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Mechanistic explanations as common ground for progress in the learning sciences: a meta stance

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Abstract

Human learning unfolds across nested levels of activity, posing significant challenges for the learning sciences in developing coherent causal explanations in and across analytical levels. This article explores whether mechanisms and mechanistic explanations, as articulated within the new mechanistic philosophy, can provide a shared conceptual foundation for strengthening cumulative knowledge production in learning research. We argue that adopting a mechanistic meta stance can enhance the quality and cumulativity of learning research by offering a framework for precise and integrative constitutive causal explanations that connect multiple levels of analysis in the study of learning.

Keywords: learning sciences, learning research, mechanisms, mechanistic schema and sketches, mechanistic explanations, multiple levels, philosophy of science, cumulative path, meta stance

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1. Introduction

The learning sciences and learning research, as interdisciplinary fields of knowledge, have been maturing through the contributions of the journals of learning societies (*Journal of the Learning Sciences* and *International Journal of Computer-Supported Collaborative Learning*), other relevant educational psychology journals (e.g., *Cognition and Instruction*; *Educational Psychologist*; *Mind, Culture, and Activity*; *Learning and Instruction*; and *Learning, Culture, and Social Interaction*), conferences, systematic reviews, meta-analyses, handbooks, and policy reports, such as *How People Learn* (Bransford et al., 2000; National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). Over the last 25 years, the field has established itself as the most important field of knowledge dedicated to describing, predicting, and explaining human learning (Cress et al., 2021; Fischer et al., 2018; Hoadley, 2018; Sawyer, 2014). Part of the field's success can be attributed to a gradual recognition that the learning phenomenon can and should be studied at multiple levels of analysis (NASEM, 2018). Thus, any introduction to the learning sciences today will emphasise the multifaceted nature of learning and how different research communities within the field have contributed valuable and specialised knowledge (e.g., Fischer et al., 2018). However, a high degree of specialisation can lead to fragmentation.

There have been longstanding discussions about whether a more unified conceptual vocabulary across perspectives might strengthen the field's capacity for cumulative knowledge production (e.g., Baker & Reimann, 2024; Reimann & Baker, 2025). On this point, no consensus has been reached. For example, while Alexander et al. (2009) argued for the integration of diverse perspectives on human learning, Säljö (2009) sympathised with this ambition but made a case for maintaining a "productive tension" between perspectives. Both positions can be problematised. A particular challenge with the integration argument is the problem of epistemic privileging in the learning sciences, that is, when one perspective, such as the cognitive, socio-cognitive, or socio-cultural perspective, comes to define what counts as the only adequate explanation of a given phenomenon. Conversely, a particular challenge with the "productive tension" argument is that epistemic pluralism can turn into a situation in which perspectives simply coexist side by side if sufficient common ground is not established to develop a robust cumulative path. A challenge shared by both positions, at least in the ways they have so far been articulated, is that neither has offered the concrete and precise analytical tools needed to systematically investigate causal processes across perspectives. In this article, we put forward an approach – a meta stance based on analysis of mechanisms and mechanistic explanations – as common ground for progress in the learning sciences. Our argument is motivated by the recognition that human learning occurs at nested levels of activity within multiple interconnected cognitive, social, and cultural layers (e.g., Greeno & Engeström, 2014; Saxe et al., 2015; Tomasello, 2014). We will now justify this position in greater detail.

What is truly distinctive about humans compared to other species is how our biological and cultural aspects are reciprocally intertwined in ways that give us a unique capacity to adapt and further advance human culture through learning (Donald, 1991; 2001; Heyes, 2018; Valsiner & van der Veer, 2000; Wertsch, 1991; 1998). Similarly, students' learning cannot be explained without understanding their gradual exposure to culture and meaning-making processes (e.g., Greeno & Middle School Mathematics Through Applications Project Group, 1998; Järvelä et al., 2016; Saxe et al., 2015). This exposure paves the way for the development of intersubjectivity and common knowledge (Edwards & Mercer, 1987; Mercer, 2013) as the participants coordinate meaning making processes through shared concepts and language in activities that unfold over time (Greeno, 1989; Greeno & Middle School Mathematics Through Applications Project Group, 1998; Rommetveit, 1974, 1992, 1998).

It can be argued that the learning phenomenon is deeply cultural in the sense that we describe here (e.g., Fischer et al., 2018; NASEM, 2018), and it follows that specialised knowledge domains are justified because descriptions and explanations of human learning need to account for varied forms of participation in highly differentiated sociocultural practices that traverse multiple levels (e.g., psychological/social). Each of these levels has associated scientific communities with their corresponding histories and traditions regarding what is considered analytically possible, relevant, valuable, and sufficient, among others. This complexity involves different epistemological premises, units of analysis, and terminology. Herein lies what leading scholars in the learning sciences have labelled "the multilevel problem": the problem of describing and explaining how learning occurs at nested levels of activity within multiple interconnected cognitive, social, and cultural layers (e.g., Greeno & Engeström, 2014; Ludvigsen et al 2016; Ludvigsen, Lund & Oshima, 2021; Saxe et al., 2015). A key feature of such nesting is that phenomena emerge from reciprocal interactions among components. The causality involved in these interactions is therefore *constitutive* – that is, the reciprocal activities do not precede the phenomena but compose them (see also Maxwell, 2004; 2021 about qualitative methods and causal explanations). It is worth noting that the learning sciences share this "problem" with many neighbouring fields, such as neuroscience, cognitive science, cognitive psychology, and the social sciences (e.g., Glennan, 2010; Eronen & Bringmann, 2021; Thomas & Sharp, 2019).

To summarise the argumentation so far, we should acknowledge the need to develop a more unified conceptual vocabulary (Baker & Reimann, 2024; Ludvigsen, Arnseth, Silseth & Steier, 2025; Reimann & Baker, 2025) in the learning sciences. However, if we take the position that learning fundamentally occurs at nested levels of activity, the "multilevel problem" must be addressed in a way that acknowledges the epistemic integrity of different perspectives on learning while also making constitutive causal explanations possible across them. We propose an approach - a meta stance - that can explain reciprocal interactions between perspectives in ways that enable constitutive causal explanations across analytical levels. Specifically, we propose a meta stance grounded in the new mechanistic philosophy, in which mechanistic explanations provide shared standards for reasoning about causality. This is, of course, a contested position; nevertheless, all learning research rests on an epistemology, whether made explicit or left implicit.

2. Aims and key questions addressed

The search for mechanisms is now a key task in many research fields (e.g., neuroscience, cognitive sciences, areas in psychology, and molecular biology and ecology), but mechanistic explanations are rare in the learning sciences and learning research. However, a few scholars have initiated work related to mechanisms, foremost of whom are James G. Greeno and Neil Mercer (e.g., Greeno & Engeström, 2014; Greeno & van de Sande, 2007; Mercer, 2013; van de Sande & Greeno, 2012). In the work of these scholars, causal explanations are described as specific types of turn-taking and domain-specific activity within broader set of activities. However, the epistemological premises for mechanistic explanations were not formulated in these initial works.

A full-text search across the *Journal of the Learning Sciences*, the *International Journal of Computer-Supported Collaborative Learning*, and other learning-oriented journals (see above) revealed that the concept of mechanism had never been used in conjunction with mechanistic explanations. This strongly suggests that the concept of mechanistic explanation has not been systematically applied in the interdisciplinary fields of the learning sciences and learning research. Thus, the potential of a mechanistic stance within these fields remains largely unexplored. Before we elaborate on the key epistemological premises for mechanistic explanations, we clarify what a mechanism is.

As noted by Bechtel and Abrahamsen (2005), the concept of mechanism is interpreted differently across various branches of the philosophy of science. Despite these differences, however, many of the conceptualisations share a common overarching theme: mechanisms describe a structure comprising components and the interactions among them that collectively produce phenomena. The following definition of the term "mechanism" has been proposed to capture this overarching theme: "A mechanism for a phenomenon consists of entities (or parts) whose activities are organised so as to be responsible for the phenomenon" (Glennan & Illari, 2017b). Definitions of mechanisms are further elaborated and justified later in this article, both regarding mechanistic philosophy and how mechanistic explanations can be used in the learning sciences.

It is important to note that the mechanistic explanatory models we propose here should not be equated with statistical models of correlated variables. Statistical models identify and quantify associations between variables and may suggest candidate causal processes, but they do not, in themselves, specify the mechanisms through which such processes are produced. Moving from association to mechanism requires an explicit epistemological stance and a supporting theoretical account.

In this article, we discuss the following: (a) how a mechanistic stance, understood as a meta-stance, supports the formalisation of constitutive causal mechanisms by requiring analytical precision about the components involved, the relationships between them, and the broader set of activities system they compose, and (b) how this, in turn, may create opportunities to strengthen connections between specialised knowledge domains in the learning sciences. Against this backdrop, we ask two main questions:

- How can explanations in learning research be conceptualised from a mechanistic stance?
- How can mechanistic explanations connect knowledge domains in learning research?

Regarding the structure of this article, we have clarified the issue of how we understand the learning phenomenon as occurring at nested levels of activity within multiple interconnected cognitive, social, and cultural layers. We have also hinted at how mechanistic explanations rooted in mechanistic philosophy may provide a way to address the multilevel problem in the learning sciences.

In the following section, we first turn to mechanistic philosophy and mechanistic explanations to illuminate the epistemological premises and further elaborate on key concepts, such as mechanism and mechanistic explanation. This paves the way for discussing mechanistic explanations as candidates for the learning sciences and learning research. While there may be many entry points to such a discussion, we have chosen to use existing and influential explanations that represent attempts to address the multilevel problem in the learning sciences: Mercer's (2013) explanations of the observed effects of collaborative learning on individual learning and Greeno and Engeström's (2014) explanation of learning in interacting activity systems. We argue that the works of these scholars represent a move toward a more mechanistic thinking about explanation. In this sense, the explanations can function as productive stepping stones toward a more articulated mechanistic explanation.

3. The new mechanistic philosophy: epistemological premises

Twenty-five years ago, Machamer et al. (2000) published a "manifesto" titled "Thinking about Mechanism," in which they described a mechanistic approach to analysing various biological systems. Notably, the authors also speculated on whether such an approach might extend to cognitive and social mechanisms, but they did not explore this matter further. Nevertheless, it is fair to say that this work crystalised and catalysed a new mechanistic stance in the philosophy of science and gave the stance its now-standard vocabulary and a clear research agenda. What we refer to here as the "new mechanistic philosophy" (Craver & Tabery, 2015; Glennan, 2010; Glennan & Illiari, 2017b) is therefore a relatively new stance in the philosophy of science that has already had a tremendous impact in various specialised sciences, such as neuroscience, cognitive sciences, areas in psychology, and molecular biology, although the important groundwork was laid in earlier days by scholars such as Cartwright (1983; 1989), Cummins (1975), and Salmon (1984). The new mechanistic philosophy can be understood as a response to several historically dominant conceptions of what counts as knowledge and explanation in science as well as the methodological enactments of such epistemological premises (for an account of the historical development of mechanism-based explanation in the social sciences, see Ylikoski (2026)).

Conceptually, the new mechanistic philosophy critiques the Hempelian idea that explanation primarily consists in subsuming phenomena under general laws (Hempel, 1965), as articulated in mechanistic accounts (e.g., Craver & Tabery, 2015). Instead, the mechanistic approach argues that we explain by showing how a phenomenon is produced by the organised parts and activities within a system. This emphasis on organisation and causal structure reflects a shift from nomological explanation to mechanistic explanation (Salmon, 1984), in which understanding arises from uncovering the processes that generate a phenomenon rather than from its derivation from general laws. Thus, the main line of argumentation among mechanistic philosophers emphasises that causality should be considered constitutive (e.g., Bechtel, 2009b; Craver & Darden, 2013; Craver & Tabery, 2015; Glennan et al., 2022), and the main question is how the internal structure of a system enables the system's functioning. In this question lies a rejection of naïve either-or thinking. Instead, mechanistic philosophers emphasise *multilevel explanation*, in which mechanisms connect rather than collapse different domains of inquiry (Craver, 2007; Craver & Tabery, 2015). Thus, rather than choosing between competing explanatory frameworks, the mechanistic view emphasises how causal mechanisms span and connect multiple levels, integrating them into coherent accounts of complex phenomena.

Methodologically, the new mechanistic philosophy can be seen as a reaction against explanatory strategies that rely primarily on statistical models that identify regularities without specifying the underlying causal processes. For example, in fields such as neuroscience and genetics, mechanistic philosophers argue that genuine understanding requires linking identified regularities to the organised activities of the parts that produce them (Machamer et al., 2000). This has implications for how empirical research is conducted. Because mechanisms are situated and organised within concrete systems, mechanistic inquiry often proceeds through detailed case studies or small-scale analyses that reveal how particular configurations of components and processes generate specific outcomes. The focus shifts from detecting patterns across populations to uncovering how the system under investigation works. In other words, methodological reasoning is grounded in the search for constitutive causal organisation rather than statistical generalisation. Since this organisation is often hard to represent adequately in words or arithmetic alone, diagrammatic models are frequently employed to formalise especially complex mechanisms (Glennan et al., 2022).

Mechanistic philosophy, as well as the account of causality presented here, aligns with a realist epistemology in the sense that mechanisms are treated as real structures in the world (Bechtel, 2009a; Craver, 2007). However, it does not adopt a "naïve" realism because it also recognises that any description of a mechanism is partial and theory-dependent (Glennan, 2017; Maxwell, 2012).

Let us now return to the specific concept of mechanism and how one can systematically describe, in mechanistic terms, what constitutes a given phenomenon. In this article's introduction, we presented what has been labeled a *minimal* definition in mechanistic philosophy: "A mechanism for a phenomenon consists of entities (or parts) whose activities are organised so as to be responsible for the phenomenon" (Glennan & Illari, 2017b). Bechtel and Abrahamsen (2005) suggested a slightly more comprehensive definition: "A mechanism is a structure performing a function in virtue of its component/parts, operations, and the organisation. The orchestrated functioning of the mechanism is responsible for one or more phenomenon" (p. 423). In his article "Looking Down, Around, and Up: Mechanistic Explanation in Psychology," Bechtel (2009a) elaborates on the latter definition and suggests a procedure for developing mechanistic explanations in psychology. His reasoning exemplifies what a mechanistic and multilevel approach to explanation can entail in practice and illustrates how the mechanistic position differs from the aforementioned naïve either-or thinking based on Hempelian logic.

Bechtel (2009a) takes the cognitive function of visual processing as an example of a psychological phenomenon. By looking down, the phenomenon is decomposed into its component parts and operations, which are themselves organised as sub-mechanisms. In the case of visual processing, this can mean examining how different brain areas respond to visual stimuli. A key point is that these components are not merely anatomical structures but active parts within organised mechanisms performing specific functions that together realise the capacity to process visual stimuli. By looking around, Bechtel (2009a) means to situate these mechanisms within a network of other cognitive systems at the same level. In the case of vision, this involves asking how seeing is coordinated with capacities such as directing attention, recognising objects, remembering what has just been seen, and guiding action. The aim is not to reduce visual processing to these other capacities, but to show how the overall performance depends on their interactions and mutual constraints. By looking up, finally, the focus shifts to the broader context in which the mechanism operates: the task the person is engaged in, the environment that supplies information, and the practical purposes that shape what counts as successful visual processing. On this perspective, explaining visual processing also involves understanding why the system is organised as it is, namely, to support an organism's ability to navigate, select relevant information, and act appropriately in a changing world.

Now we see how mechanistic explanations are both multilevel and integrative. In Bechtel's example, they connect lower-level neural processes, mid-level cognitive functions, and higher-level situational contexts within a single explanatory framework. It is also important to emphasise that mechanisms at different levels are described in level-specific terms. At the neural level, mechanisms are characterised in terms of biophysical processes (for example, neurotransmission) and the concepts appropriate to that domain. At the cognitive level, mechanisms are described in terms of information processing, which is not straightforwardly reducible to neural activity, even though it depends on it. At the level of situated activity, mechanisms involve interactions with the environment that depend on, but are not fixed by, individual cognition. In this sense, each level retains a degree of epistemic autonomy - its own explanatory targets and standards - while mechanistic explanations bring these levels into an explanatory dialogue.

In the process of *looking down, around, and up*, researchers may have varying amounts of theoretical or empirical evidence supporting their mechanistic explanations. It is therefore important to distinguish between different types of mechanistic accounts in terms of their robustness and trustworthiness. Darden (2002) draws a distinction between two kinds of mechanistic explanations that can be helpful in this regard: *mechanistic sketch* and *mechanistic schema.* The former typically marks the early stage in the development of an explanation - a tentative account characterised by certain degrees of uncertainty about which entities and activities exist, and their relevance. The latter represents a more robust and trustworthy mechanistic explanation, supported by stronger evidence concerning how particular entities and activities work together to produce the phenomenon.

While Bechtel (2009a, c) describes how explanation proceeds by *looking down, around, and up* across analytical levels, Darden's (2002) concepts of sketch and schema capture how this process unfolds over time as scientists construct and refine multilevel models. This refinement, however, is not a matter of adding as much detail as possible, but of identifying the details that are explanatorily relevant to the phenomenon under investigation (Craver & Kaplan, 2020).

Recognizing learning as a phenomenon that unfolds across interconnected cognitive, social, and cultural levels invites us to consider how a mechanistic stance might improve research in the learning sciences by addressing the multilevel problem and offering a path to more cumulative knowledge production. Drawing on the previous sections, we now turn to the questions of how explanations in learning research can be conceptualized from a mechanistic stance, and how mechanistic explanations can connect knowledge domains in learning research.

4. Mechanistic explanations in the learning sciences

In the previous sections, we introduced what many scholars consider one of the most intriguing problems in the learning sciences: the multilevel problem (e.g., Greeno & Engeström, 2014; Saxe et al., 2015). We have argued that this problem highlights the need for concrete and precise analytical tools that allow for the systematic investigation of constitutive causal processes across nested levels of activity.

In the following sections, we account for and reanalyse in mechanistic terms two robust contributions from the learning sciences that we think already represent a move toward mechanistic thinking about explanation: Mercer's (2013) explanations of the effects of collaborative learning on individual learning and Greeno and Engeström's (2014) explanation of learning in interacting activity systems.

Given that our argumentation is conceptual, building on two robust contributions in the learning sciences can be a productive stepping stone. The following concepts from mechanistic philosophy are used in the analysis: *looking around, down, and up* (Bechtel, 2009a), *components/parts, operations, organization, and mechanism* (Bechtel & Abrahamsen, 2005), and *mechanistic sketch* and *mechanistic schema* (Darden, 2002).

In his article “The Social Brain, Language, and Goal-Directed Collective Thinking: A Social Conception of Cognition and Its Implications for Understanding How We Think, Teach, and Learn”, Mercer (2013) proposes three explanations for the effects of collaborative learning on individual learning and development: *co-construction*, *appropriation*, and *transformation*. In other words, three explanations that address a specific part of the multilevel problem in the learning sciences in different ways because they connect different analytical levels (individual cognition and social activity). It is important to recognise that Mercer’s (2013) argument builds on 30 years of research on the use of language as a social mode of thinking. This work is grounded in the sociocultural stance originally developed by Vygotsky (1978, 1987).

The first of Mercer’s (2013) explanations that we focus on is *co-construction.* This explanation posits that when collaborative learning influences individual learning, it is because learners use dialogue to jointly build ideas and strategies that are more robust than what they would typically develop alone, and individuals can later draw on these jointly produced understandings in subsequent independent work.

A related line of thought, though not identical to Mercer’s (2013), is developed by Greeno and Engeström (2014), who analyse learning in terms of participation in, and reciprocal relations within, organised activity systems such as classrooms. This perspective likewise connects individual learning to the social organisation of activity, while placing greater emphasis on how multiple elements of the setting jointly shape what learners can do and come to understand. For example, in a classroom context, co-construction could be further specified with reference to interactions between the properties of an instructional design with specified features and how such properties are enacted by students. The properties of classrooms as settings of enacted processes consist of content related to a specific knowledge domain (epistemic challenges), general and domain-specific norms, and rules for participation. Such rules and norms can be conceptualised as resources that can support students in their ways of participating, and they provide direction for the students’ cognitive efforts. These differences between Mercer’s account and Greeno and Engeström’s in how these processes are specified, can hamper the description and analysis of mechanisms.

In the case of the co-construction explanation, we believe that there is a potential for developing a mechanistic schema. Processes involved appear to be well documented in a number of qualitative and quantitative studies (e.g., Mercer, 2013; Strømme & Furberg, 2015; van de Sande & Greeno, 2012). In these and similar studies, descriptions include both the social and individual cognitive levels. However, the level of specificity varies, so further specification is required.

The second of Mercer’s (2013) explanations that we focus on is *appropriation.* This explanation posits that when collaborative learning influences individual learning, it is because learners pick up useful information, explanations, or problem-solving strategies from one another during joint activity, and then apply what they have taken up when working on their own later. The roles of language and dialogue are important, but in a somewhat limited sense. Through dialogue, information is transmitted “with a fair degree of accuracy from one mind to another” (Mercer, 2013, p. 155).

Again, further specification can be undertaken with reference to van de Sande and Greeno (2012), who demonstrated that causal influence can be traced partly to properties of individual participants that bring about changes in the activity system. This explanation is described in great detail with regard to the domains of mathematics and physics (Greeno & van de Sande, 2007; van de Sande & Greeno, 2012), through a situation in which students have different understandings of a given problem. To develop common ground, the students must participate in activities in which their different understandings become transparent, after which they will be able to use knowledge resources, both as listeners and as sources, to align their reasoning through a combination of positional and conceptual framing. The argument here is that this learning is dependent on what the students know in advance – activated norms and rules for communication – and the use of knowledge resources. In effect, learning occurs both as a change in individual understanding and as a reorganisation of what becomes shared and usable within the activity system.

Appropriation can be seen as a more complex explanation than co-construction. In many studies, either the social or cognitive level is underspecified, indicating a weak connection between the two levels. For example, studies may provide rich descriptions and analyses of sociocultural settings, but the cognition enacted is not necessarily clearly specified. Such studies, which involve simply describing interactional moves without the relevant content, leave much to the unknown for explaining learning as activities (e.g., Furberg & Silseth, 2021). The opposite is true for studies that focus on self-regulation, which describe individual processes (e.g., cognition and emotions) but do not specify their sociocultural settings and how the interactions unfold (Järvelä et al., 2016). We think that it is reasonable to treat the appropriation explanation as a mechanistic sketch, even if many of its dimensions have been identified in numerous studies.

The third of Mercer's (2013) explanations that we focus on is *transformation.* This explanation posits that when collaborative learning influences individual learning, it is because participating in reasoned discussion changes the *quality* of an individual's subsequent thinking e.g., by making individuals more reflective about reasons, more aware of alternative viewpoints, and better able to monitor and regulate their own reasoning when they later work alone. Mercer (2013) explains how collective processes can encourage a "reflective stance" (p. 155) and strengthen individuals' capacity for inner dialogue, which can in turn serve as a tool for collective problem-solving.

The transformation explanation shares key components and modes of organising activity with accounts of horizontal learning within and across activity systems. Engeström's (1987) concept of horizontal learning creates an explicit connection between individual actors and system-level dimensions, such as rules, division of labour, and communities. This specification builds on the analysis of a distributed cognitive system in different settings. One example is based on work in a research laboratory. The researchers' work with the laboratory infrastructure and instruments can be considered a cognitive partnership. Nersessian et al. (2003) used the concept of "problem space" to argue that problem-solving can also be considered distributed model-based reasoning. Through participation in sociotechnical systems, participants collectively develop their capabilities. Another example is when caregivers in home-care situations shift their focus from providing biomedical support to supporting patients' life situations (Engeström & Kerosuo, 2015), moving from a delimiting involvement to a more expansive engagement with the object of the activity. Here, the explanatory focus shifts from activity-system components and the organisation of activities to changes in practices across multiple activity systems. The implication is that the involved activity systems undergo learning and expansion, creating new learning trajectories for participants.

Engle (2006), Greeno (1994), and many other researchers have developed conceptual stances that explain transformation as the expansion of activities or horizontal learning, which implies a collective transformation (Engeström & Sannino, 2010). One can argue that Engle's (2006) approach is underspecified to a certain degree when it comes to the cultural and system levels, while collective transformation (Engeström, 1987) can lead to an under specification of the subject's transformation. Such mechanistic sketches are important because they can contribute hypotheses for addressing the nested-level problem in the learning sciences. This means that a mechanistic sketch can be seen as a tentative description and analysis with a specific set of limitations. This could be with regard to concepts, conceptual structure, research designs and empirical data.

Other contributions from cultural-historical activity theory (CHAT), including work by Engeström and colleagues, vary in what is specified in empirical analyses (e.g., Engeström & Sannino, 2010; Sannino & Engeström, 2018). In second- and third-generation CHAT studies, the organisational level is often specified through relations between interconnected activity systems, whereas other elements of the expansive learning model are sometimes left less fully articulated. At the same time, Engeström and Sannino (2018) differentiate forms of agency across successive generations of CHAT, which provides additional conceptual resources for analysis (see also Engeström & Sannino, 2021).

In studies by Roth and colleagues (e.g., Roth, 2018; Roth & Jornet, 2019), the subject position – and transformations of subjects within culturally and historically constituted activity – tends to be described more explicitly and become part of the analysed transformations.

The "eight roots" of expansive learning (Engeström & Sannino, 2010) provide a robust conceptual basis for analysing collective transformation. Its epistemological orientation to dialectical movement, contradictions (primary, secondary, and tertiary), and object transformation offers rich resources for specifying how collective transformation is historically constituted. From this perspective, explanation is primarily constitutive, in that it traces how the phenomenon under study is produced through historically developing configurations of activity. In this way, a CHAT stance can enrich and nuance Mercer's more communicative and language-oriented account by bringing a broader societal and historical horizon into view. Central CHAT concepts also enable more detailed specification of how multiple individuals coordinate with one another and with material and symbolic artefacts. Moreover, the movement from the abstract to the concrete can be used to describe mechanisms through which participants jointly develop ideas into mediated actions and activities that become manifest in transformed objects of activity.

Despite being a strong and robust stance and programme for collective transformation in learning research, we would argue that the transformation explanation can probably be classified as a sketch. One main reason is that the CHAT studies vary both in their levels of specification and in which dimensions of activities and activity systems are emphasised. This makes it a challenge to develop a clear cumulative path. Another reason is that the mechanisms associated with the eight roots must be specified in relation to one another, which makes the overall specification both complex and problematic. The expansive model by Engeström (1987; Engeström & Sannino, 2010) aims for explanation of collective transformations, which is a different ambition from what we propose. Our epistemological premises provide an additional reason for treating the collective transformation explanation as a sketch.

Developing mechanistic explanations in the learning sciences requires connecting different types of analyses of learning from a meta-stance. From our epistemological position, CHAT represents only one of several necessary perspectives. We do not consider CHAT capable of serving as a meta-stance for the various perspectives within the learning sciences. Rather, we argue that such a meta-stance should be grounded in epistemological premises that can operate across perspectives in the learning sciences. This is why we advocate a turn toward the description and analysis of mechanisms and toward mechanistic explanation. This position, of course, remains open to contestation.

The three aforementioned explanations are not proposed by Mercer (2013) as mutually exclusive but still relatively distinct approaches. That said, as these three explanations are formulated today, we are faced with three different explanations that partly overlap, and they all appear to have various degrees of support. We have argued for how we can elaborate and nuance these explanations by bringing in activity theory, but at a cost: the conceptual landscape now covers two different analytical lenses that put different analytic emphases on the components involved. This is not trivial because the ambition to address the multilevel problem requires a formalised and explicit language that clearly articulates the *what*, *how*, *when*, and *why* of explanations. A mechanistic stance invites us to clarify and may enable a more systematic comparison and evaluation of the three explanations.

Let us attempt to conceptualise the phenomenon of collaborative learning influencing individual learning and development from a mechanistic stance. We follow Bechtel (2009a) and start by *looking down*—decomposing the phenomenon into its lower-level parts, operations, and sub-mechanisms. These lower-level mechanisms set the conditions for the higher-level phenomenon by explaining how it is produced or realised. In this re-analysis, we use the co-construction explanation because we have argued that this is the most robust of the explanations.

When we are *looking down*, we ask: which underlying cognitive, communicative, and affective mechanisms make co-construction possible? This may include cognitive mechanisms, such as attention, working memory, and perspective-taking, which allow individuals to track, interpret, and integrate others' contributions; linguistic and communicative mechanisms that structure joint meaning-making (e.g., turn-taking, referencing, and uptake); or emotional and motivational mechanisms that regulate engagement and openness to others' ideas. Importantly, when Bechtel (2009a) talks about *looking down*, he does not limit the analysis to biological or cognitive sub-mechanisms. The key idea is to decompose the phenomenon being explained into the organised components and processes that make it possible (e.g., Bich & Bechtel 2022). In a classroom context, for example, this can also include material and technological conditions (e.g., a particular instructional design may structure turn-taking).

Whereas *looking down* reveals the constitutive parts and operations that make a phenomenon possible, *looking around* uncovers how that mechanism is embedded in a network of related processes that influence or constrain its functioning. When we are *looking around*, we ask: what are the interconnected mechanisms that operate within the same analytical level? This may include mechanisms of communication and coordination (e.g., negotiation of meaning or shared attention), normative and motivational mechanisms (e.g., group norms, trust, or perhaps goal alignment that sustains participation), and instructional mechanisms (e.g., task design or teacher facilitation, which may structure collaboration). These are examples of mechanisms that co-exist with the co-construction process at the same analytical level. We can note how task design can be defined both as a constitutive mechanism (*looking down*) and an interacting process that constrains other mechanisms at the socio-cognitive level (*looking around*). This simply means that task design can both set material conditions for social activities and interact with participants and other resources.

Whereas *looking around* maps a mechanism's horizontal relations with its neighbouring mechanisms, *looking up* explores how the activities of the focal mechanism enable, sustain, or transform broader systems in which it is embedded. With regard to the phenomenon we are seeking to explain, when we are *looking up*, we ask: how are patterns of interaction within groups constituted within a classroom culture? How do individual developmental outcomes, such as increased metacognitive awareness, contribute to collective forms of knowledge building? How do institutional norms, assessment systems, or curricular structures evolve in response to such collaborative learning processes? Here, *looking up* reveals how local mechanisms works in the emergence and maintenance of higher-level phenomena, such as classroom interactions, learning communities, and disciplinary practices.

5. Summary and discussion: mechanisms and mechanistic explanations in the learning sciences

In this article, we argue that mechanisms and mechanistic explanations, as a meta stance, can improve the quality and cumulativity of learning research. We started from the premise that longstanding debates over whether the field should pursue a unified conceptual vocabulary or maintain a productive tension between perspectives have yielded no consensus and, in different ways, risk either epistemic privileging or mere coexistence without sufficient common ground for cumulative progress. This hampers the development of the learning sciences as a field of knowledge. The mechanistic stance in the philosophy of science offers a pathway to be analytically precise and develop constitutive causal explanatory models that can be used across research communities and thus connect multiple levels of analysis in the study of learning. The following research questions guided us:

- How can explanations in learning research be conceptualised from a mechanistic stance?
- How can mechanistic explanations connect knowledge domains in learning research?

As stated in this article's introduction, from the perspective of mechanistic philosophy and mechanistic explanations, it is reasonable to classify mechanisms through components/parts, operations, and organisations in many specialised sciences. As mentioned earlier, we claim that mechanistic philosophy can enrich the learning sciences with an epistemology that can improve the cumulative path of the sciences. The first step is to describe different mechanisms and use mechanistic explanations in a systematic way.

The terms *looking down*, *looking around*, and *looking up* (Bechtel, 2009a, 2009c) provide the learning sciences and learning research with a clear challenge to continue attempting to explain what, why, and how participants learn across levels. As a community of scholars, we must create suitable models of the phenomena that we need to explain.

One way of engaging complexity at an adequate level, we have argued, is to develop more sophisticated forms of explanation. The concepts of *mechanistic schema* and *mechanistic sketch* make it possible to differentiate mechanistic explanations in terms of analytic precision and robustness, and to distinguish between explanations at an early stage of development and those that are more mature. These categories, however, are best treated as analytical tools rather than sharply delineated kinds: in practice, it is not always straightforward to determine whether a given explanation should be classified as a sketch or a schema. We have offered reasons for classifying particular explanations one way rather than the other; however, if a mechanistic stance is to be developed in the learning sciences, domain-sensitive criteria for such classifications must also be articulated.

In this article, we argue that the learning sciences should move beyond treating research designs and theoretical perspectives as isolated traditions, and instead articulate mechanistic descriptions that can be compared, refined, and integrated across studies and perspectives. This, we suggest, requires an integrative pluralism in which high-quality studies from different traditions are brought into explanatory dialogue through explicit claims about mechanisms in learning activity.

6. Conclusion and limitations

Ambitions to integrate cultural, social, and cognitive levels have long informed explanatory models in the learning sciences. The stance we propose, however, is explicitly mechanistic. Our core claim is that a mechanistic stance equips learning scientists with concepts for describing how learning is produced through organised interdependencies, rather than merely locating it at one level or another. If learning occurs at nested levels of activity, then an adequate mechanistic explanation must describe how intra-mental processes are coupled with inter-mental activity - that is, how cognitive and social processes are integrated in the organisation of learning activity. On this view, the causality of learning activities is primarily constitutive: learning results from how the relevant components and processes are organised and coordinated in activity. A mechanistic stance therefore opens the way for more nuanced explanations of learning across settings, responding to recent calls for stronger explanatory accounts in the field (e.g., Baker & Reimann, 2024; Reimann, 2021).

This implies the need to analyse how learning scientists define units of analysis and levels of description (Baker et al., 2021; Cress et al., 2021; Fischer et al., 2018), how connections across levels are warranted, and what kinds of explanations such connections can support. Developing shared, domain-sensitive criteria for these choices is an urgent task if the learning sciences are to achieve further cumulative progress.

One promising direction is the use of analytic models, such as graphical representations and diagrams, to make constitutive relations explicit. Such modelling can draw inspiration from mechanistic practices in biology and psychology (e.g., Bechtel, 2009a). While this approach may involve a measure of reduction in order to gain clarity, its point is not to replace higher-level descriptions but to increase analytic precision and enable integration across studies that start from different conceptual positions. In this sense, formal representations can serve as stepping stones for theory development and communication in the learning sciences (Baker et al., 2021). Together, the representational resources and conceptual distinctions developed in this article offer ways to formalise descriptions of mechanisms in learning activities and to advance explanation of learning as a multilevel phenomenon.

Although the new mechanistic philosophy has shaped debates about how to describe, understand, and explain the sciences for the past three decades, many specialised fields have yet to be examined systematically using its assumptions, concepts, and explanatory standards. This article is an attempt to bring some of its central concerns to bear on the learning sciences and learning research. We argue that the new mechanistic philosophy opens a space for reconsidering what the learning sciences are, what they might become, and how learning scientists can contribute to the explanation of human learning. Our contribution should be understood as steps in this direction: we sketch how learning mechanisms might be described and how mechanistic explanations of learning might be developed. The analytical perspective adopted throughout is the new mechanistic philosophy of science. In this way, it aims to lay the groundwork for subsequent argumentation and refinement in learning research.

Keypoints:

- The article argues that the learning sciences and CSCL would benefit from a more unified conceptual vocabulary across theoretical perspectives, thereby strengthening the field's capacity for cumulative knowledge production.

- Human learning is widely recognised as occurring at nested levels of activity, across interconnected cognitive, social, and cultural layers.
- An adequate mechanistic explanation of learning must therefore account for how intra-mental processes are coupled with inter-mental activity across these layers.
- The mechanistic stance in the philosophy of science offers a pathway for developing constitutive causal explanations of learning across multiple levels of activity.
- The concepts of *mechanistic schema* and *mechanistic sketch* help differentiate mechanistic explanations in terms of analytical precision and robustness.

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Statement

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