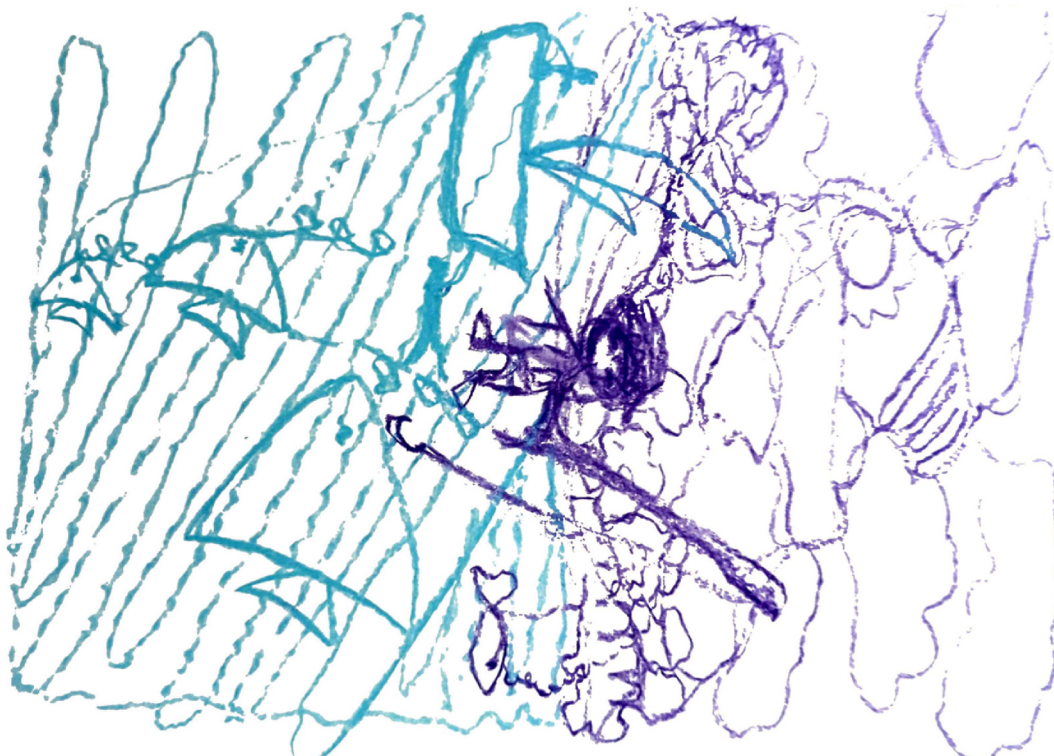


Fig. 7. Drawing made by Taylor and Kate.

By examining the triangulation of data, it was possible to identify how the embodied experience, particularly whole-body engagement in the drawing task, supported the reflective processes, creating experiential anchors for concept learning. The behavioural observations in this study indicate that certain combinations of motions and emotions during the interaction could create the experience that materialises the idea behind the concept. We observe a similar phenomenon to those reported in studies on whole-body movements and concept learning (Cutica et al., 2014; Glenberg, 2017; Macedonia & Klimesch, 2014)– movements in an engaged activity can extend inner cognitive processes and make abstract thoughts and ideas more concrete, salient, and easy to remember. However, our study goes beyond this by providing insights into developing learning processes that integrate perception, sensorimotor, emotional, and reflective processes. Students are building experiential repertoire while living the situation of learning the theory itself. We don't assume this is the only or best way to do it, but we view it as an interesting approach to thinking about embodying concept learning in higher education.

5.2. Building competence in social cognition within an embodied learning experience

The second finding concerns how embodied practices facilitated progressive learning and promoted competence building, specifically enhancing participants' abilities in social cognition. We identified that participants improved their competencies for collaboration, following the tenets of enactive theory, opening new ways of engaging with materials and others as they faced a new opportunity to work together. Participants acknowledged this learning process in group discussions. The category *Learning with the task* in the theme *Task as a guide for action* brought together participants' perception of how the task afforded opportunities to "be aware of others and oneself" and "learn to see cues in the interaction" that allowed for the interaction to be maintained, which summarises quite clearly the idea of coordination described by enactive theories. For example, participants shared observations related to unspoken negotiations involved in the interaction while recognising what they had learned from the experience to deal with such moments of tension. In the three excerpts below, participants are talking about their experiences in the second round of the task:

"I already had this understanding like, OK, it's not easy to draw like that, so how could I do it? I was thinking, how would I do it? So, of course, it affects us when I start the next time" (Mary, 31 years old, Female).

"(...) based on my experience with her (Anna) in the first round ... So, I felt the same way when she (Julia) said, you know ... like, I was far away. I was thinking like: OK, we need to meet. But will she come down? OK, let's hurry up to go up there" (Suki, 29 years old, Female).

"(...) then, in the second round like you were still the same person in there. So I was like, oh, let's see how we are going to collaborate together and draw. It was kind of similar to the position that she took in the previous round, drawing fiction, and I was like, oh, yeah, I felt I knew what was going on. So when we met, finally, I was like, OK, who's going to lead the drawing? Let me start. And then she will keep following and I wanted to give up, you know, the give space to you (Julia). But you were kind of waiting and allowing me to like, turn off like, OK, let's keep doing it" (Suki, 29 years old, Female).

We also observed such results in the increased frequency and time spent in motions depicting synchrony (e.g., movement together) or seeking engagement (e.g., movement toward the other and gaze at others' work, emotional responses such as smile and laughter) in the task *Letting it Flow* in almost all the groups. The increase in these specific behaviours was interpreted as a signal of a learning process occurring through the experience of working together, resulting in more non-verbal negotiations embodied in the movements that participants

expressed. In other words, participants were able to work together better in their second round of interaction.

Lastly, learning through 'experiencing' can also be translated from the subtle changes in participants' descriptions of their introspective notes. The content analysis of introspective notes from the first round reveals an experience characterised by diffuse attention, feelings of discomfort, stress, and overall thoughts that focus on the results of the action together (see Table 2). Although the activity remains the same in the second round, we observe a change in what participants become aware of. The introspective notes in the second round include sensations of attentiveness and relaxation, as well as direct mention of being more aware and having more clarity of the other in the interaction. Participants describe themselves as partners and coordinators and use a broader scope of feelings that characterise participants' positive states and thoughts. This reveals, in practice, an important theoretical point in enactive theory– the experience with others shapes how we perceive ourselves and our surroundings (De Jaegher & Di Paolo, 2007). Consequently, this implies more complex reflections and reasoning each time we engage in social encounters.

Previous studies, particularly from an experiential learning perspective, have shown that embodiment in learning can promote competence building (i.e., students become more proficient at performing a specific task). However, to our knowledge, our results describe for the first time the associations between perceptual, sensorimotor, and reflective processes behind this competence building. It offers insights into how such associations change and transform how students perceive, sense, and feel themselves, others, and material across multiple iterations of similar situations (i.e., interacting with different partners and materials). Each experience is unique but collectively enhances students' competencies for interacting with others. Thus, one could point out that the individual experience of drawing with others, while encouraging reflection on one's sensations, feelings, and thoughts, builds participants' intersubjective competencies (i.e., social cognition), which is precisely what enactive cognition approaches support student-teachers in reflecting. They had an opportunity to be aware of and recognise the tensions and ambiguities that rule all social encounters and learn how to respond to them, as theorised in the enactive cognition approach (De Jaegher & Di Paolo, 2007).

It is important to recognise that from the perspective of researcher positionality, researchers were heavily implicated in delivering the practice that circumscribed the study. Although researchers' practices are not the focus of the study, it is relevant to note that they have insights into how students' experiences happened, which is part of the investigative work. If the data were to be analysed by researchers who had not participated in the course implementation, other insights could be found.

6. Conclusions

This study explored how student-teachers come to understand concepts central to theories of embodied cognition as applied to education by directly experiencing these concepts through embodied learning practices. Building on methods to grasp and study intersubjectivity (PRISMA, see De Jaegher et al., 2017; De Jaegher, 2022), our embodied learning approach focused on providing participants with lived experiences of specific theoretical concepts of enactive cognition and the necessary space and time for reflecting on them. At the same time, our analytical approach integrated first, second, and third-person perspectives, aligning multiple aspects of the experience (perceptual, sensorial, and reflective) and allowing for different possibilities of conceptual learning to be explored. This combination of first-, second-, and third-person perspectives differs from other embodied practices, which, although highlighting playfulness and the involvement of the body in cognitive processes (Ayala et al., 2013; Chao et al., 2013), do not account for reflective instances in learning.

Our results provide insights into how perceptual, sensorimotor, and

reflective associations occur in student-teachers' experiences within embodied learning practices. Notably, it indicates that reflective processes on such associations (i.e., becoming aware of how these aspects of the experience contribute to one's understanding of the concept) are key in concept/theory learning, particularly that reflecting collectively (i.e., participating in others' sense-making) is more relevant and effective for students. The embodied experience creates a sensorial bond to a specific theoretical notion (Foglia & Wilson, 2013; Wilson, 2002), and our study suggests that this bond is consolidated through reflection that brings awareness of such bodily connections. The individual sensations, feelings, and thoughts promoted during the embodied practices influence what and how students make sense of theoretical concepts, which can lead to variations in the knowledge students construct. However, the reflection, particularly the collective sharing, unites and expands individual experiences, a phenomenon that has not been explored in previous studies on embodiment in learning. The implication being that without such a reflective process on the experience, learning may not be optimised. Opening up such moments of shared meaning-making in concept learning shows the potential of intersubjectivity present in classroom practices in higher education contexts.

Furthermore, based on our findings learning process involves a rich interplay of perceptual, sensorimotor, and reflective processes and repeating the experience with similar embodied associations broadened concept understanding and enhanced students' competencies. Participants reported becoming more attuned to their own presence and the presence of others, learning to see cues in the interaction deriving from body language, positioning, and emotional expressions. A configuration of unspoken negotiations and tensions that reveal perceptual sensitivity. It was also possible to unravel participants sensorimotor processes. For example, movement synchrony, engaging seeking behaviours (e.g., physical gestures like moving toward others, gazing at their work, and responding to emotional expressions), and bodily negotiations, including participants physically adjusting their actions in response to others (e.g., leading vs following behaviours). Lastly, regarding the reflective processes, participants' notes revealed shifts from stress and diffuse attention to relaxation and clarity, indicating deeper self-awareness and emotional regulation. They described strategic planning and adapting based on previous experiences (e.g., "how could I do it?" or "let's see how we are going to collaborate"), which led to see themselves as "partners and coordinators," reflecting a more complex understanding of social roles and shared agency.

Overall, these processes illustrate how embodied learning fosters social cognition by enabling learners to perceive and interpret social cues, coordinate actions with others through bodily engagement, and reflect on their experiences to build awareness and theoretical insight. This triangulation of perceptual, sensorimotor, and reflective processes is a compelling demonstration of how enactive cognition can be operationalized in educational practice, which to the best of our knowledge has not been described in the literature. Our findings prompt us to reflect on the type of embodiment we incorporate into higher education teaching and learning practices. Building on previous notions of embodiment as a property of conceptual thinking (Dove, 2022; Lakoff, 1994), we argue in favour of exploring practices that go beyond focusing on movement and gesture or the idea of learning by doing to bring forth multiple perspectives on student-teachers' experiences. This approach provides insights into a phenomenological perspective on concept learning, which is yet understudied in the education sciences, at least. This is particularly relevant in curriculum development activities or processes where testing pedagogical methods is demanded.

While many scholars have sought to promote embodied practices, particularly by incorporating gestures and motion into learning processes (Alibali & Nathan, 2012; Goldstone & Son, 2005; Hostetter & Alibali, 2008), the role of reflection on experiences during this process remains underexplored. Furthermore, in a practice designed for embodied learning, we observe that when conceptual learning is driven by students' experiences, the teacher navigates according to how

students collectively make sense of their engagements and reflective processes. Observing and taking into consideration the individual experiences students may have during the class may be a key point to consider when developing embodied practices in teacher higher education. This includes relational, creative, and argumentative processes as part of learning goals.

In the past two decades, we have witnessed a significant increase in empirical works under embodied cognition theories in education. However, we agree with Francesconi (2023) that theoretical and critical reflections on how 4E cognition approaches answering broader educational questions are still scarce. In future studies, researchers could find new insights by integrating physiological data as part of methods for analysing bodily engagements and movements. For example, using eye-tracking to accurately capture gaze behaviours and patterns of individual attention to others bodily movements. Studies could also further explore cultural differences in this embodied sense-making, revealing different nuances of the phenomenon that could open a broader educational discussion.

CRediT authorship contribution statement

Juliene Madureira Ferreira: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gwen Ineson:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Data curation.

Declaration of competing interest

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Data availability

The authors do not have permission to share data.

References

- Abrahamson, D. (2009). Embodied design: Constructing means for constructing meaning. *Educational Studies in Mathematics*, 70(1), 27–47.
- Agostini, E., & Francesconi, D. (2021). Introduction to the special issue embodied cognition and education. *Phenomenology and the Cognitive Sciences*, 20, 417–422. <https://doi.org/10.1007/s11097-020-09714-x>
- Alessandrini, N. (2020). *Object use and the development of conceptual thinking in nursery school: A material engagement approach*. Doctoral thesis. Universidad Autonoma de Madrid.
- Alexander, P. A., Dinsmore, D. L., Fox, E., Grossnickle, E. M., Loughlin, S. M., Maggioni, L., Parkinson, M. M., & Winters, F. I. (2011). Higher order thinking and knowledge: Domain-general and domain-specific trends and future directions. In G. Schraw, & D. R. Robinson (Eds.), *Assessment of higher order thinking skills* (pp. 19–46). Information Age Publishing. Information Age.
- Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from Learners' and Teachers' gestures. *The Journal of the Learning Sciences*, 21(2), 247–286. <https://doi.org/10.1080/1058406.2011.611446>
- Ayala, N. A. R., Mendivil, E. G., Salinas, P., & Rios, H. (2013). Kinesthetic learning applied to mathematics using Kinect. *Procedia Computer Science*, 25, 131–135.
- Barnes, M. E. (2017). Practicing what we preach in teacher education: A critical whiteness studies analysis of experiential education. *Studying Teacher Education*, 13(3), 294–311. <https://doi.org/10.1080/17425964.2017.1365701>

- Barsalou, L. W., Kyle Simmons, W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, 7(2), 84–91. [https://doi.org/10.1016/S1364-6613\(02\)00029-3](https://doi.org/10.1016/S1364-6613(02)00029-3)
- Barton, K. C. (2015). Elicitation Techniques: Getting People to Talk About Ideas They Don't Usually Talk About. *Theory & Research in Social Education*, 43(2), 179–205. <https://doi.org/10.1080/00933104.2015.1034392>
- Beard, C. (2018). Learning experience designs (LEDs) in an Age of complexity: Time to replace the lightbulb? *Reflective Practice*, 19(6), 736–748. <https://doi.org/10.1080/14623943.2018.1538962>
- Bergen, B., & Feldman, J. (2007). Embodied concept learning. *Handbook of Cognitive Science*, 313–331. <https://doi.org/10.1016/B978-0-08-046616-3.00016-5>
- Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11(4), 589–597. <https://doi.org/10.1080/2159676X.2019.1628806>
- Braun, V., & Clarke, V. (2021). *Thematic analysis: A practical guide*. Sage Publications.
- Braun, V., Clarke, V., Terry, G., & Hayfield, N. (2018). Thematic analysis. In P. Liamputtong (Ed.), *Handbook of research methods in health and social sciences* (pp. 843–860). Springer.
- Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A Study of thinking*. Chapman & Hall Limited.
- Castro-Alonso, J., Ayres, P., Zhang, S., De Koning, B. B., & Pass, F. (2024). Research Avenues supporting embodied cognition in learning and instruction. *Educational Psychology Review*, 36(10). <https://doi.org/10.1007/s10648-024-09847-4>
- Chao, K. J., Huang, H. W., Fang, W. C., & Chen, N. S. (2013). Embodied play to learn: Exploring kinetic-facilitated memory performance. *British Journal of Educational Technology*, 44, 5.
- Congdon, E. L., Novack, M. A., Brooks, N., Hemani-Lopez, N., O'Keefe, L., & Goldin-Meadow, S. (2017). Better together: Simultaneous presentation of speech and gesture in math instruction supports generalization and retention. *Learning and Instruction*, 50, 65–74. <https://doi.org/10.1016/j.learninstruc.2017.03.005>
- Cox, E. (2010). *Experiential learning and learning styles*. International Studies Association and Oxford University Press. <https://doi.org/10.1093/acrefore/9780190846626.013.175>
- Cutica, I., Iani, F., & Bucciarelli, M. (2014). Learning from text benefits from enactment. *Memory & Cognition*, 42(7), 1026–1037.
- De Jaegher, H. (2013). Embodiment and sense-making in autism. *Frontiers in Integrative Neuroscience*, 7(15), 41611. <https://doi.org/10.3389/fnint.2013.00015>
- De Jaegher, H. (2021). Loving and knowing. Reflections for an engaged epistemology. *Phenomenology and the Cognitive Sciences*, 20(5), 847–870. <https://doi.org/10.1007/s11097-019-09634-5>
- De Jaegher, H. (2022). PRISMA — Embodying intersubjectivity research. <https://www.prismamethod.net/>. (Accessed 20 February 2024).
- De Jaegher, H., & Di Paolo, E. (2007). Participatory Sense-Making: An enactive approach to social cognition. *Phenomenology and the Cognitive Sciences*, 6, 485–507. <https://doi.org/10.1007/s11097-007-9076-9>
- De Jaegher, H., Pieper, B., Clénin, D., & Thomas, F. (2017). Grasping intersubjectivity: An invitation to embody social interaction research. *Phenomenology and the Cognitive Sciences*, 16, 491–523. <https://doi.org/10.1007/s11097-016-9469-8>
- Denzin, N. K. (1978). Triangulation: A case for methodological evaluation and combination. *Sociological Methods*, 339–357.
- Denzin, N. K., & Lincoln, Y. S. (Eds.). (1994). *Handbook of Qualitative Research*. SAGE Publications.
- Dewey, J. (1963). *Experience and education* (2nd ed.). Collier Books.
- Di Paolo, E. (2018). The enactive conception of life. In A. Newen, L. de Bruin, & S. Gallagher (Eds.), *The Oxford handbook of cognition: Embodied, embedded, enactive, and extended* (pp. 71–94). Oxford University Press.
- Di Paolo, E. A., Cuffari, E. C., & De Jaegher, H. (2018). Linguistic bodies. In *The continuity between life and Language*. MIT Press.
- Doppelt, Y., & Barak, M. (2021). Design-based learning in electronics and mechatronics: Exploring the application in schools. In I. Henze, & M. J. de Vries (Eds.), *Design-based concept learning in science and technology education* (pp. 110–134). Brill Sense Publications.
- Dove, G. (2022). *Abstract concepts and the embodied mind*. Oxford University Press.
- Dove, G. (2023). Concepts require flexible grounding. *Brain and Language*, 245, Article 105322. <https://doi.org/10.1016/j.bandl.2023.105322>
- Emig, J. (2001). Embodied learning. *English Education*, 33(4), 271–280. <http://www.jstor.org/stable/40173296>
- Fantasia, V., De Jaegher, H., & Fasulo, A. (2014). We can work it out: An enactive look at cooperation. *Frontiers in Psychology*, 5, 874. <https://doi.org/10.3389/fpsyg.2014.00874>
- Ferreira, J. M., & Bottema-Beutel, K. (2023). The interactional structure of accounts during small group discussions among autistic children receiving special education support in Finland. *Journal of Autism and Developmental Disorders*, 54, 1928–1946. <https://doi.org/10.1007/s10803-023-05916-9>
- Flick, U. (2004). Triangulation in qualitative research. In U. Flick, E. von Kardoff, & I. Steinke (Eds.), *A companion to qualitative research* (pp. 178–189). Sage Publication.
- Foglia, L., & Wilson, R. A. (2013). Embodied cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(3), 319–325.
- Francesconi, D. (2023). 4E cognition and education beyond the crossroads of learning and Bildung. *Constructivist Foundations*, 18(2), 169–171. <https://constructivist.info/18/2/169>
- Francesconi, D., & Tarozzi, M. (2019). Embodied education and education of the body: The phenomenological perspective. In M. Brinkmann, J. Türling, & M. Weber-Spanknebel (Eds.), *Leib – Leiblichkeit – Embodiment: Pädagogische Perspektiven auf eine Phänomenologie des Leibes* (pp. 229–247). Wiesbaden: VS Springer.
- Gallagher, S. (2005). *How the body shapes the mind*. Oxford University Press.
- Gallagher, S. (2023). *Embodied and enactive approaches to cognition*. Cambridge University Press.
- Gallagher, S., & Bower, M. (2014). Making enactivism even more embodied. *Trends in Interdisciplinary Studies*, 5(2), 232–247.
- Gallagher, S., & Lindgren, R. (2015). Enactive metaphors: Learning through full-body engagement. *Educational Psychology Review*, 27, 391–404. <https://doi.org/10.1007/s10648-015-9327-1>
- Gallese, V., & Lakoff, G. (2005). The Brain's concepts: The role of the Sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, 22(3–4), 455–479. <https://doi.org/10.1080/02643290442000310>
- Gillies, R. M., & Rafter, M. (2020). Using visual, embodied, and language representations to teach the 5E instructional model of inquiry science. *Teaching and Teacher Education*, 87, 102951. <https://doi.org/10.1016/j.tate.2019.102951>
- Glenberg, A. M. (2017). How reading comprehension is embodied and why that matters. *International Electronic Journal of Environmental Education*, 4(1), 5–18.
- Goldin-Meadow, S., Cook, S. W., & Mitchell, Z. A. (2009). Gesturing Gives Children. *New Ideas About Math. Psychological Science*, 20(3), 267–272. <https://doi.org/10.1111/j.1467-9280.2009.02297.x>
- Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *The Journal of the Learning Sciences*, 14, 69–110.
- Gross, Z., & Rutland, S. D. (2017). Experiential learning in informal educational settings. *International Review of Education*, 63, 1–8. <https://doi.org/10.1007/s11159-017-9625-6>
- Guerrettaz, A. M., Zahler, T., Sotirovska, V., & Boyd, A. S. (2020). We acted like ELLs: A pedagogy of embodiment in preservice teacher education. *Language Teaching Research*, 26(6), 1274–1298. <https://doi.org/10.1177/1362168820909980>
- Harper, D. (2002). Talking about pictures: A case for photo elicitation. *Visual Studies*, 17(1), 13–26. <https://doi.org/10.1080/14725860220137345>
- Hegna, H. M., & Ørbaek, T. (2021). Traces of embodied teaching and learning: A review of empirical studies in higher education. *Teaching in Higher Education*, 29(2), 420–441. <https://doi.org/10.1080/13562517.2021.1989582>
- Hostetter, A. B., & Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review*, 15(3), 495–514. <https://doi.org/10.3758/pbr.15.3.495>, 2008 Jun.
- Hutto, D. D., Kirchhoff, M. D., & Abrahamson, D. (2015). The enactive roots of STEM: Rethinking educational design in mathematics. *Educational Psychology Review*, 27(3), 371–389. <https://doi.org/10.1007/s10648-015-9326-2>
- Jackendoff, R. (1992). *Languages of the mind: Essays on mental representation*. MIT.
- Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination and reason*. University of Chicago Press.
- Jusslin, S., Korpinen, K., Lilja, N., Martin, R., Lehtinen-Schnabel, J., & Anttila, E. (2022). Embodied learning and teaching approaches in language education: A mixed studies review. *Educational Research Review*, 37, Article 100480. <https://doi.org/10.1016/j.edurev.2022.100480>
- Kersting, M., Amin, T. G., Euler, E., Gregoric, B., Haglund, J., Kondrup, H., & Steier, R. (2023). What is the role of the body in science education? A conversation between traditions. *Science & Education*. <https://doi.org/10.1007/s11191-023-00434-7>
- Kinsella, E. A. (2007). Embodied reflection and the epistemology of reflective practice. *Journal of Philosophy of Education*, 41(3), 395–409. <https://doi.org/10.1111/j.1467-9752.2007.00574.x>
- Kiverstein, J., & Clark, A. (2009). Introduction: Mind embodied, embedded and enacted: One church or many? *Topoi*, 28(1), 1–7.
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall.
- Kosmas, P., Ioannou, A., & Zaphiris, P. (2018). Implementing embodied learning in the classroom: Effects on children's memory and language skills. *Educational Media International*, 56(1), 59–74. <https://doi.org/10.1080/09523987.2018.1547948>
- Kyselo, M. (2015). The enactive approach and disorders of the self - the case of schizophrenia. *Phenomenology and the Cognitive Science*, 15, 591–616. <https://doi.org/10.1007/s11097-015-9441-z>
- Kyselo, M., & Tschacher, W. (2014). An enactive and dynamical system theory account of dyadic relationships. *Frontiers in Psychology*, 5, 452. <https://doi.org/10.3389/fpsyg.2014.00452>
- Lakoff, G. (1994). What is a conceptual system? In W. F. Overton, & D. S. Palermo (Eds.), *The nature and ontogenesis of meaning* (pp. 41–90). Lawrence Erlbaum Associates, Inc.
- Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to western thought*. Basic Books.
- Lakoff, G., & Turner, M. (1989). *More than cool reason: A field guide to poetic metaphor*. University of Chicago Press.
- Laner, I. (2021). Reflective interventions: Enactivism and phenomenology on ways of bringing the body into intellectual engagement. *Phenomenology and the Cognitive Sciences*, 20, 443–461. <https://doi.org/10.1007/s11097-020-09673-3>
- Lawrence, R. L. (2012). *Bodies of knowledge- embodied learning in adult education: New directions for adult and continuing education, number 134*. Incorporated: John Wiley & Sons.
- Lerner, G. H., Zimmerman, D. H., & Kidwell, M. (2013). Formal structures of practical tasks: A resource for action in the social life of very young children. In J. Streeck, C. Goodwin, & C. LeBaron (Eds.), *Embodied interaction: Language and body in material world* (pp. 44–58). Cambridge University Press.
- Lindblom, J. (2007). *Minding the body interacting socially through embodied action*. Linköping University, Institute of Technology [Doctoral dissertation].
- Macedonia, M., & Klimesch, W. (2014). Long-term effects of gestures on memory for foreign language words trained in the classroom. *Mind, Brain and Education*, 8(2), 74–88.

- Malafouris, L. (2018). Mind and material engagement. *Phenomenology and the Cognitive Sciences*, 18, 1–17. <https://doi.org/10.1007/s11097-018-9606-7>
- Margolis, E., & Laurence, S. (2007). The ontology of concepts—abstract objects or mental representations? *Notis*, 41(4), 561–593. <https://doi.org/10.1111/j.1468-0068.2007.00663.x>
- Mitchell, D. M., & Reid, J. (2017). (Re)turning to practice in teacher education: Embodied knowledge in learning to teach. *Teachers and Teaching*, 23(1), 42–58. <https://doi.org/10.1080/13540602.2016.1203775>
- Murphy, G. L. (2002). *The big book of concepts*. The MIT Press.
- Nathan, M. J., & Walkington, C. (2017). Grounded and embodied mathematical cognition: Promoting mathematical insight and proof using action and language. *Cognitive Research: Principles and Implications*, 2(1), 1–20. <https://doi.org/10.1186/s41235-016-0040-5>
- Newen, A., De Bruin, L., & Gallagher, S. (2018). 4E Cognition: Historical roots key concepts, and central issues. In *The Oxford Handbook of 4E Cognition* (pp 3–18). Oxford University Press.
- Nistor, V., & Samarasinghe, D. A. S. (2019). Academic staff induction and assessment on implementing experiential learning and reflective practice. *IAFOR Journal of Education*, 7(2), 149–167. <https://doi.org/10.22492/ije.7.2.08>
- Oakes, L. M. (2008). Categorization skills and concepts. In M. M. Haith, & J. B. Benson (Eds.), *Encyclopedia of infant and early childhood development* (pp. 249–259). Academic Press. <https://doi.org/10.1016/B978-012370877-9.00043-8>
- Oakes, L. M., & Rakison, D. H. (2003). Issues in the early development of concepts and categories. In D. H. Rakison, & L. M. Oakes (Eds.), *Early category and concept development* (pp. 3–23). Oxford University Press.
- Paloma, F. G., & Tafuri, D. (2017). Embodied Cognition. Body, movement and sport for didactics. *Italian Journal of Educational research*, 17, 41–52.
- Pylyshyn, Z. W. (1986). *Computation and cognition: Toward a foundation for cognitive science*. MIT Press.
- Rustici, C. M. (1997). Sonnet writing and experiential learning. *College Teaching*, 45(1), 16–18. <https://doi.org/10.1080/87567559709596180>
- Schilhab, T., & Groth, C. (2024). *Embodied Learning and Teaching using 4E approach: Exploring perspectives in teaching practices*. Routledge.
- Shanks, D. R. (2015). Concept learning and representation: Models. In J. Wright (Ed.), *International encyclopedia of the Social & Behavioral Sciences* (pp. 538–541). Elsevier. <https://doi.org/10.1016/B978-0-08-097086-8.43020-5>
- Shapiro, L. (2011). *Embodied cognition*. Routledge Press.
- Siegler, R. S., & Crowley, K. (1991). The microgenetic method: A direct means for studying cognitive development. *American Psychologist*, 46(6), 606–620.
- Streeck, J., Goodwin, C., & LeBaron, C. (Eds.). (2013). *Embodied interaction: Language and body in material world*. Cambridge University Press.
- Uithol, S., & Gallese, V. (2015). The role of the body in social cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, 6(5), 453–460. <https://doi.org/10.1002/wcs.1357>
- Varela, F. J., Rosch, E., & Thompson, E. (1991). *The Embodied Mind: Cognitive Science and Human Experience*. MIT university Press.
- Wakefield, E. M., & Goldin-Meadow, S. (2021). How gestures help learning. In S. A. Stolz (Ed.), *The body, embodiment and education* (pp. 118–135). Routledge.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9(4), 625–636.