Overview

Situated cognition

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Following the cognitive revolution, when knowing and learning have come to be theorized in terms of representations stored and processed in the mind, empirical and theoretical developments in very different scholarly disciplines have led to the emergence of the *situated cognition* hypothesis, which consists of a set of interlocking theses: cognition is embodied, fundamentally social, distributed, enacted, and often works without representations. We trace the historical origins of this hypothesis and discuss the evidential support this hypothesis receives from empirical and modeling studies. We distinguish the question of where cognition is located from the question of what cognition is, because the confounding of the two questions leads to misunderstandings in the sometimes-ardent debates concerning the situated cognition hypothesis. We conclude with recommendations for interdisciplinary approaches to the nature of cognition.

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INTRODUCTION

At the end of the 1980s, just about at the time when the cognitive revolution—based on information processing and the mind as computer metaphor—had become the dominant approach to cognition and learning, a new way of theorizing human performance emerged: situated cognition. There are claims that the situated cognition view has grown rapidly over the past decade, including in the areas of cognitive and social neuroscience and (cognitive, social, and developmental) psychology.[1] Such claims are substantiated by citation counts. Thus, for example, 'Situated Cognition and the Culture of Learning'[2]—one of the first articles on the topic of 'situated cognition' that has achieved cult status with over 11,000 Google citations (2250 Thomson Reuters)—argued knowledge to be situated in the activities, contexts, and cultures where it is produced; Suchman's seminal *Plans and Situated Actions*[3] (over 9000 Google citations) constituted a substantial critique of dominant assumptions about the relationship of human actions, communication, and machine intelligence. Citations (Google) to the article have increased nearly linearly to the present day (Figure 1). The citation numbers in the Thomson Reuter Web of Science database to the term 'situated cognition' have increased exponentially over the last half-decade (Figure 1), in part because of an increasing interest in the experimental ('hard') sciences where the uptake initially had been much slower than in education and educational psychology, for example. Thus, not even a decade ago, the field of social psychology had 'not yet fully appreciated the implications of the shift from computation to . . . an alternative . . . that cognition is for action and that embodiment and the situated nature of adaptive action are crucial constraints' (Ref 4, p. 104). The influence of the situated cognition perspective on cognitive science can be seen, among others, in the shift from intelligent tutoring systems research to systems that emphasize interactivity.[5]

In the following, we begin by circumscribing situated cognition as a set of interlocked theses and proceed to describe the historical context in which these theses emerged. We then articulate the evidence mobilized in support of these theses from (1) empirical studies and (2) modeling studies.[a] In the scholarly debate concerning such studies mobilized in support of the situated cognition hypothesis, two issues tend to remain unattended or are confused: the where and

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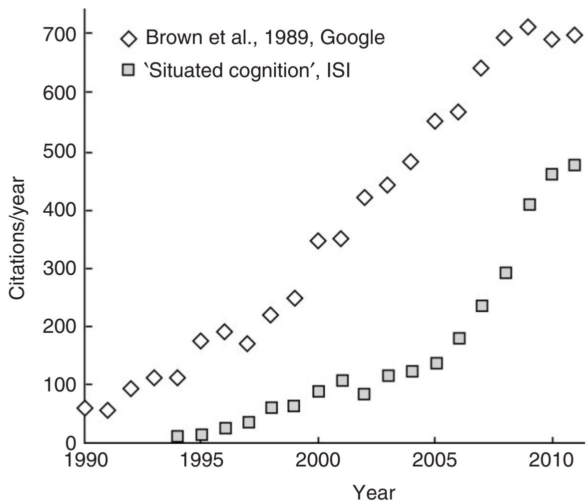

FIGURE 1 | The number of citations to the topic-initiating article by Brown et al.[2] (in Google) and to the key term 'situated cognition'. Source: Thomson Reuters Web of Science.

what of cognition. In the Section 'Situating Situated Cognition', we discuss the situated cognition literature in terms of the units of analysis that existing studies employ. We conclude with a call for interdisciplinary approaches that combine rigorous studies of human experience and cognitive science.

SITUATED COGNITION—A SET OF INTERLOCKED HYPOTHESES

The central aspect of the situated cognition hypothesis is that intelligent behavior arises from the dynamic coupling between intelligent subject and its environment rather than only from the agent's mind (brain, control system) itself.[6] It has been suggested that *situated* actions rather than mental plans and processes constitute the appropriate unit of analysis.[3] This view sharply contrasts with the traditional view that cognition consists of the mind's processing of information that is available in the environment and registered by a control system.[7,8] From a situated cognition perspective, information exists not prior to, but emerges from, and is a function of, the organism–environment relation (coupling). It has been argued that the shift within cognitive science to the situated cognition hypothesis is at least as profound as was the cognitive revolution that led to the overturning of the then-dominant behaviorist paradigm.[9] However, there are different interpretations within the field concerning the nature of 'situated cognition'; the differences are sometimes large, depending on the relative status given to the organism's body and environment in the constitution of cognition. In this article, we treat situated cognition as a scientific hypothesis that includes the following, generally interconnected but sometimes independently treated theses:

1. Cognition arises from, and is connected to, the interactions that the material body of an agent entertains with its physical environment; cognition is *embodied* and *situated*.
2. Cognition arises from, and is connected to, the interactions that an agent entertains with its social environment: cognition is *situated* in its social context. This context may be immediate, when typical behavior arises in relation to other agents, or mediate, such as when typical behavior arises within larger social contexts (communities, social networks, society).
3. Cognition arises in, and for the purpose of, action: cognition is *enacted*. Relations of reference to the surrounding world and purposes (intentions) characterize human behavior and tool-use: *in-order-to*, *what-for*, *what-in*, and *for-the-sake-of-which*.
4. Cognition is distributed across material and social settings because of features (1)–(3). Language-use and material practices are relevant categories that capture such features.
5. A lot of intelligent behavior does not require explicit internal (mental) representation. What is important instead is how the world presents itself to the agent.

The situated cognition hypothesis fundamentally challenges traditional notions of the boundaries and, therefore, the locus of cognition. Understanding the implications of a situated approach involves a reorganization of our ways of understanding cognition as such, and not just the addition of the 'situated' modifier to commonly held conceptions of mind and thinking.

THE HISTORICAL ORIGINS OF THE SITUATED COGNITION HYPOTHESIS

The situated cognition hypothesis arose within a particular cultural–historical scholarly context where its constitutive theses already existed within and across academic disciplines, including phenomenological philosophy, cultural–historical activity theory, ecological psychology, American pragmatism, computer science, cybernetics, and theoretical biology.[10]

Phenomenological Philosophy

Important historical precedents include the philosophical (phenomenological) analysis of everyday activity and the nature of what is salient in the consciousness of the agent (subject). Often-cited analyses are those concerning the use of physical tools (e.g., hammering) and language.[11,12] Thus, in the case of a competent carpenter, it is not the hammer that appears in the consciousness of the agent but the *hammering a nail in the wall in-order-to hang a picture*. Hammering is understood to be part of a situated, embodied *practice* (set of patterned actions). This does not prevent the agent to make the hammer itself present in/to consciousness; the latter occurs, e.g., when there is something wrong, e.g., when a hammer is too light or heavy or when it is broken (i.e., in case of a 'breakdown'). Subsequent phenomenological analyses showed how the understanding of space itself arises from the agent's active explorations in its vicinity, so that the 'places in space do not stand out as objective positions' but 'inscribe around us the varying range of our aims or of our gestures' (Ref 13, p. 168). Early phenomenological analyses of the everyday lifeworld[14] led to accounts of how fundamental social phenomena are produced in and through concerted, mundane actions[15] and to a critical examination of the unavoidable gap between (abstract, mental) plans and situated practical action, which is, in any case, singular and always adapted to the contingencies of context.[3] More recent phenomenological studies focus on the primacy of movement and the *incarnate* nature of cognition (see Box 1). Phenomenological studies informed the study of cognition in areas such as Heideggerian AI, neurophenomenology, and interdisciplinary fields combining phenomenological philosophy and the cognitive sciences.

BOX 1

PRIMACY OF MOVEMENT: INCARNATE COGNITION

Embodiment and enactivist accounts of situated cognition often mobilize mental schemata to explain bodily movements that are said to underlie those experiences that subsequently are extended into the realm of formal thought by means of metaphorization.[16] However, on evolutionary and philosophical grounds, schema cannot be the origin of higher thought processes, for the schemata themselves have to be explained.[17] Sheets-Johnstone provides an extended critique of the points on which the embodiment and enactivist accounts fall short. Some philosophers postulate that there is a primacy of initially unmotivated, incarnate movements that become intentional movements in the course of habit formation and social feedback processes.[18] An incarnate approach, which gives primacy to movements from which habits and schemata may emerge, has been used successfully to explain the emergence of formal mathematical thought from pre-mathematical experiences in the course of a lesson sequence on three-dimensional geometry for 6-year-old children.[19]

Situation Calculus

Situation calculus is a logical approach for representing changes required in the modeling of robots or language. For example, in the formal approach to situated language use, the fundamental assumption is that semantics—what something means—is situation dependent, leading to a relational theory of meaning. Some scholars work on formalizing situation semantics mathematically, specifying information in terms of temporal and spatial location, type of individual, relations, type of situations, type of types, parameters, and polarities.[20] With these components, a calculus can be formulated (i.e., the operations that can be conducted) to arrive at more complex information types with situated meanings to the point of providing models for communication breakdown in the workplace.[21] Situation calculus works on elaborating formal theories of knowledge and action, embodied in a logical language that specifies situations, actions that transform them, and situation-dependent, changing functions called *fluents* (e.g., *hand-empty* [relational fluent] or *battery*-low [functional fluent]).[22] In this way, indexical knowledge may be formalized to show how actions can be specified so as to avoid making excessive requirements upon the internal knowledge of agents.[23]

Cultural–Historical Activity Theory

Another important historical precedent exists in (cultural–historical) *activity theory*, originally developed by Soviet social psychologists explicitly grounding their ideas about cognition in the works of Spinoza and Marx, who had championed theories in which thinking, acting (praxis), and environment are part of the same analytic unit (category).[24,25] These psychologists developed the idea that the higher, specifically human psychological functions have their origin and locus in human society generally and in the societal relations that agents participate specifically. Thus, even if persons write or think for themselves, the ontogenetic origins of these activities are those societal relations that the persons have lived through before in characteristic material settings. When such relations are absent, as in deaf–blind children, even the most fundamental human behaviors and inclinations are absent.[26] Researchers using this approach—working among others in neuropsychology—recognized that mental processes, such as speaking, thinking, reading, or writing need to be understood in terms of complex ecologies (functional systems), that involve both (1) fundamental neuromuscular and physiological processes and (2) their cultural–historical origin and nature.[27] This line of work influenced those studies that are marked by adjectives such as 'sociocultural', 'cultural–historical', and 'societal–historical'.

Ecological Psychology

Insights and experimental findings from *ecological psychology*[28] also contributed to the institution of what is now collected under the 'situated cognition' label. A key concept from ecological psychology is that of 'affordance', which denotes the possibilities for visually guided locomotion, rhythmic movement, and (grasping, wielding) action that arise for the agent from those aspects of the environment salient in/to its perception. Here, organism–environment couplings are the major determinants of behavior: A ball-shaped doorknob, e.g., affords turning to an agent, who 'directly' perceives it as a physically possible way to open a door.[29] Such affordance is not inherent to the doorknob, but refers to a relation between a material possibility and the perception of it in the course of action. The agent does not need to have a mental representation of a door; rather, the environment itself *suggests* what needs to be done. Ecological psychology had a particularly strong impact on the cognitive sciences concerned with the design of workplaces and human artifacts.

American Pragmatism

American pragmatism has been another major influence on the situated cognition hypothesis. As early as 1896, Dewey objected to the view of the 'reflex arc' as a mechanistic stimulus–response relation and argued for an organic approach in which sensation, thought, and action would form an irreducible unit. In his view, 'sensory stimulus, central connections and motor responses shall be viewed, not as separate and complete entities in themselves, but as divisions of labor, functioning factors, within the single concrete whole' (Ref 30, p. 358). Later, Dewey would articulate the notions of *continuity of experience* and *transaction* as fundamental, irreducible categories for understanding human cultural activities such as schooling and philosophical discourses on logic.[31,32] Thus, the relations between subjects and their activities are constitutive, not causal: 'The processes of living are enacted by the environment as truly as by the organism; for they are an integration' (Ref 31, p. 25). The influence of American pragmatism on situated cognition is particularly noticeable in the fields of education, to which Dewey contributed a lot, and of the learning sciences.

Theoretical Biology

There is a long history of studies in (theoretical) biology and physiology that emphasize the irreducible nature of an organism-in-environment system.[33,34] Some fundamental ideas from biology and physiology are associated with *enactivism* and *embodiment* theories, which emphasize the structural coupling between organism and environment.[35] This structural coupling—which expresses itself in the fact that 'there is no possible distinction between internally and externally generated states of nervous activity' (Ref 35, p. 23)—determines *useful* behavioral results. Such generally ecological theories of cognition emphasize that agents (organisms) cannot live without environment and that the environment has definite characteristics only with respect to the particular organism.[36,37] Especially philosophical approaches to the cognitive sciences draw inspiration from biological and physiological studies.

SUPPORT FROM EMPIRICAL STUDIES

The term 'situated cognition' emerged from discussions that occurred during the mid-1980s at the *Institute for Research and Learning* and the XEROX Palo Alto Research Center, which were influenced, among others, by ethnographic studies of mathematical performance in the everyday (work) world as well as by studies in *situation semantics* (see insert) and *Heideggerian artificial intelligence* (AI; see below). Central issues concerned the question whether (mental) representation is a requirement for explaining higher-order psychological function and the mediating role of culture in (individual, collective) cognition.

Cognition and Representation

A central aspect of the situated cognition hypothesis is that many of the complex human behaviors do not necessitate the internal representation of the world and its contents; instead, structures in the environment account for structures in behavior. Knowing does not mean mentally representing facts and rules *about* the world but refers to how an organism functions *in* the world. Research on perception, memory, and learning is shedding light on the ways in which behavior can be based in organism–environment couplings rather than on mental (internal) descriptions of the external world.

Perceiving and Remembering Without Representing: The World as Memory

One of the strongest arguments for a nonrepresentational basis of perception comes from research on 'change blindness'.[38] Change blindness refers to the empirical evidence that changes in an image often go unnoticed when the change occurs while the eye blinks or when there is a changeover to another, almost identical image. Because an internal representation of the visual field would presuppose a complete replica of the real thing, blinking should not prevent us from noticing or reconstructing those changes. A comparison of the representations of the images prior to and following an eye blink would make it possible to detect the change. Change blindness therefore provides empirical support for the situated cognition hypothesis according to which the world stands for itself rather than being represented in the mind.[39] Sustained and rich visual experience depend on the direct relation between the environment and the body, which knows where to find the information required for some next step. Seeing does not consist in exhaustively scanning the world and internally representing it—e.g., as in the CaMeRa model of cognition related to graphs.[40] Rather, it constitutes an active, situated, and experience-specific exploration of the surrounding world, where the organism can access any required information at every stage in an inquiry.

Research has also explored the idea that remembering—a function that classical literature in cognitive science explicitly relates to the retrieval of stored representations—may be explained without resorting to the notion of 'retrieving'. From a situated view, memory traces can be seen as 'incomplete, partial, and context-sensitive, to be reconstructed rather than reproduced' (Ref 41, p. 229). These memory traces are complemented with situational (social and environmental) aspects that again can be seen as integral rather than external to the cognitive process of remembering. Nelson and Fivush[42], e.g., review research that shows how the ways in which parents structure conversations about past events with their children strongly influence how children come to construct their own narrative history, suggesting that memory is culturally mediated and remembering contingent to situations.

Learning and Solving Problems Without Representations: The Question of Transfer

The emergence of the situated cognition hypothesis, especially as it pertains to educational research, can be traced to a number of ethnographic studies that moved research on learning and cognition outside the laboratory and into everyday practice settings.[3,43] Lave's *Cognition in Practice*[44]—one of the early, frequently cited examples of the situated approach (over 6500 Google citations)—reports studies of arithmetic practices across settings, including grocery shopping, simulation experiments of grocery shopping, and school-like tests. These studies demonstrated important discontinuities in peoples' ways of approaching 'structurally identical' tasks as a function of the setting, suggesting an inherent situativity in problem solving, as different solution strategies were enacted depending on the problem presentation. Lave proposed to locate cognition in *practices*, patterned actions that are specific to certain cultural–historical settings and communities. Following these early studies, a number of related works instituted a 'practice turn' in educational research, where groups of learners are considered to constitute *communities of practice*[45], and learning as a process of *legitimate peripheral participation* and of *cognitive apprenticeship*.[2]

One of the most controversial issues that arose together with the practice turn was the challenge that it posed to the notion of learning transfer. The idea of transfer was fundamental to educational research, because it assumed that the curriculum contents (e.g., in science, mathematics, or geography) could be appropriated in the school and later applied in other, within- and out-of-school situations.[46,47] This assumption is not supported by research evidence, which reports no or insignificant correlations between number of, and achievement in, school-based mathematics courses and mathematical behavior in the everyday world.[44] A debate emerged in which scholars from an information-processing approach interpreted the claims on situativity as a negation of the possibility of transfer.[48] Proponents of the situated cognition hypothesis, on the other hand, deemed such accusation misled[49] because it ignored the fundamental difference in the premises on learning: in the context of the situated cognition hypothesis, learning is not viewed as the acquisition of knowledge contents, but in terms of expanding the learner's action possibilities in larger systems of activity. An alternative to the classic transfer paradigm is based on Gibson's notion of 'affordance',[28] and may be defined as a question of whether individuals are *attuned to constraints* of a situation's affordances.[50] It is not an internal model that transfers to another setting but a set of subject–environment relations. In line with this approach, some recent research conceptualizes learning transfer without explicitly resorting to the notion of mental representation, but rather to situational aspects. Transfer has been explained as a result of 'focusing frameworks', where the situational objects that are noticed and made salient across situations are (1) a function of teacher–student interactions[51] and (2) highly influenced by the ways in which educational situations are 'framed'.[52]

Cognition as a Feature of Society

Many social psychologists generally and activity theorists particularly accept K. Marx's thesis that specifically human forms of cognition are not inherited, but exist in society-specific cultural practices. Thus, the founder of activity theory suggested that 'the *psychological* nature of man is the totality of societal relations shifted to the inside' so that 'development proceeds not toward socialization but toward *individualization* of societal functions' (Ref 24, p. 1023, 1025, original emphasis, underline added). Studies of tool use and practices among primates support such suggestions.[53,54] We exemplify this feature of the situated cognition hypothesis in the context of the nature of language and the embodiment of the social.

The Nature of Language

From the sociocultural and cultural–historical perspectives that underlie the situated cognition hypothesis, language is not a system of correspondences between symbols and elements in the world, but a means for humans to coordinate their situated actions[3] with others and for agents to stimulate their own minds.[24] It has been suggested that signs[55] generally and language[24] specifically originally function to influence the behavior of others before the individual can use it to influence its own behavior. This is especially the case because language arises from, and is grounded in, bodily experiences that are structured by the body and its movements; once these movements are encoded in symbolic form, they can be used as metaphors to describe and refer to other types of entities.[56] For example, the experience of something being inside or outside of a container may be used to think or talk about the mind: The container metaphor suggests that there are things inside the mind (e.g., internal representations) and other things outside the mind (e.g., inscriptions, material representations). A pragmatic perspective supports the contention that there is no difference between knowing a language and knowing one's way around the world more generally.[12,57] Shared bodily experiences and the function of language to influence the behavior of others makes language *inherently* a cultural tool available to all members: it embodies a system of ideas (i.e., an ideology)[58] or a system of categorization of experiences in the world.[56] However, this system is not deterministic, but evolves together with and because of situated actions. The signification of a word never is the same. Because each experience transforms the objective conditions in which further experiences are had,[31,32] each utterance becomes the seed for changing culture.[59] Moreover, because language embodies implicit rules for its own use, competent speakers can situationally generate statements on a topic even though they have never thought about this topic before and, consequently, without having a representation thereof.[60] Again, from the situated cognition hypothesis these rules are not considered formal symbolic relations stored in the mind that then generate new language combinations. Language is learned by participating in societal relations: it is a means for entertaining, and the result of, societal relations. Language-use inescapably points to the societal, shared nature of cognition.[12,14,24]

Embodiment of the Social

Another way to investigate the forms in which cognition is embodied and situated in the material world is by looking at how people coordinate and organize their actions in society-specific activities. A number of researchers from backgrounds as diverse as linguistics, psycholinguistics, cognitive anthropology, psychology, or computer science inquire into ways in which people constitute social order and intercomprehension by investigating the embodied co-articulation of different semiotic fields during face-to-face interactions.[61] From this *embodied interaction* perspective, language is not seen as an isolated system, but as forming part of larger, multimodal social intercourse, involving both the body (gestures, postures) and the material elements of the situation (objects being indexed or referred to). Many studies exhibit the embodied, enacted, and distributed aspects of cognition in studies of communication in a variety of workplaces and everyday settings.[62] This work suggests that an exclusive focus on the representational properties of communication—e.g., inscriptions in the form of charts, maps, graphs—interferes with an appropriate understanding of how these entities are embedded within collectively organized human practices. Thus, for example, professional vision in archeology arises from and interacts with talk, writing, and tools as people communicate—using words, gestures, body position, and body orientation—over and about salient issues (e.g., producing a map).[63] Other studies show how prosody (speech intensity, volume, and pitch), intellectual disagreement, language, body orientation, body position with respect to the playing field, and emotion interact in the course of children's playing a game of hopscotch.[64] That is, an argument that plays out at the group level simultaneously is reflected in body movements that the participants are not conscious of. Intonation, rhythm, and facial expressions of different speakers tend to be aligned in agreement, but are significantly different in disagreement not only over the outcome of games, but also during debates concerning conceptual issues.[65] Consistent with the notion of cognition as socially situated and embodied, recent studies in experimental psychology show for example that (1) automaticity—response to threat with aggressive (fight) or distancing behavior (flight)—is a function of the situation (subject in enclosed booth or in open field)[66], (2) eye movements, gazing times, and memory for images are highly responsive to being informed that others are looking at the same images at the same time[67], and (3) place cognition is a function of active perception.[68]

SUPPORT FROM MODELING STUDIES

Support for the situated cognition hypothesis also comes from modeling studies in AI, robotics, artificial neural networks, and associated mathematical models (see Box 1). An important point of discussion centers on the question of representation and whether it is necessary for the acting subject to have a representation of the world in its mind or whether other forms of relating to the world not only are possible, but also accomplish tasks that traditional AI and cognitive psychology have ascribed to mental representations.[69] There appears to be a general sense that modeling studies may be able to set constraints on theories of cognition, e.g., concerning the need for representations to explain higher-order behavior.

Heideggerian AI

One approach to AI and the modeling of human behavior took as its starting point Heidegger's description of everyday ways of being.[70] This approach relies on careful, phenomenological analyses of human experience for the purpose of designing computing systems consistent with the experience—e.g., the absence of a mental representation of a hammer while hammering a nail into a wall. Researchers working in this direction modeled, for example, the activities in a short-order kitchen, where a cook works on multiple orders simultaneously.[71] Accomplishing the entirety of the tasks involved would exceed the capacities of human cognition based on representations of kitchen, tools, materials, orders, and so on. Rather, following Heidegger's analysis that tools are 'ready-to-hand', a function that is an integral part of a *what-for* orientation, the kitchen as a whole is taken as its own representation. Thus, e.g., a sandwich in a particular state and at a particular place in the kitchen requires a specific action to move it into its next production stage. The state of the kitchen itself *suggests* what needs to be done next. The cook is the agent who enacts these transformations. As a result, many orders can be worked on simultaneously without requiring mental representation and computation. This is also important in learning, for 'what the learner acquires through experience is not *represented* at all but is *presented* to the learner as more and more finely discriminated situations' (Ref 70, p. 250). This development does not require representation of the environment *in* the agent's mind, but may occur in terms of the changing relations and the adaptation of a mental pointer system ('deictic codes').[72]

Situated Robotics

Important existent proofs that intelligent and complex behavior is possible without mental representation derives from situated robotics and other artificial life modeling endeavors. Situated robotics can be understood as a valuable foil for (1) articulating and explaining the different aspects of the situated cognition hypothesis[73] and (2) studying the sufficient conditions of cognition. It thereby constitutes a meta-methodological tool for those natural sciences concerned with cognition in its varying guises.[6] In the early years, robots were controlled by software that represented the environment in which the robots moved. These robots therefore could operate only in fixed, pre-defined environments. As an alternative, situated robotics focused on building robots that learned and developed by moving around and interacting with complex and dynamically changing environments *without explicit*, *stored representations*.[74] On the basis of Wittgenstein's idea of language as a game,[12] some designers of situated robotics work on the problem of (1) not only allowing communication between and with situated robots in their environment and grounding communication (language) in the material world (2) but also developing suitable language games from the bottom up.[75] Another approach to the emergence of language focuses on the embodiment of meanings of symbolic forms and takes the communicative forms to be embodied and emergent from collective activity.[55] Because the communication is itself an aspect of the material environment, future developments may well erase the distinction between (communicative) symbols and this environment. Making its starting point with results from experiments with live organisms, recent work in robotics often tests specific emergent hypotheses, for example, how place cognition might be a function of the agent's active exploration of the environment.[68] That is, rather than maps (representation), movement-based modifications in the agent-in-setting unit affect next actions and behaviors emerge as a result of evolution in organisms (i.e., evolved robots).

Artificial Neural Networks

Artificial neural networks (ANNs) also are used in arguments that support the situated cognition metaphor because they do not work with classical forms of representation. ANNs have been used, for example, to show the relative influences of environment and network characteristics on language learning.[76] Thus, language learning may be thought of in terms of a linguistic environment that changes from low to higher complexity (e.g., words and short sentences of children's babble before longer sentences of older children) or in terms of the organism being exposed to the full language, but with developmental constraints on what the organism can handle. Elman shows that ANNs learn efficiently when exposed to the language in its full complexity, but by varying a parameter that corresponds to the empirically observed short-term memory constraints. In ANNs, linguistic and other structures are not encoded and stored. Rather, regular patterns can be found—e.g., by means of factor analysis—in the activation levels of the artificial neurons *in the course of processing* and forwarding the stimuli received at the sensorial periphery. Such modeling is consistent with the *enactivist* dimension of the situated cognition hypothesis. As shown in a study of balance beam problems, artificial neural networks can be used to model the reflexive nature of cognition.[77] Thus, a second-order network constructed to analyze the activation levels of a first-order network reveals the same type of structure that a factor analysis reveals. ANNs that can modify the number of neurons and the linkages have been used successfully to model stage-wise cognitive growth that does not require mental representation.[78]

SITUATING SITUATED COGNITION

In the previous sections we review research supporting the situated cognition hypothesis. However, how the alleged situatedness of cognition is to be understood is still a controversial issue. The debates about situated cognition often focus on the question of *where* cognition is located, failing to first answer the question as to *what* is referred to when using the term cognition. Territory (material processes) and map (models, concepts, names) do not appear to be distinguished. But names and the things they name are different, though their mutual implications make it impossible to consider them independently.[79] If the latter question—i.e., *What* is cognition?—is not answered and explicated, the debate about whether or not the situated cognition hypothesis is intelligible, plausible, and fruitful is likely to founder on the rocks of mutual misunderstanding. In the following, we provide brief responses to these two questions.

Where Is Cognition?

The situated cognition hypothesis is integrally related to theses that go under the banners of embodied, enactivist, embedded, and distributed cognition.[80] Much discussion has concerned whether cognitive processes should be understood as extending beyond the skin—as to include aspects of the environment as constitutive of cognitive phenomena—or not. We can distinguish two positions in the debate on situativity from the latter perspective: the embedded cognition hypothesis, and the extended cognition hypothesis.[81] The extended cognition thesis argues that some cognitive processes may be seen as extending beyond the skin of the individual agent to include external aspects. A recurrent notion in this regard is 'cognitive off-loading'—the observation that part of any situated cognitive operation involves an active relation with the environment. Consider, e.g., skilled baggers in supermarkets who spatially group items to be bagged in functional groups, according to weight, shape, or fragility.[82] 'Thinking' about which item comes next in the bagging process, though still occurring in the mind, is not accomplished in a disembodied, disembedded manner, but actively involves operating on the physical environment. In this sense, the physical actions performed are not just pragmatic in that they are convenient, but are 'epistemic actions' that truly modify a problem-solving act.[83] Proponents of the extended cognition hypothesis argue that in examples such as the one of the baggers, 'epistemic action . . . demands spread of *epistemic credit*' (Ref 84, p. 8). The embedded cognition hypothesis, in turn, suggests that, while external aspects may help to produce and explain cognitive phenomena, these are not constitutive of cognition. Rather, there is a causal relation between the external (extra-cranial) aspects—the manipulations of the items to be bagged in the example above—and cognition.[85] Cognition is produced by the brain; and the fact that extra-cranial aspects play a central role in a given cognitive function does not concede them the cognitive 'credit'.[86] Empirical investigations cannot solve the problem, as these cannot distinguish between the two perspectives, that is, between different claims about *where* cognition lies.[81]

Another way of framing the question of situated cognition involves defining first the range of phenomena that we consider cognitive. Some psychologists have warned long ago to consider higher psychological functions as structures inherent in nature rather than as human constructs, and not to confuse brain and person: it is the person controlling the brain by means of external stimuli.[24] This is consistent with empirical observations, where, for example, situational characteristics such as the number and arrangement of milk cartons on a pallet and the number of milk cartons that constitute the customer's order *together* determine what the actions of the person organizing the delivery will do and calculate.[43] Some present-day neuroscientists agree noting that 'brains do not experience—organisms do' (Ref 87, p. 319). To understand cognition, therefore, we need to consider the agent in its ecological context, which together allow us to understand the role that the processes inside the brain play—especially if understood as an evolutionary feature that represents an advantage.[88]

What Is Cognition?

How cognition is understood and modeled depends on the categories used, the smallest units of analysis into which human behavior can be decomposed while preserving the characteristics of the relevant whole. In recent years, there has been a shift from units defined by properties inherent to the brain to units defined by correlations and dynamic patterns that include the brain, body, and environment leading to the study of cognitive ecosystems.[89] In choosing a particular unit of analysis, the researcher actively defines the boundaries of the phenomenon and, thereby, situates cognition and frames the domain that needs to be theorized: The unit of analysis determines what is to be understood as cognition and what lies outside it. Different models bear different implications for how the notion of representation is understood. Notions such as *distributed cognition* arise as the result of taking, for example, ship navigation—a task involving a team of people and the coordination of several representational devices—as the unit of cognitive analysis.[90] Different approaches to the study of cognition can be drawn in regard to how integral the notions of body and environment are to the minimal unit of analysis.

Self-Actional Models

In the classical approach to cognition, the (sensory) experience in one or more situations gives rise to representations, which are the results of abstractions from the concrete situations (Figure 2(a)). As abstractions, they can be used in (applied to) all other situations that are consistent with the structure retained in the abstraction. Representations are symbols stored in memory in the form of declarative and procedural 'knowledge' that describe objects in and transformations of the environment. The more abstract the representation, the larger the set of situations to which it can be applied. From this view, relations with the environment involve the enactment of production rules—abstractions of functional relations with the environment—that are activated by environmental stimuli. In 'turning to the left' while driving a car, for example, cognition involves the enactment of production rules of the type 'IF the road curves to the left THEN turn to the left'. The body is considered, as the environment, to be the 'raw sensory input' for cognitive processing. Cognitive phenomena include encoding, retrieval, or processing of information. Because the elemental units of this model (representations) are used to explain the behavior of what is defined as the cognitive system, we label this model as *self-actional*.[79]

Interactional Models

In much of the situated cognition literature, the application of representations is de-emphasized or absent. Rather, researchers focus on how a situation *presents* itself to the subject (Figure 2(b)). No boundary is drawn between environment, body, and mind. Research adopting this model emphasizes the mutually constitutive (dialectical) nature of situation and presentation (activation).[43,44] The minimal unit is a unit of *inter*action between two entities: subject and environment. Cognitive phenomena are not restricted to what happens inside the brain, but refer to the interactions within the person-in-situation unit. Interactional models adopt a nondualist approach to agency. In the cognitive system, mind, body, and environment are considered both agent and structure: acting and acted-upon. However, these models face a challenge in that the connections across situations are rarely addressed or explained, making it difficult to theorize stability and long-term growth to the extent that a representational

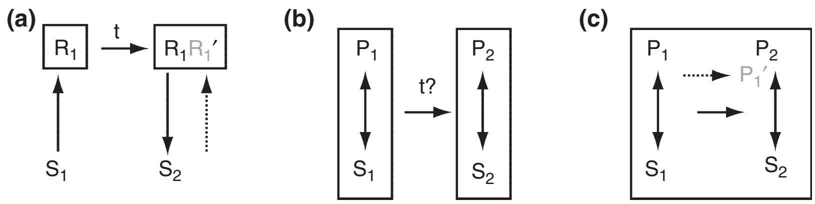

FIGURE 2 | Different units of analysis lead to different ways of conceptualizing the nature of cognition. (a) Classical representation approach. (b) A nontransactional interpretation of the situated cognition approach. (c) Transactional, dialectical approach, where time is not external, but is integrated with the units of analysis.

approach does. Time is often unaddressed or taken as the context of the unit of analysis. Thus, for example, models of situated construction of attitudes are good at explaining situated appropriateness and differences across situations, but fail to address enduring characteristics.[91] In fact, there is very little research that followed subjects across time with changing conditions (situations). Lave's study of mathematics in the supermarket, on simulated shopping problems, and on best-buy word problems[44] emphasizes discontinuities more so than continuities that arise from the same bodies being involved in and moving between material settings.

Transactional Models

A third type of model focuses on what is present in the consciousness of the subject, in subject–environment transactions, and, simultaneously, includes the transformed situation itself (Figure 2(c)). Time becomes internal to the phenomenon rather than constituting an external factor. For example, a study investigating students' conceptual activities in a science learning activity showed how the problem itself was continuously transformed, and, with it, the way in which the task presented itself.[92] New problem and solution strategies emerge unpredictably, whereas previously stated problem definition and solution alternatives fell to the wayside. That is, the minimum analytic unit contains the transformation (temporal dimension) and the forces of development within itself. If a satisfactory criterion for a good model states that the smallest category is that unit which preserves properties of the whole, then knowing and known have to be understood as constituting one, transactional system. As a consequence, there is an inner contradiction because what in other models are different situations here are part of the same minimum unit of analysis. Dynamical models in cognitive science, which focus on continuous change (rather than states), the dynamical coupling of environment and subject, and on alternative approaches to representation attempt to capture both continuity and discontinuity.[93,94] Different minimum units that preserve the characteristics of the whole have been proposed, including experience [pereživanie],[32,87] activity,[24,25] and consciousness.[25] In cultural–historical approaches, society constitutes the defining whole.[24,25,95] A transactional unit of analysis allows accounting for the re-presentational aspects of cognition without turning representations into the *cause* of behavior. Thus, researchers working within this frame can theorize cognitive processes both as parallel and as sequential.[96] The parallel aspects highlight the conceptual nature of perception, where perceiving is both imposing certain structure on the world as well as letting the world guide perception, involving affection at least as much as intention. The sequential aspects highlight the spatiotemporal extension of cognition, allowing representations to reside both in the mind, the body, and the (material and social) environment; and it highlights a reflective dimension that is not reduced to any single instant, but which implies internal temporal connections. Rather than an inherent representational function of the brain, re-presentational (imagistic, narrative) functions emerge from the fact that time is inherent to the unit of analysis. From this view it is possible and plausible to study the role of the body and the (material, social, and societal) environment in presenting and re-presenting the world during cognitive activity.

From Biology to Culture

A transactional unit of analysis involves a multiplicity of constitutive levels. Across the different academic fields where situated cognition approaches are used, four levels of analysis may be identified (Table 1). The first level is concerned with the biology (neural, physiological) and always inaccessible to consciousness. The second level concerns the body and its fundamental operations that tend to be automatic but can be brought into conscious awareness (e.g., those movements of the body that are involved in shifting gears but that tend to be unconscious in the performances of competent drivers). At the third level are individual or collective agents that

TABLE 1 | Levels of Analysis

	Dimension		
Level	Agent	Process	Consciousness
1	Neural, physiological (biology)	(Fundamental) biological processes	Pre-conscious (pre-noetic)
2	Body	Operations	Automatic, conditioned, unconscious
3	Individual, collective agent (subject)	Actions	Conscious goals
4	Culture, network, society	Activities, practices	Collective motives

pursue conscious goals, which they realize through actions. The fourth, most global level is defined by culture (society), characterized by collective practices (activities) that realize collective motives (e.g., generalized provision of food, shelter, and other needs). The imaging-related metaphors of *zooming* and *focusing* may assist understanding how the choice of the analytic unit determines what enters into the analytic lens.[97] Zooming limits what comes into the picture, making invisible anything that lies outside and the connections between inside and outside; focusing refers to finding the appropriate method to provide the best image of the entities in the chosen field.

CONCLUSION

One of the most significant implications that results from expanding the unit of analysis in situated cognition is that phenomena, which previously where seen as epiphenomenal to cognition and therefore remained unexplained by cognitive accounts, are now thoroughly explored with the aim of providing a substantial (fundamental) contribution to understanding intelligent behavior. Perceiving, remembering, or reasoning are not independent phenomena—to be explored as operations of the brain *alone*—but are integral to agents-in-their-context-acting-for-a-purpose-and-with-tools. Because the unit of analysis that the situated cognition hypothesis in the interactional and transactional versions proposes cuts across levels (see Table 1), the study of cognitive phenomena thus understood requires interdisciplinary methods capable of accounting for the connections between the levels.

There are already studies in the neurosciences recognizing philosophical studies that have anticipated their results. Thus, a team studying the neural processes involved in spatial perception noted that the findings they reviewed were inconsistent with traditional cognitive science, which is based on mental representations, but emphasized the role of motor-to-sensory pathways in object and space perception.[98] The authors note that the single neuron studies reviewed are close to insights that had arisen from phenomenological studies of space perception. Other scholars relate their work concerning the role of mirror neurons in joint action and affect to the phenomenological studies (Husserl, Merleau-Ponty) of self-other identity and affect.[99] There are mathematical (catastrophe-theoretic) modeling approaches that provide the mediating link between physical (scientific) and cognitive (computational vision) explanations of visual perception and phenomenological descriptions thereof.[100] Some researchers concerned with aspects of situated cognition explicitly suggest that '*disciplined first-person* accounts [of experience] should be an integral element of the validation of a neurobiological proposal, and not merely coincidental or heuristic information' (Ref 101, p. 344). The possibilities and implications of such an approach remain to be explored and tested empirically.

To understand intelligent behavior means accounting for the role of human experience, however subjective it might appear, by any suitable means. There are efforts to combine the rigorous study of human experience and the cognitive sciences,[102] an effort sometimes referred to as the naturalization of phenomenology or the phenomenological mind.[103] The perhaps most ardent advocate for an integration of research approaches across all levels, F. J. Varela, proposed neurophenomenology.[101] This approach is designed to deal with the 'hard problem' of cognitive science, the interrelation of human *experience* and associated brain activity; it may thereby also address the 'grounding problem' of cognitive science, that is, the question of how *abstract* (mental), nonphysical representations are connected to physical actions of real people. Varela argues that studies of neural correlates of experience require not only the methods of the neurosciences, but also rigorous approaches to the study of experience and invariants thereof. Attention, present-time consciousness, body image, perceptual filling in and fringe/center, and emotion are but some of the domains where careful scientific and first-person, phenomenological studies can lead to concerted convergent accounts of an '*embodied*, situated, or *enactive* cognitive science' (Ref 101, p. 346).

Because of the embodiment that the situated cognition hypothesis postulates, a direct connection between thought and affect—missing in other approaches to cognition—is established. Social aspects of situatedness give rise to the shared nature of affect (emotion), such as in experiences of empathy or collective emotions (e.g., grief over the loss of a leader or 'national' elation over a win at some world championship). Recent studies using a wide spectrum of ethnographic methods, such as monitoring of pitch and speech intensity, have started to investigate the regulative functions of emotions in (mundane) situated cognitive activities such as during everyday work in a fish hatchery.[104] Cognitive ethnographic studies are also being mobilized to account for the connections between cultural practices and situated collective conceptualizations.[105] Further work needs to be conducted in everyday settings similar to the early studies on the cognitive aspects of mathematics in the everyday world.

Solving the question of transfer from a situated perspective is still a challenge to accomplish. There is a tension between the need to address change and at the same time explain recurrence and stability. Whereas the mentioned developments have been useful in advancing our understanding of how the subject–situation relations are involved in learning, these have at some extent remained interactional in that explanations of learning have centered on intellectual aspects, continuity across situations consisting in structural relations of information structures. Other approaches that have attempted to account for the developmental aspects of change and continuity, for example across the school and the world of work, have overlooked the mechanisms by which the intellectual aspects of conceptualization emerge and evolve.[106,107] Furthermore, the role of the body in transfer constitutes an important question that requires an answer from the situated cognition hypothesis.

To solve questions concerning the role of language, studies need to be conducted that document and explicate how communication with abstract symbols may arise from bodily behavior. It is only in this way that we can come to better understandings about how (linguistic, symbolic) behaviors have evolved from their evolutionary precedents and how (new) (linguistic, symbolic) communication arises in the course of development along the life span. Thus, for example, one study shows how symbolic behavior among bonobo (pygmy chimpanzee) arises from movements designed to engage in carrying behavior.[55] Similarly, studies among teen-aged students in hands-on science show how hand-arm movements—initially modifying and exploring the setting with the senses (i.e., ergotic, epistemic movements)—subsequently become iconic (symbolic) hand gestures the contents of which later are represented in symbolic (e.g., abstract physical model), linguistic, and pictorial forms.[108] Both interdisciplinary field and laboratory studies are required for testing the universality of such changes in communicative behavior and the precise role that language plays when communication is understood more holistically: spread across bodies and situations.

In summary, the situated cognition hypothesis opens a horizon of research questions that bears great potential for expanding what cognitive science has to say about competent and intelligent human behavior. To create new research, the cognitive sciences, which already span, as the editors of *The Cambridge Handbook of Situated Cognition* state, 'a wide range of projects in philosophy, psychology, neuroscience, anthropology, robotics, and other fields' (Ref 109, p. 9) may find it useful to follow research in other emerging fields—including biotechnology, nanoscale science and engineering, genomics, medicine, and other strategic disciplines—where theoretical and methodological interdisciplinarity are correlated with innovation.[110] To encourage novel approaches in the field, a special issue in *Topics in Cognitive Science* on the theme of interdisciplinary approaches may constitute an ideal starting point for launching this topic anew. Of particular interest may be those places where humans and machines (e.g., intelligent robots) come to relate and reconfigure each other—as intimated in the title of Suchman's *Human–Machine Reconfigurations*.[3]

NOTES

[a] Here we understand 'support' in terms of the Bayesian approach, which (a) establishes probabilities $p(H|D)$ for hypothesis H given the data D—in contrast to the classical statistical approach that establishes probabilities $p(D|H)$ of data D given hypothesis H—and (b) uses both quantitative and qualitative data (e.g., in determination of priors) in support for a hypothesis H or its alternate H_{alt}: $p(H_{alt}|D) = 1 - p(H|D)$.

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