Phenomenology and the Cognitive Sciences (2023) 22:841–865
https://doi.org/10.1007/s11097-022-09806-w

The strong program in embodied cognitive science

Guilherme Sanches de Oliveira[1]

Accepted: 7 February 2022 / Published online: 25 February 2022

Abstract
A popular trend in the sciences of the mind is to understand cognition as embodied, embedded, enactive, ecological, and so on. While some of the work under the label of "embodied cognition" takes for granted key commitments of traditional cognitive science, other projects coincide in treating embodiment as the starting point for an entirely different way of investigating all of cognition. Focusing on the latter, this paper discusses how embodied cognitive science can be made more reflexive and more sensitive to the implications that our views of cognition have for how we understand scientific practice, including our own theorizing about cognition. Inspired by the "strong programme" in the sociology of scientific knowledge, I explore the prospect of an analogously "strong" program in embodied cognitive science. I first draw from Dewey's transactional notion of "situation" to identify a broad sense in which embodied cognitive science takes cognition, as an embodied phenomenon, to be *situated*. I then sketch a perspective I call *situated reflexivity*, which extends the Deweyan analysis to understand scientific practice in the same terms, and thereby illustrates what research in line with a strong program in embodied cognitive science can look like. This move, I propose, has the potential of setting up a new inquiry situation that makes more salient the embodiment of scientific practice and that, through this, can help organize our own embodied cognitive activities as we try to make sense of scientific work, including our own.

Keywords Embodiment · Situation · Reflexivity · Scientific practice · Embodied cognitive science

1 Introduction

An increasingly popular trend in the sciences of the mind is to eschew strict brain-centric reductionism and instead view cognition as embodied, embedded, situated, extended, enactive, ecological, and so on. Research under these labels (and related

✉ Guilherme Sanches de Oliveira
gui.cogsci@gmail.com

[1] Department of Psychology & Ergonomics, Technische Universität Berlin, Berlin, Germany

ones, such as "4E cognition") is diverse, including a number of different projects and perspectives. In some circles the label "embodied cognition" is used as a category-term to distinguish some cognitive processes (i.e., those that are embodied) from others (i.e., those that aren't): understood this way, it makes sense to consider particular phenomena such as social cognition, language and consciousness and ask whether they are embodied or not (e.g., Goldman & de Vignemont, 2009; Arbib et al., 2014; Prinz, 2009). In other circles, however, "embodied cognition" designates not a category that applies only to some cognitive phenomena but rather a way of understanding and investigating *all of cognition*: from this perspective the "whether" question doesn't arise (its answer in every case would be "yes"), and investigation is instead concerned with the question "how." This second use of "embodied cognition" is illustrated by work on a variety of topics, from wide computation (e.g., Wilson, 1994, 2004), distributed cognition (e.g., Hutchins, 1995, Hutchins & Klausen, 1996), the extended mind and the "natural-born cyborgs" view (e.g., Clark & Chalmers, 1998; Clark, 2003; Menary, 2010), up to the radical, anti-representational views of ecological psychology (e.g., Gibson, 1979; Richardson et al., 2008; Chemero, 2009) and enactivism (e.g., Maturana & Varela, 1980; Varela et al. 1991; Di Paolo et al., 2017; Gallagher, 2017). In this sense, embodiment is not a hypothesis about particular instances of psychological and behavioral phenomena, but is rather the starting assumption that informs how we conceptualize, investigate and understand any and all psychological and behavioral phenomena. In other words, "embodied cognition" in this sense amounts to a *research program* for cognitive science as a whole, rather than simply a complement to more traditional theoretical and methodological commitments.

The focus of this paper is on this second sense of "embodied cognition" as a research program. The goal here is to contribute to the field's ongoing development by proposing a specific way of understanding embodied cognitive science, organizing our research activities and opening up new avenues for inquiry. Inspired by and in analogy to the "strong programme" in the sociology of scientific knowledge (SSK), this paper invites practitioners to think of their work in embodied cognitive science as part of a similarly "strong" research program. Now, the label "strong program" in the context of embodied cognitive science might lead some readers to think of the "radical" anti-representational approaches already mentioned, which I am also going to be drawing from in my proposal. So it's good to make it clear from the start that what's at issue in the present paper is tangential to discussions about representation, computation and information processing: as will become clear, a crucial feature of the strong program is that it is marked by *reflexivity*, which has more to do with how and what we study than with whether we posit representations in our explanations of cognitive phenomena.

Section 2 provides an overview of the original "strong programme" in SSK and a brief preliminary discussion of reflexive research in the sciences of the mind. The idea of a "strong programme" in SSK was only possible in light of some understanding of what the usual, "non-strong" program in SSK was. Similarly, in order to develop a strong program in embodied cognitive science, it's important first to be clear on the nature of the research program itself. Section 3 elaborates on the brief description provided here in the introduction to propose a candidate account of what

brings us together in embodied cognitive science. There I draw from Dewey's notion of "situation" to propose a view of what it means to take cognition, as an embodied phenomenon, to be *situated*. Section 4 then sketches how this account of embodied cognition as situated (from Sect. 3) can be made reflexive through application of insights from the "strong programme" in SSK (from Sect. 2). The resulting view, which I call *situated reflexivity*, is offered as a particular example of what, more generally, work in line with a strong program in embodied cognitive science can look like. As such, after sketching the view, I conclude in Sect. 5 by briefly discussing paths for future development, not only for situated reflexivity itself but also for other potential approaches that embrace the strong program in embodied cognitive science.

2 The "strong programme" in SSK and the challenge of reflexivity

The Strong Programme[1] is the approach in the sociology of scientific knowledge (SSK) developed in the 1970s by a number of researchers primarily at the University of Edinburgh and most prominently articulated under that specific name first by David Bloor in his 1976 book *Knowledge and Social Imagery* (Bloor, 1991; see also, e.g., Bloor, 1981, 1984, 2007). A seemingly obvious place to start describing the Strong Programme would be to differentiate it from whatever the "weak" alternative in SSK was. But it's helpful to begin with a prior and even more fundamental distinction between the project of SSK in general and the philosophy of science it was reacting to.

2.1 The strong programme and its four tenets

The dominant philosophical attitude in the mid-twentieth century was to approach science with an almost exclusively logical and epistemological focus. This attitude was neatly expressed by Karl Popper when he stated that in order to understand scientific knowledge we need to understand "the objective logical relations subsisting among the various systems of scientific statements, and within each of them" (Popper, 2005, p. 22). From this perspective, leaving aside how certain ideas come to be accepted or rejected by scientists, what matters is, given an ideal standard of rationality, to understand why certain ideas *ought* to be accepted and others rejected. The Strong Programme emerges alongside related but independent work (e.g., Kuhn, 1970) as a reaction to this overly abstract, intellectualized and normative picture of scientific knowledge. As Barnes et al. (1996) put it decades later: "The concern at that time was mainly to oppose the arguments of rationalist philosophers who wished to treat science as a unique form of human activity, one which required no empirical understanding other than that implied by describing it as rational" (p. xii). In contrast, proponents of the sociological approach in science and technology

[1] I will use the British spelling to refer to the original approach in the sociology of scientific knowledge, and the American spelling for my proposal of an analogous approach in embodied cognitive science.

studies sought to develop *causal* explanations of science, understanding scientific knowledge "purely as a natural phenomenon" (Bloor, 1991, p. 5). In direct opposition to the dominant philosophical attitude, this meant focusing on identifying "the conditions which bring about belief or states of knowledge" (p. 7) independently of ideal standards of rationality. Importantly, for them, the *social factors* that philosophers had long neglected—such as perceptions of prestige and authority, at the individual and interpersonal scales, up to institutional structures that sustain and reinforce particular epistemic practices—become of central importance: after all, these are key conditions that shape real-world science and that make a unique contribution to how scientific ideas, theories and practices fare, and especially to which are rejected and which come to be accepted as knowledge.

This fundamental contrast with the dominant philosophical approach helps delineate the contours of what a sociological approach to scientific knowledge was generally interested in. But, out of all the different ways of doing research in SSK, what made the strong programme "strong" was the fact that, in addition to favoring a *causal* approach to understanding the nature of scientific knowledge, Bloor proposed that explanations should be *symmetrical* and *impartial* as well as *reflexive*.

Beginning with symmetry and impartiality, the strong programme proposes that, rather than using one set of explanatory principles to explain when things go "wrong" in science and a different one to understand when things go "well," the same explanatory principles should be employed to make sense of all of science. For example, we might think that extra-empirical social factors (e.g., racist ideology) are important for explaining how, in the past, scientists embraced scientific theories and practices that have since been discredited (e.g., eugenics). But it's inadequate to assume that social factors only play a role in these cases of "failure" or "bad science," and that these theories and practices came to be rejected and replaced on purely rational grounds; rather, the idea is that social factors must also have contributed to the shift to whatever is now accepted as "good science." Bloor proposes that we apply the same explanatory principles no matter the case: if our explanation of the bad or failed science of the past is in terms of how certain social conditions influenced the work of scientists, then it must have been a shift in those social conditions (rather than the elimination of social conditions altogether) that occasioned the better or more successful science of the present. As he puts it, our explanations are to be "impartial with respect to [the] truth and falsity, rationality or irrationality, success or failure" of the scientific theory in question; similarly, our explanations are to be symmetrical in that "The same types of cause would explain, say, true and false beliefs" (1976/1991, p. 7).

These stances on symmetry and impartiality help to shed light on the sense in which, as mentioned above, the strong programme favors a "causal" explanatory approach. Bloor (1976/1991) describes the pursuit of causal explanations of scientific knowledge in contrast with what he refers to as a *teleological* perspective on rationality. By this he means the assumption that instances of true belief, rational behavior, and successful knowledge acquisition are natural and self-explanatory, and that failure is the exception that demands explanation. He illustrates this teleological perspective with the example of logical reasoning. When someone works successfully from premises to a logically warranted conclusion, this success is seen as

simply following from logic itself, that is, from relations of entailment between the propositions in question. But, as Bloor puts it, "when someone makes mistakes in their reasoning then logic itself is no explanation. A lapse or deviation may be due to the *interference* of a whole variety of factors" (1976/1991, p. 8, emphasis added). What makes this interpretation of logical reasoning 'teleological' is the assumption that epistemic success is 'meant to be' and that failure, in contrast, is the result of an interference on the natural flow of events, a divergence from what should have been. Bloor gives another suggestive image to illustrate this perspective: "As when a train goes off the rails, a cause for the accident can surely be found. But we neither have, nor need, commissions of enquiry into why accidents do not happen" (p. 8). Applied to scientific knowledge, this teleological perspective sees success as in some sense uncaused and almost inevitable, leaving only errors to be explained by reference to some cause or other: "the rational aspects of science are held to be self-moving and self-explanatory. Empirical or sociological explanations are confined to the irrational" (p. 10). The strong programme's causal explanatory orientation is to be understood as a rejection of precisely this teleological stance on success. In line with the principles of symmetry and impartiality, the idea is that causal explanation should apply across the board rather than being relegated to instances of error. Success is not self-explanatory. If social and other conditions play a causal role in contributing to bringing about failure, then causes like these must also be at play when it comes to success, be it in logical reasoning, for instance, or in the development of scientific knowledge.

Lastly, the principle of reflexivity complements the strong programme in proposing that the explanatory lens that sociologists employ to understand science should also be turned against sociological work itself and applied to make sense of the sociologists' own explanatory practices. As Bloor explains, "In principle [SSK's] patterns of explanation would have to be applicable to sociology itself" and this has to be the case for, he adds, "otherwise sociology would be a standing refutation of its own theories" (p. 7). Bloor elaborates on this view as follows:

> There is no reason why a sociologist or any other scientist should be ashamed to see his theories and methods as emanating from society, that is, as the product of collective influences and resources and as peculiar to the culture and its present circumstances. Indeed if sociologists tried to evade this realisation they would be denigrating the subject-matter of their own science. (Bloor, 1991 p. 44)

In short, according to the strong programme, if sociologists appeal to social causes to explain scientific knowledge in all its instances (successful or not, in line with currently dominant ideological leanings or not, etc.), then the same causes must be seen as contributing to sociological explanations of scientific knowledge—that is, the same types of causes sociologists identify elsewhere must also play a role in explanations of their own work as sociologists of scientific knowledge. To do the sociology of science in line with the strong programme, then, means reflexively to approach your subject matter (e.g., specific aspects of scientific practice and knowledge production) with the awareness that your own work must be amenable to explanation in the terms of your analysis. Importantly, this opens up the possibility of

using SSK concepts, tools and methods to make SSK itself an object of study by focusing on specific aspects of SSK practice and knowledge production.

2.2 The four tenets of the strong programme and research in the sciences of the mind

The goal of this paper is to propose a way in which these ideas from the strong programme in SSK can inspire a corresponding strong program in embodied cognitive science. Toward this goal, it's helpful briefly to consider the extent to which the four tenets of the strong programme are present in the sciences of the mind more generally.

Work in the sciences of the mind is already by default concerned with *causal* explanation in the relevant sense. Different fields focus on different phenomena and produce different theories and explanations, with varying emphasis on what happens at the neural level or at the level of psychological traits or of cognitive processes and so on. Still, the sciences of the mind are part of the natural sciences, and as such, the normative (typically logical and epistemological) concerns and teleological perspective against which SSK emerged aren't a factor when it comes to determining how we go about investigating mind and behavior. To be sure, commitment to a causal explanatory approach in this sense does not entail a commitment to reductionism. In different fields, researchers reject mechanistic approaches in favor of dynamical, covering law, historical and/or evolutionary explanations. In the broad sense described above, these count as causal in that they aim to identify conditions that bring about the phenomena in question, as Bloor puts it, and this is the case even if the conditions at play are dynamical relations, say, rather than mechanisms. Put differently, regardless of the particular explanatory approach favored, the sciences of the mind are causal in the sense of typically avoiding viewing phenomena as self-explanatory: some approaches seem to rely on notions that maintain some kind of teleological flavor (e.g., some ways of construing biological function or self-organization, for instance), but even those are in the business of identifying conditions that contribute to bringing about the phenomena in question.

Work in the sciences of the mind also seems, by and large, to be impartial and symmetric in the relevant senses. Some research projects and ways of framing research questions persist despite increasingly appearing to be ideologically problematic. This is the case, for example, when it comes to research focusing on racial and sex differences at the neural, psychological or cognitive levels. These are particularly contentious because they run the risk of reifying in biological terms differences that, if real, might ultimately be better explained in sociocultural terms. Still, even questionable efforts like these tend to be part of a broader naturalistic project of explaining *all* aspects of human mind and behavior in the *same* terms (be they neural, psychological, cognitive etc. in each case). Some research questions may be ill-posed and/or ill-motivated, but that won't in all cases entail partiality or asymmetry in the explanatory approach and in the causal conditions posited.

Lastly, but more importantly for the purposes of this paper, we need to consider how reflexivity figures in the sciences of the mind. A first point to note is that,

although the principle of reflexivity in the sense found in SSK is obviously not limited to sociological analyses, it doesn't seem to apply universally to all of science either. It seems reasonable to expect chemists and physicists to apply their particular causal explanatory approach impartially and symmetrically to all instances of the phenomena they study. But chemists and physicists don't appear to have a special burden to understand themselves (e.g., their theories, methods and practices) in exactly the same terms that they employ to explain their objects of study (e.g., atoms, molecules, reactions, etc.). The same cannot be said of sciences that have humans as their object of study, which includes the sciences of the mind: it *is* appropriate to expect that the ideas and theories we develop to understand human behavior also, self-referentially, apply to the particular human behavior of developing scientific explanations of human behavior. Some examples of reflexivity in the sciences of the mind (though not under the same name) include initiatives under the rubric of "psychology of science" in the traditions of personality and social psychology (e.g., Feist & Gorman, 2012; Feist, 1993, 2006a, 2006b; Richards, 2002) as well as "cognitive science of science" in the computational, cognitivist approach (e.g., Thagard, 1993, 2012). Both of these lines of research apply theories and concepts from the relevant fields to make sense of particular aspects of scientific practice, such as creativity, problem solving, discovery, explanation, conceptual change, and so on. In comparison to these developments in neighboring fields, embodied cognitive science has clearly lagged behind. Some passing remarks and other detailed but narrowly focused discussions can be found in work by Maturana and Varela (1980, 1987) as well as by others in the enactive tradition influenced by them (see, e.g., Stewart, 2010; Bottineau, 2010; Di Paolo et al., 2017). Although unquestionably insightful, these examples can be seen as exceptions that prove the rule. As a research program, embodied cognitive science is far from producing anything close to a systematic effort at reflexive research. This is where drawing inspiration from the strong programme in SSK can be especially helpful, or so I will propose.

3 Embodied cognition: getting clear on the situation

The embodied cognitive science research program has been described as rejecting the "smallist" and "localist" orientation of mainstream cognitive science, and, accordingly as starting from the assumption that cognition spans brain, body and environment (Chemero & Silberstein, 2008; Sanches de Oliveira & Chemero, 2015; see also, e.g., Wilson & Golonka, 2013). Inclusion of the environment is a relatively uncontroversial feature of the research program, one that's often voiced in the admission that, as an embodied phenomenon, cognition is in some important sense *situated*. But in what sense? A whole body of work already exists that explores related ideas under the label of "situated cognition" (e.g., Clancey, 1997, 2009; Kirsh, 1991, 2009; Kirshner & Whitson, 1997; Lave, 1988; Robbins & Aydede, 2009a; Suchman, 1987). What exactly is meant by "situated cognition," however, is a matter of debate (Robbins & Aydede, 2009b; Roth & Jornet, 2013; Wilson, 2002). At least on some formulations, situated cognition and embodied cognitive science are not simply similar and compatible but they actually overlap

conceptually and historically (see, e.g., Gallagher, 2009). On other formulations, "situated cognition" is understood broadly enough as to encompass even work in science and technology studies in the vicinity of SSK (see brief discussion in Solomon, 2007). While these convergences and overlaps are suggestive, there are other formulations, still, where "situated cognition" is interpreted in a more traditional cognitivist vein as being roughly equivalent to the first sense of "embodied cognition" reviewed in Sect. 1 (e.g., Wilson, 2002). For present purposes, then, rather than trying to fix on the meaning of one disputed label ("embodied cognition") by reference to another disputed label ("situated cognition"), it will be more productive to look for an independent reference point. Following Gallagher's (20172017) lead, here I draw from John Dewey's notion of "situation" to clarify what it means for cognition, as inherently embodied, to be situated.

In two books he published in 1938—*Logic: The Theory of Inquiry* and *Experience and Education*—Dewey describes a "situation" variously as a "contextual whole," a "field of observation," and the "total environment." For him, a situation is the horizon or complex organic (i.e., material, biological, conceptual, affective, etc.) condition that gives shape to our experience of the world: we always find ourselves participating in *some* situation, and the particular situation we're in at a given point in time informs what we do and how we relate to objects, people, and the world around us. As he puts it:

> What is designated by the word "situation" is *not* a single object or event or set of objects and events. For we never experience nor form judgments about objects and events in isolation, but only in connection with a contextual whole. This latter is what is called a "situation." (Dewey, 1938/2008, p. 72)

And he adds:

> In actual experience, there is never any such isolated singular object or event; *an* object or event is always a special part, phase, or aspect, of an environing experienced world—a situation. The singular object stands out conspicuously because of its especially focal and crucial position at a given time in determination of some problem of use or enjoyment which the *total* complex environment presents. There is always a *field* in which observation of this or that object or event occurs. (Dewey, 1938/2008, p. 72-73)

These and other passages emphasize how, for Dewey, we experience objects and the environment always in *relational* rather than absolute terms. We don't experience apples, dogs, chairs, gardens and lakes, for example, in terms of the colors and textures and other intrinsic, elementary characteristics that these objects have, which are more or less stable and enduring. Rather, we experience them in terms of their meaning to us, which is variable and changes over time depending on what we are up to, whether we're hungry, in a hurry, seeking solitude, feeling playful, or having a picnic with friends, and so on. While the absolute, intrinsic properties of objects and events matter, they are always accompanied by different subjective states, and these "objective and internal conditions"

all constitute the experience: "Any normal experience is an interplay of these two sets of conditions. Taken together, or in their interaction, they form what we call a *situation*" (Dewey, 1938/1997, p. 42); as such, the environment for a person is not just the physical space surrounding that person, but it is "whatever conditions interact with personal needs, desires, purposes, and capacities to create the experience which is had" (p. 43). Finally, it's in this sense, understood as an interplay of objective and subjective conditions, that for Dewey situations enable and limit in particular ways individual experience: "control of individual actions is effected by the whole situation in which individuals are involved, in which they share and of which they are co-operative or interacting parts" (Dewey, 1938/1997, p. 53). For him, then, the control of individual actions is not a subjective business that merely happens to be surrounded by space and stuff. Rather, we are always in some situation or other, and the particular situation we are in shapes our experience and informs what we do, which includes how we think: "a qualitative and qualifying situation is present as the background and the control of *every* experience" (Dewey, 1938/2008, p. 76).

The *relational* character of situations is central to Dewey's view and worth emphasizing. Some of what Dewey is proposing about situations, and in particular about how we engage with objects *in* situations, is relevantly related to the Gibsonian theory of affordances and affordance perception. For Gibson and others after him, rather than perceiving absolute properties of an object and having to infer or somehow estimate how to interact with the object, we instead directly perceive the affordances or possibilities for action that the object makes available to us. Yet the object's affordances aren't reducible to the characteristics the object has on its own: affordances are made up by the relation between features of the agent (including the agent's sensorimotor makeup) and the characteristics of the object/environment (Chemero, 2003, 2009; Gibson, 1966, 1979; Rietveld & Kiverstein, 2014). Dewey's view of our engagement with objects and the environment "in a situation" thus overlaps at least partially with what, later, Gibson would call affordance perception. At the same time, Dewey's notion of "situation" is also broader in that it can be seen as explaining why, out of all the affordances a given environment could present to typical members of a species, only a subset of those will be salient to an individual member of the species—i.e., because of that individual's particular situation. This relates to recent discussions about von Uexküll's notion of the "Umwelt" as the agent-specific sense of environment in which affordance perception is situated (e.g., Baggs & Chemero, 2020, Fultot & Turvey, 2019; Feiten, 2020).

These connections to ecological psychology offer a good occasion to clarify the nature of Dewey's view of situation and its relevance for embodied cognitive science more generally. Dewey's point is not (simply) about how, in particular situations, the world appears to individuals in a relational or agent-relative manner. This interpretation would be too individualistic, and in tension with the pragmatist understanding of "experience" as an objective affair rather than mere "subjective private consciousness" or appearances in a Cartesian theater (Dewey, 1929, p. 11; see also James, 1909, 1912). In the foregoing I have used terms like 'interaction', 'interplay' and 'relations' without further qualification, much like Dewey himself tended to do in his earlier work. Later, however, Dewey came to frame his perspective in more

explicitly *transactional* terms (see Dewey & Bentley, 1946a, 1946b; Dewey, 1948). The important difference is that, rather than understanding organism and environment as fully independent, pre-formed and self-contained entities that merely come into contact with each other, Dewey sees the entire organism-environment situation as the more fundamental unit that enable organism and environment to become what they are when taken individually. Dewey illustrates this view with the example of a commercial transaction in which buyer and seller exchange some goods. Terms like 'buyer', 'seller', and 'goods' only make sense in reference to a transaction: "No one exists as buyer or seller save *in and because of* a transaction in which each is engaged"; moreover, "specific things *become* goods or commodities because they are engaged in the transaction"; and all participants, including the goods in question, undergo at least some amount of change "because of the exchange or transfer" (Dewey, 1948, p. 197). So, despite what terms like 'interaction' and 'relation' might suggest, it's this transactional picture that Dewey means to offer with his notion of situations as made up of subjective and objective conditions. As he puts it elsewhere: "This interaction is the primary fact, and it constitutes a *transaction*. Only by analysis and selective abstraction can we differentiate the actual occurrence into two factors, one called organism and the other, environment" (Dewey, 1931, p. 252). Subjective and objective factors don't add up to yield a situation. On the contrary, the (transactional) situation is the basis from which we can come to identify, for analytical purposes, subjective and objective contributors.

This transactional perspective finds an echo in ecological psychology not only in the notion of affordances as relational, as just seen, but also in the broader Gibsonian approach of understanding psychological phenomena at the "ecological" scale, in terms of an organism-environment mutuality or reciprocity (Lombardo, 1987; Heft, 2001; for critical discussions of this connection see, e.g., Costall, 2004, 2017; cf. Pedersen & Bang, 2016; van Dijk, 2021). Transactional thinking can also be found in the enactivist conception of autopoiesis and in related views of the self as emergent from (rather than a precondition for) organism-environment relations, through an interplay of the organism's self-differentiation from and participation in its world (see, e.g., Kyselo, 2014; Thompson, 2004; Di Paolo & Thompson, 2014). Importantly, however, transactionalism is not limited to these specific strands, but can be seen as a feature of embodied cognitive science more generally (Crippen & Schulkin, 2020).

It's in line with this transactional reading that Dewey's notion of situations as relational can help us make sense of the embodied cognitive science research program. Understanding cognition as "situated" in this technical sense amounts to an alternative way of explaining cognitive phenomena, not in terms of states and processes internal to individuals, but in terms of relations between individuals and the world. And this neatly captures the view, common in contemporary embodied cognitive science, of cognition as the interplay of brain, body and environment (see Fig. 1). In Dewey's perspective, situations encompass subjective conditions such as our states of interest and need (in all their neural, biological, affective, conceptual dimensions), as well as "objective" conditions such as the intrinsic features of objects around us and patterns of engagement with those objects and with other people, who also bring in their own subjective conditions of interest and need, and so on. This inherently transactional nature means that

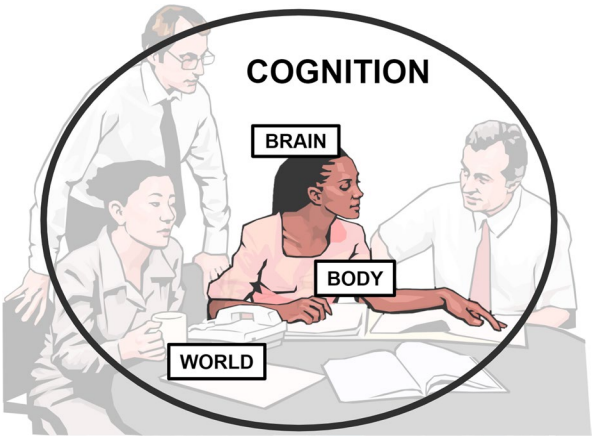

Fig. 1 In embodied cognitive science, cognition is understood as the interplay of brain-body-world, where "world" encompasses not only surfaces and objects but also other people we engage with. Importantly, the claim that, as an embodied phenomenon, cognition is *situated* means that, more than simply happening in some physical space, cognition is always part of some or other definite *situation*—i.e., in Deweyan terms, a complex, qualitative contextual whole that is constituted by transactions between organism and environment and that enables and constrains experience in particular ways

situations cannot be reduced to appearances in subjective consciousness: for instance, complex relational factors such as gender, ethnicity, and other social markers of identities and roles with the potential to occasion power differentials are always present and contribute to the qualitative character of the situation, even if they aren't salient as such to some individuals some of the time. Insofar as we are always in some situation or other, we are always in some particular material and social arrangement with these absolute and relational characteristics.

Finally, understanding cognition as situated in this Deweyan, relational sense of "situation" can help clarify the general orientation of the embodied cognitive science research program as being at odds with the smallist and localist research program of mainstream cognitive science. Our embodied existence "in" the world means that we can't help but find ourselves "in" situations. Dewey explains what this "in" means:

> The statement that individuals live in a world means, in the concrete, that they live in a series of situations. And when it is said that they live *in* these situations, the meaning of the word "in" is different from its meaning when it is said that pennies are "in" a pocket or paint is "in" a can. It means, once more, that interaction is going on between an individual and objects and other persons. The conceptions of *situation* and of *interaction* are inseparable from each other. An experience is always what it is because of a transaction taking place between an individual and what, at the time, constitutes his environment. (Dewey, 1938/1997, p. 43)

Dewey's description resonates with the existential flavor of the phenomenological understanding of being as "in the world" (see, e.g., Heidegger, 1927/2001;

Merleau-Ponty, 1945), by which phenomenologists meant much more than just a matter of occupying a certain amount of physical space. Together with pragmatism, this phenomenological stance on the nature of embodied experience provides some of the conceptual (even if not necessarily methodological) foundations for contemporary embodied cognitive science (see, e.g., Chemero, 2009; Kaufer & Chemero, 2021; Gallagher, 2017; Di Paolo et al., 2017; Heras-Escribano, 2019). So, when researchers in embodied cognitive science say that, as an embodied phenomenon, cognition is *situated*, a broad, nonpartisan (e.g., neither strictly ecological nor enactivist) way of understanding what this means is: beyond saying that cognition happens somewhere involving some body, we're saying that it happens in particular existential contexts made up of organism-environment transactions that, at specific points in time, guide how resources from brain, body and world get harnessed in particular ways for particular purposes.

4 Embodied cognitive science *embodied*: the perspective of situated reflexivity

The goal of this section is to illustrate and motivate a strong program for embodied cognitive science (inspired by that from SSK explored in Sect. 2) by showing how our understanding of cognition as embodied and situated (Sect. 3) can, reflexively, inform our understanding of science. This positive proposal, which I call "situated reflexivity," is one example among potentially many different paths for a strong program in embodied cognitive science. Accordingly, after presenting this sketch I close the paper (in Sect. 5) by discussing broader theoretical and methodological points that apply not only to this but also to other potential approaches that would fall within a strong program in embodied cognitive science.

The starting point for us is to see what consequences a view of embodied cognition following the Deweyan notion of situation has for an embodied understanding of science in general, and cognitive science in particular. Put simply, if we explain cognition in terms of brain-body-world transactions in some specific situation, then the same must be the case for cognition at play in our own work as scientists, including even the practices we engage in when we work on embodied, situated approaches to cognitive phenomena. That is, if we think that the embodied cognition framework is a fruitful way to make sense of cognition, then we can't apply it only to the "ordinary folk" but must also turn the same explanatory approach toward understanding ourselves. And this leads to seeing science as an embodied practice, something that embodied cognitive agents *do* by harnessing brain, body and environmental resources according to the particular "situations" they find themselves "in" (see Fig. 2).

Insofar as it results from the relation between various "objective" and "subjective" conditions (as Dewey puts it), the situation of a cognitive scientist includes the immediate physical space and behavior setting you find yourself in when developing some specific part of your work. Discussing a particular aspect of the research (such as an idea for a new theoretical or experimental project) can happen, for example,

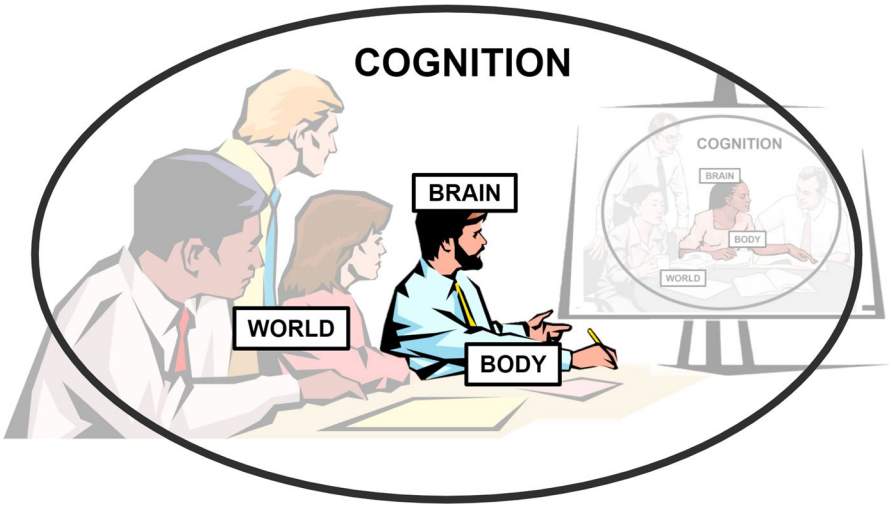

Fig. 2 Applying the principle of reflexivity to the idea that *cognition, as a brain-body-world transaction, is situated* leads to the recognition that researchers discussing the idea of embodied cognition (whether in agreement or not) are themselves, by necessity, also "in" some "situation" or other. The situation involves not only a particular physical space, but also some philosophical background, some theoretical and methodological assumptions, and other such factors that guide our embodied actions in the world—which includes how we engage with concepts, hypotheses, instruments, and methods at given points in time, seeing some as more or less attractive, viable, promising, and so on

in a break room with supportive colleagues from your lab or research group, or in a big lecture hall at a convention center with conference participants in the audience who may turn out to be less receptive. These seemingly external conditions are, of course, already relational: besides including what's out there in the physical environment, they encompass elements of what you bring into the picture at that particular point in time and space. You, like any other researcher in the field, have some or other philosophical background, you have been trained (by other people) in some tradition or other that has its own theoretical and methodological assumptions, and so on—and these and other similar factors play a role not only in *how* you do the work that you do, but even in *what* work you do. Abstract considerations about statistical significance, for example, can contribute to the success you anticipate some research ideas (and not others) to have. But so can factors such as your work contract status, institutional standards for performance review, and journal editing practices in your specific field. If reappointment criteria at your university places higher value on some types of publications rather than others, and if journals tend to publish certain kinds of research more than others, then having tenure or having only two years left in your contract puts you in different situations, informing which work you see as worth pursuing in ways that are specific to those circumstances. More generally, how you engage with concepts, hypotheses, instruments, methods—and even which of these you see as more or less useful, attractive, viable, and promising—all depend on how subjective and objective conditions affect one another in that situation. And, of course, all of these facts that apply to you also apply to your interlocutors, be they

close collaborators in the break room or complete strangers at the conference who may be in a significantly different situation than you.

I call the perspective I'm sketching here *situated reflexivity* because it combines the Dewey-inspired view of situated-embodied cognition discussed in Sect. 3 with the reflexive attitude explored in Sect. 2. Just as you might explain embodied cognition in the case of an "ordinary" person as the situation-driven harnessing of brain-body-world resources to solve problems, for instance, it follows that your doing just that—i.e., engaging in explanatory practices as a cognitive science researcher who's an embodied cognitive agent—is also to be understood as the harnessing of brain-body-world resources to solve problems in some situation or other. Thinking in this way raises a number of interesting questions, opens up promising new avenues for research, and it also has the potential to inform pressing philosophical debates.

The first and more obvious point to emphasize is that the perspective of situated reflexivity invites careful investigation of scientific situations. The conceptual bases of the perspective are in line with a broadly pragmatist approach to naturalizing science and understanding it as in continuity with other aspects of human life. This idea is aptly summarized in Richard Rorty's motto, *natural science is not a natural kind* (Rorty, 1991). Rorty finds support for his view in William James, for example, claiming that, for James, "no distinction of kind separates the sciences from the crafts, from moral reflection, or from art" (Rorty, 1980, p. 723). Similar ideas are present in Dewey's thought as well, as illustrated in his claim: "The history of the development of the physical sciences is the story of the enlarging possession by mankind of more efficacious instrumentalities for dealing with the conditions of life and action" (Dewey, 1929, p. 11). From a pragmatist perspective, then, science is, at its best, an instrumentally useful practice: when science gives us truth, that means, to co-opt James' words, that science is carrying us "prosperously from [some] part of our experience to [some] other part, linking things satisfactorily, working securely, simplifying, saving labor" (James, 1907, p. 58). In this light, Dewey can be read as suggesting that the historical development of science is the historical development of ever better tools for enriching human life and for attaining human goals. Importantly, however, here "better" (as in "better tools") stands for some context-dependent and *situation*-specific measure of effectiveness rather than an objective, atemporal and decontextualized measure of accuracy in representing (or mirroring, for Rorty) absolute reality.

This pragmatist link to other human practices is suggestive, but it can be easily misunderstood. Recognizing that science stands on a continuum with other human concerns and activities doesn't entail that there are no distinguishing features: it's not like, once we have an account of, say, "ordinary" (non-scientific) problem solving, we can call it a day. For instance, recent work on education and instructional design, especially in STEM fields (i.e., in science, technology, engineering and mathematics), provides great insight into the development of complex cognitive abilities such as mathematical reasoning from a broadly embodied, enactive and ecological perspective (e.g., Abrahamson, 2021; Abrahamson & Sánchez-García, 2016; Heft, 2021; Hutto et al., 2015). The phenomena these studies focus on and the results are no doubt important and promising. But of course, from understanding

aspects of STEM education, there is still a big step to accounting for what we do when we *do* science rather than *learn* about it as students. Despite the continuities, arguably there are also many important differences between my mathematical reasoning at the grocery store (see, e.g., Lave, 1988), an engineer's mathematical reasoning in designing a bridge, and a mathematician's mathematical reasoning in making discoveries about the dodecahedron (Athreya et al., 2020) or exotic spheres (Goette et al., 2020). Recognition that science is a part of life and on a continuum with other human practices is crucial, but it's insufficient if it doesn't also acknowledge the differences.

This is where a relational understanding of situation and, accordingly, of cognition as situated, can be particularly useful. The recognition of continuity calls for consideration of how sometimes abilities like the ones we use in our daily activities come to be harnessed in unique ways for the purposes of doing scientific work. The relational perspective of situated reflexivity expands this focus and helps us identify particular features that account for the differences. But what kind of features and differences? Internalist views would appeal to differences in intra-organismic characteristics and processes, while externalist views would posit difference-makers in the objective "context." In contrast, by thinking in terms of organism-environment transactions, situated reflexivity considers how these varied resources interact with, and change, one another in the (relational) cognitive situation of scientists. And this makes it possible to go beyond mere acknowledgement of continuity to reveal the integral, constitutive role played by the specific inquiry situations that particular researchers, research groups and academic communities find themselves "in."

In this context, important targets of investigation would include the differences and relations between distinct situations *within science*, on the one hand, and *between scientific and non-scientific situations*, on the other. The former relates to ongoing interest and concern with interdisciplinarity (see, e.g., Thorén & Persson, 2013; Andersen & Wagenknecht, 2013; Andersen, 2016; MacLeod, 2018), where an important outcome would be a better understanding of how to promote collaborative projects that bring together researchers from potentially very different disciplinary backgrounds. As for the latter, a better understanding of situations (scientific and otherwise) could also contribute to addressing concerns at the interface of science and society, from issues relating to science communication and public understanding of science (e.g., Keren, 2018; Millar & Wynne, 1988; Simis et al., 2016) to more directly political questions having to do with public trust and uptake of scientific findings in policy making (e.g., Oreskes & Conway, 2011; de Melo-Martín & Intemann, 2018; Goldenberg, 2021; Oreskes, 2021). Finally, at the intersection of the two we find initiatives where non-scientists are more than mere consumers of scientific knowledge but play an active role in the the scientific process itself through what is sometimes called "participatory research," "citizen science," and "community-based research" (see, e.g., Koskinen & Mäki, 2016; Dunlap et al., 2021), which can be seen as versions of interdisciplinary research where the parties collaborating include not only scientists but also non-scientists of various backgrounds. Consideration of cases like these can contribute to deepening our understanding of the different types of situations at play in science. At the same time, by approaching cases like these through the lens of situated reflexivity, researchers in embodied cognitive

science might also be able to bring further clarity to them and identify ways for promoting more fruitful and productive situations for relations internal to science as well as between science and society at large.

Examination of previous reflexive efforts in the sciences of the mind can also provide useful guidance for research further developing the perspective of situated reflexivity. Consider, for instance, Thagard's (2012) work mentioned previously investigating science from a computational, cognitivist perspective. Thagard focuses on topics and aspects of science such as: explanation, justification, belief revision, conceptual change, problem solving, discovery, creativity, and the role of "values" in science. Many of these issues will be recognizable to anyone familiar with traditional cognitive science and philosophy of science. Here, a strong program in embodied cognitive science along the lines of the situated reflexivity view motivates at least two types of projects. On the one hand, in contrast with the internalist options provided by Thagard and others, we can work toward developing relational, situational accounts of these aspects of scientific work in embodied terms. And on the other hand, we can also ask whether this way of categorizing aspects of embodied scientific practice is appropriate in the first place: it may be that an embodied situational view of cognition motivates partitioning the phenomenon in different ways. For instance, traditional cognitivist research described by Thagard (2012) accounts for scientific innovation in terms of the combination of mental representations and it accounts for problem solving in terms of the creation, adaptation and use of mental models. In questions such as these, embodied cognitive scientists might be in a position to offer alternatives that rectify the disembodied nature of these accounts, but we may also find that a complete overhaul is called for because the phenomena need to be more fundamentally reframed (see Sanches de Oliveira, 2022).

Besides these more philosophical focal points, situated reflexivity also motivates work of a more traditionally psychological nature. Conceptualizing embodied cognition as situated in the Deweyan sense in terms of organism-environment transactions raises a developmental question about how these relations unfold and change over time. Accordingly, and reflexively, conceptualizing scientific practice in the same embodied, situated way raises questions about how training and apprenticing as a scientist and, over the long run, the work that goes into building a scientific career, fit into those dynamic patterns of organism-environment transaction. Different researchers in embodied cognitive science will be differently positioned to explore these questions empirically: some through more or less conventional laboratory experiments, setting up an inquiry situation where participants engage in shorter-term development, e.g., in learning and scientific discovery; others might be better positioned to, through a longitudinal lens, gain insight into longer-term aspects of the phenomena in question; and others still will be able to further shed light on these changes through an observational, natural history approach following examples set by some versions of ecological psychology (see, e.g., Barker, 1968; Schoggen, 1991/2014; Heft, 2001, 2018). This list is, of course, far from comprehensive, but it serves to indicate some of the possibilities for different researchers given where embodied cognitive science is at the moment.

5 Conclusion: a strong program beyond the analogy

The goal of this paper has been to explore the prospect of a strong program in embodied cognitive science inspired by the strong programme articulated by Bloor and colleagues in the sociology of scientific knowledge.[2] This involved considering the consequences that our view of cognition as spanning brain, body and environment have for understanding science, including the practices we engage in when we investigate and explain cognitive phenomena as spanning brain, body and environment. The perspective of situated reflexivity just sketched is one example of how work in embodied cognitive science can proceed oriented by a strong program following a Deweyan interpretation of our broad commitments to embodiment. As is clear from the pointers provided above, there are many different ways situated reflexivity could be further developed, but the orientation is the same, namely applying a Dewey-inspired view of organism-environment transactional situations reflexively to understand science. But, of course, these directions don't exhaust all the possibilities for a strong program in embodied cognitive science: after all, other potential embodied approaches to scientific practice not explicitly tied to analysis in Deweyan situational terms are potentially viable and desirable. For this reason I now close with a more general discussion, to clarify the nature of my proposal as it applies to the prospect of a strong program broadly construed, independently of alignment with the specific perspective of situated reflexivity I favor.

Even interpreting my proposal modestly, thinking purely in terms of an analogy to SSK would already be beneficial to embodied cognitive science. As the recent literature suggests, many of us are interested in and working on developing accounts that can be properly described as reflexive even in the absence of the term. Consider, for example, recent work on model-based research from a broadly enactive-embodied perspective (Rolla & Novaes, 2020), work on neuroscientific practice through the lens of Gibsonian ecological psychology (van Dijk & Myin, 2019), and work on art and design practices as providing not only content but also the means for inquiry in the philosophy of embodied cognition (see Rietveld, 2019 and responses by Ingold, 2020, Feiten et al., 2021, among others). For authors like these, the label "strong program" I am proposing might seem to be merely "a new name for an old way of thinking," to paraphrase James (1907). Even so there might be something important to be gained by embracing the name because of what comes with it. Anywhere in science, explicitly framed research programs are useful because of how they can guide inquiry by organizing both research activities and the insight gained through them. Research programs articulate explicit goals and concerns, and through this they can draw attention to features in our objects of study, and in our approaches to studying them, that might otherwise have remained implicit and occluded from view; this, in turn, can open up new avenues of inquiry. And the fact

[2] A different but very interesting and promising alternative approach for this paper would have been to draw inspiration from the reflexivity and situated views of knowledge at play in feminist epistemologies and in feminist science studies more generally (see, e.g., Haraway, 1988; Longino & Lennon, 1997; Campbell 2004; Code, 2014; Ashton & McKenna, 2020; Anderson, 2020). I thank one of the reviewers for this suggestion.

is that, despite their clear commonalities, reflexive efforts like the ones just mentioned have remained separate, almost as if they are concerned with entirely independent phenomena. Conceptualizing them as part of a larger vision and direction in our field—a strong program in embodied cognitive science—can help reveal their convergence in terms of shared objectives, which in turn can motivate exploring the potential convergence of the insight these projects have to offer. Here, even thinking of this strong program as being merely analogous to the one in SSK could thus help us take a step beyond disconnected, piecemeal work and move toward a concerted effort to address issues that many of us already agree are worth investigating.

Besides the analogy, however, I believe that even greater benefits are available to us through closer approximation between embodied cognitive science and the strong programme in SSK.[3] Given the nature of the embodied cognitive science research program as articulated here, reflexive theorizing for us involves a recognition of the importance of interpersonal, sociocultural, structural and institutional conditions. The character of our reflexive shift makes the comparison to the strong programme in SSK seem particularly apt: after all, the strong programme's goal was precisely to emphasize the interpersonal, sociocultural, structural and institutional aspects both of scientific work (i.e., SSK's object of study) and of research about that scientific work (i.e., SSK itself). This might seem like an indication of what both SSK and embodied cognitive science got right independently of one another: namely, that relational, transactional thinking suits better our inquiry situation than the analysis of our objects of study in purely internalist, individualistic terms. But as mentioned in Sect. 3, there is reason to see historical and conceptual ties connecting contemporary embodied cognitive science to anthropological and sociological approaches to scientific practice via "situated cognition" research (Solomon, 2007; Gallagher, 2009; see also, e.g., Sutton, 2006; Silver, 2016). This being the case, it's interesting that many practitioners in embodied cognitive science today are not aware of these ties and are not familiar with these bodies of work. Other than nods by Andy Clark (2003) and Gallagher (2020) to Latour, most influential books in embodied cognitive science from the past two decades entirely neglect anthropological and sociological studies of science. For this reason, approaching the idea of a strong program as more deeply linked to SSK (rather than merely in analogy to it) has the potential precisely to enrich and reorient some current discussions by inviting more

[3] One potential objection to this approximation is based on the fact that SSK is antirealist whereas some strands in embodied cognitive science, most prominently ecological psychology, present themselves as being realists (see, e.g., Chemero, 2009). But this tension is only apparent because the "realisms" in question apply to different domains. SSK's anti-realism is metascientific (or second-order) and concerns the nature of scientific theory and knowledge, whereas Gibsonian "direct realism" is scientific (or first-order) and concerns the nature of perception. In short, even if Gibsonians are realists about perception, this doesn't entail realism about the nature of scientific theories, including their own theory of perception. In line with this observation, the ecological (direct realist) perceptual theory of affordances has been argued to motivate anti-realism with regard to scientific models, conceptualized as tools with affordances (Sanches de Oliveira, 2016). More generally, debate about scientific realism has been argued to be orthogonal to what's at stake in realism/anti-realism distinctions within non-representational embodied cognitive science (Zahidi, 2014).

careful consideration of these neglected, albeit relevant and related, fields. Here I limit my consideration to methodological implications of this link.

In one of his many pieces defending the strong programme against philosophical objections, Bloor (2001) affirms that the strong programme's objective "was to codify and clarify an emerging body of case-studies, particularly by historians of science," to which he adds that "The real life-blood of the sociology of scientific knowledge lies with such empirical work" (p. 15210). Besides the analysis of historical case-studies, which was the clear favorite for Bloor and others in the Edinburgh school, another prominent method in the sociology of science is that of ethnographic observation of working scientists (e.g., Knorr-Cetina, 2013; Collins, 1992; Latour & Woolgar, 1979/1986; Latour, 1987). A major benefit of taking seriously the idea of a strong program in embodied cognitive science as informed by SSK is the possibility of drawing from these sorts of anthropological and sociological methods to complement the theoretical and experimental methods and approaches already dominant in embodied cognitive science. Historical case-studies have been popular in some circles where research focuses on historical records of scientific reasoning approached from the perspective of distributed cognitive processing (see, e.g., Tweney, 1985, 1989, 2014; Nersessian, 1992, 2002, 2008). Observational approaches appear in some work targeting interpersonal coordination and communication from an embodied perspective employing both qualitative and quantitative analysis methods (e.g., Rączaszek-Leonardi et al., 2018, 2019; Trasmundi, 2020; Trasmundi & Steffensen, 2016), but usually without attention to instances of scientific practice. And in fact, both historical and observational approaches are typically absent in conventional descriptions of what "4E cognition" and embodied cognitive science are all about (see, e.g., Clark, 2014; Shapiro, 2014, 2019; Shapiro & Spaulding, 2021). On the one hand, then, pursuing reflexive research through close attention to anthropological and sociological (including historical) approaches in science studies would be beneficial for us because it would significantly expand the embodied cognitive science methodological toolkit. On the other hand, this (re)approximation need not be a one-way street. Beyond embodied cognitive science researchers merely co-opting what others have already been doing well for a long time, we would also be in a position to bring in our own conceptual tools to collaborative investigations and, through that, contribute with potentially new and insightful ways to advance understanding of the phenomena under investigation. Besides the specific Dewey-inspired transactional and situational perspective advocated here, other possibilities include complementing conceptual, experimental and observational investigations of scientific practice with analysis in terms of affordances (drawing from ecological approaches) or sensorimotor contingencies (drawing from enactive approaches), to mention just two.

In short, then, a strong program developed merely in analogy to the one in SSK and that simply encouraged embodied cognitive science researchers to engage in reflexive work would already be a boon to our field. Framed as such, the strong program would invite researchers to consider how they can turn their methods toward understanding scientific practice in general and even embodied cognitive science practice in particular. And interpreted less modestly, the strong program motivates consideration of additional methods and approaches that we might

want to consider as we try to make sense of mind and behavior from an embodied standpoint. In either case, a strong program for embodied cognitive science is as methodologically pluralistic as the science itself. For instance, enactivists and ecological psychologists already have different preferred research practices, and the strong program doesn't demand that researchers in either tradition give up on those methods. The idea, rather, is to apply the same methods (of laboratory experimentation, theoretical analysis, computational and mathematical modeling etc.) in a different way, and to be open to potential new methods and approaches. In this respect, the more radical framing that draws a closer link to research in the anthropological and sociological traditions is perhaps the most helpful insofar as it explicitly draws attention to specific possibilities of what to try and where to look for guidance.

Seeing embodied cognition through a reflexive lens allows us to reconceptualize scientific work in ways that go against dominant narratives in academic and popular culture alike. This is a direction many of us are already taking informally and independently, in a piecemeal fashion. This paper's argument brings this very fact to the forefront of attention and thereby enables us to directly confront our concerns and the wide-ranging consequences that our view of cognition can have. This proposal can also be expressed reflexively. For the past few decades, thinking of our work as being part of such a thing as "embodied cognitive science" created an inquiry situation that enabled progress by organizing the different but often overlapping intuitions, hypotheses, methods and theories different researchers from different backgrounds had been developing and using. Moving forward, thinking in terms of a strong program for embodied cognitive science can contribute to the field's development as it grows and matures, and it can do so not only because it organizes disparate efforts and interests many of us already have, but also because it supports and enriches this work by helping us see differently what is possible. This sets up a new situation in which we are better positioned to understand scientific work (including our own work) and are further empowered to contemplate what else we might work on, why and how.

Funding Open Access funding enabled and organized by Projekt DEAL.

Declarations

Conflict of interest The author has no competing interests to declare that are relevant to the content of this articles.

References

Abrahamson, D. (2021). Grasp actually: An evolutionist argument for enactivist mathematics education. *Human Development, 65*(2), 10–26.

Abrahamson, D., & Sánchez-García, R. (2016). Learning is moving in new ways: The ecological dynamics of mathematics education. *Journal of the Learning Sciences, 25*(2), 203–239.

Andersen, H. (2016). Collaboration, interdisciplinarity, and the epistemology of contemporary science. *Studies in History and Philosophy of Science Part A, 56*, 1–10.

Andersen, H., & Wagenknecht, S. (2013). Epistemic dependence in interdisciplinary groups. *Synthese, 190*(11), 1881–1898.

Anderson, E. (2020). Feminist Epistemology and Philosophy of Science. *The Stanford Encyclopedia of Philosophy*, Edward N. Zalta (ed.) https://plato.stanford.edu/archives/spr2020/entries/feminism-epistemology/

Arbib, M. A., Gasser, B., & Barrès, V. (2014). Language is handy but is it embodied? *Neuropsychologia, 55*, 57–70.

Ashton, N. A., & McKenna, R. (2020). Situating feminist epistemology. *Episteme, 17*(1), 28–47.

Athreya, J. S., D. Aulicino, W. P. Hooper, and with an appendix by Anja Randecker (2020). Platonic solids and high genus covers of lattice surfaces. *Experimental Mathematics*, 1–31.

Baggs, E., & Chemero, A. (2020). The third sense of environment. In J. B. Wagman and J. J. Blau (Eds.), *Perception as Information Detection: Reflections on Gibson's Ecological Approach to Visual Perception*, Chapter 1. Routledge.

Barker, R. G. (1968). *Ecological psychology; concepts and methods for studying the environment of human behavior*. Stanford University Press.

Barnes, B., Bloor, D., & Henry, J. (1996). *Scientific knowledge: A sociological analysis*. University of Chicago Press.

Bloor, D. (1981). The strengths of the strong programme. *Philosophy of the Social Sciences, 11*(2), 199.

Bloor, D. (1984). The sociology of reasons: Or why "epistemic factors" are really "social factors". In *Scientific rationality: The sociological turn*, pp. 295–324. Springer.

Bloor, D. (1991). *Knowledge and social imagery* (2nd ed.). University of Chicago Press.

Bloor, D. (2001). Strong Program, in Sociology of Scientific Knowledge. In N. J. Slemser & P. B. Bates (Eds.), *International encyclopedia of the social & behavioral sciences* (pp. 15208–15210). Pergamon.

Bloor, D. (2007). Ideals and monisms: Recent criticisms of the strong programme in the sociology of knowledge. *Studies in History and Philosophy of Science Part A, 38*(1), 210–234.

Bottineau, D. (2010). Language and enaction. In J. Stewart, O. Gapenne, & E. Di Paolo (Eds.), *Enaction: Toward a new paradigm for cognitive science* (pp. 267–306). MIT Press.

Campbell, K. (2004). The promise of feminist reflexivities: Developing Donna Haraway's project for feminist science studies. *Hypatia, 19*(1), 162–182.

Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology, 15*(2), 181–195.

Chemero, A. (2009). *Radical embodied cognitive science*. MIT press.

Chemero, A., & Silberstein, M. (2008). Defending extended cognition. *In Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 30, No. 30). Chicago

Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representations*. Cambridge University Press.

Clancey, W. J. (2009). Scientific antecedents of situated cognition. In P. Robbins & M. Aydede (Eds.), *The cambridge handbook of situated cognition* (pp. 11–34). Cambridge University Press.

Clark, A. (2003). *Natural-born cyborgs: Minds, technologies, and the future of human intelligence* (1st ed.). Oxford University Press.

Clark, A. (2014). *Mindware: An introduction to the philosophy of cognitive science.* (2nd ed.). Oxford University Press.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis, 58*(1), 7–19.

Code, L. (2014). Ignorance, injustice and the politics of knowledge: Feminist epistemology now. *Australian Feminist Studies, 29*(80), 148–160.

Collins, H. (1992). *Changing order: Replication and induction in scientific practice*. University of Chicago Press.

Costall, A. (2004). From Darwin to Watson (and cognitivism) and back again: The principle of animal-environment mutuality. *Behavior and Philosophy, 32*, 179–195.
Costall, A. (2017). 1966 and all that: James Gibson and bottom-down theory. *Ecological Psychology, 29*(3), 221–230.
Crippen, M., & Schulkin, J. (2020). *Mind ecologies: Body, brain, and world*. Columbia University Press.
de Melo-Martín, I., & Intemann, K. (2018). *The fight against doubt: How to bridge the gap between scientists and the public*. Oxford University Press.
Dewey, J. (1925/1929). *Experience and nature*. Open Court Publishing Company.
Dewey, J. (1931). *Philosophy and civilization*. G. P. Putnam's Sons.
Dewey, J. (1938/1997). *Experience and education*. Simon & Schuster Inc.
Dewey, J. (1938/2008). Logic - The theory of inquiry. Collected Works of John Dewey Series (Vol. 12): The later works of John Dewey, 1925–1953. Southern Illinois University Press.
Dewey, J. (1948). Common sense and science: Their respective frames of reference. *The Journal of Philosophy, 45*(8), 197–208.
Dewey, J., & Bentley, A. F. (1946a). Interaction and transaction. *The Journal of Philosophy, 43*(19), 505–517.
Dewey, J., & Bentley, A. F. (1946b). Transactions as known and named. *The Journal of Philosophy, 43*(20), 533–551.
Di Paolo, E., Buhrmann, T., & Barandiaran, X. (2017). *Sensorimotor life: An enactive proposal*. Oxford University Press.
Di Paolo, E., & Thompson, E. (2014). The enactive approach. In *The Routledge handbook of embodied cognition*, pp. 86–96. Routledge.
Dunlap, L., Corris, A., Jacquart, M., Biener, Z., & Potochnik, A. (2021). Divergence of values and goals in participatory research. *Studies in History and Philosophy of Science Part A, 88*, 284–291.
Feist, G. J. (1993). A structural model of scientific eminence. *Psychological Science, 4*(6), 366–371.
Feist, G. J. (2006a). The past and future of the psychology of science. *Review of General Psychology, 10*(2), 92–97.
Feist, G. J. (2006b). *The psychology of science and the origins of the scientific mind*. Yale University Press.
Feist, G. J. & Gorman, M. E. (2012). *Handbook of the psychology of science*. Springer Publishing Company.
Feiten, T. E. (2020). Mind after Uexküll: A foray into the worlds of ecological psychologists and enactivists. *Frontiers in Psychology, 11*, 480.
Feiten, T. E., Holland, K., Chemero, A. (2021). Doing philosophy with a water-lance: art and the future of embodied cognition. *Adaptive Behavior*. https://doi.org/10.1177/1059712320983041
Fultot, M., & Turvey, M. T. (2019). von Uexküll's theory of meaning and Gibson's organism–environment reciprocity. *Ecological Psychology, 31*(4), 289–315.
Gallagher, S. (2009). Philosophical antecendents to situated cognition. In P. Robbins & M. Aydede (Eds.), *The Cambridge Handbook of Situated Cognition* (pp. 35–51). Cambridge University Press.
Gallagher, S. (2017). *Enactivist interventions: Rethinking the mind*. Oxford University Press.
Gallagher, S. (2020). *Action and interaction*. Oxford University Press.
Gibson, J. J. (1966). *The Senses Considered as Perceptual Systems*. Houghton Mifflin.
Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Houghton Mifflin.
Goette, S., Kerin, M., & Shankar, K. (2020). Highly connected 7-manifolds and non-negative sectional curvature. *Annals of Mathematics, 191*(3), 829–892.
Goldenberg, M. J. (2021). *Vaccine Hesitancy: Public Trust, Expertise, and the War on Science*. University of Pittsburgh Press.
Goldman, A., & de Vignemont, F. (2009). Is social cognition embodied? *Trends in Cognitive Sciences, 13*(4), 154–159.
Haraway, D. (1988). Situated knowledges: The science question in feminism and the privilege of partial perspective. *Feminist Studies, 14*(3), 575–599.
Heft, H. (2001). *Ecological psychology in context: James Gibson, Roger Barker, and the legacy of William James's radical empiricism*. Psychology Press.
Heft, H. (2018). Places: Widening the scope of an ecological approach to perception–action with an emphasis on child development. *Ecological Psychology, 30*(1), 99–123.
Heft, H. (2021). Grasping what? Ecological anchors for abstract thought. *Human Development, 65*(2), 94–99.
Heidegger, M. (1927/2001). *Being and Time*. Blackwell Publishers Ltd.

Heras-Escribano, M. (2019). Pragmatism, enactivism, and ecological psychology: towards a unified approach to post-cognitivism. *Synthese*, 1–27.
Hutchins, E. (1995). *Cognition in the Wild*. MIT press.
Hutchins, E., & Klausen, T. (1996). Distributed cognition in an airline cockpit. *Cognition and communication at work*, 15–34.
Hutto, D. D., Kirchhoff, M. D., & Abrahamson, D. (2015). The enactive roots of STEM: Rethinking educational design in mathematics. *Educational Psychology Review, 27*(3), 371–389.
Ingold, T. (2020). Meeting art with words: the philosopher as anthropologist. *Adaptive Behavior*, 1059712320970672.
James, W. (1907). *Pragmatism, a new name for some old ways of thinking: Popular lectures on philosophy*. Longman, Green and Co.
James, W. (1909). *A Pluralistic Universe*. Longman, Green, and Co.
James, W. (1912). *Essays in Radical Empiricism*. Longman, Green, and Co.
Käufer, S., & Chemero A. (2021). *Phenomenology: an introduction* (2nd ed.). John Wiley & Sons.
Keren, A. (2018). The public understanding of what? Laypersons' epistemic needs, the division of cognitive labor, and the demarcation of science. *Philosophy of Science, 85*(5), 781–792.
Kirsh, D. (1991). Today the earwig, tomorrow man? *Artificial Intelligence, 47*(1–3), 161–184.
Kirsh, D. (2009). Problem solving and situated cognition. In P. Robbins & M. Aydede (Eds.), *The Cambridge Handbook of Situated Cognition* (pp. 264–306). Cambridge University Press.
Kirshner, D., & Whitson, J. A. (1997). *Situated cognition: Social, semiotic, and psychological perspectives*. Psychology Press.
Knorr-Cetina, K. D. (2013). *The manufacture of knowledge: An essay on the constructivist and contextual nature of science*. Elsevier.
Koskinen, I., & Mäki, U. (2016). Extra-academic transdisciplinarity and scientific pluralism: What might they learn from one another? *European Journal for Philosophy of Science, 6*(3), 419–444.
Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.), Volume 2 of *International Encyclopedia of Unified Science*. The University of Chicago Press.
Kyselo, M. (2014). The body social: An enactive approach to the self. *Frontiers in Psychology, 5*, 986.
Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Harvard university press.
Latour, B. & Woolgar, S. (1979/1986). *Laboratory life: the construction of scientific knowledge*. Princeton University Press.
Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge University Press.
Lombardo, T. J. (1987). *The reciprocity of perceiver and environment: The evolution of James J. Gibson's ecological psychology*. Lawrence Earlbaum Associates.
Longino, H. E., & Lennon, K. (1997). Feminist epistemology as a local epistemology. *Proceedings of the Aristotelian Society, Supplementary Volumes, 71*, 19–54.
MacLeod, M. (2018). What makes interdisciplinarity difficult? some consequences of domain specificity in interdisciplinary practice. *Synthese, 195*(2), 697–720.
Maturana, H. R. & Varela, F. J. (1980). *Autopoiesis and cognition: The realization of the living*. D. Reidel Publishing Company.
Maturana, H. R. & Varela, F. J. (1987). *The tree of knowledge: The biological roots of human understanding*. New Science Library/Shambhala Publications.
Menary, R. (2010). *The extended mind*. MIT Press.
Merleau-Ponty, M. (1945). *Phenomenology of Perception*. Routledge.
Millar, R., & Wynne, B. (1988). Public understanding of science: From contents to processes. *International Journal of Science Education, 10*(4), 388–398.
Nersessian, N. J. (1992). How do scientists think? Capturing the dynamics of conceptual change in science. In R. N. Giere (Ed.), *Cognitive models of science* (pp. 3–45). University of Minnesota Press.
Nersessian, N. J. (2002). The cognitive basis of model-based reasoning in science. In P. Carruthers, S. Stich, & M. Siegal (Eds.), *The cognitive basis of science* (pp. 133–153). Cambridge University Press.
Nersessian, N. J. (2008). *Creating scientific concepts*. MIT Press.
Oreskes, N. (2021). *Why trust science?* Princeton University Press.
Oreskes, N., & Conway E. M. (2011). *Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. Bloomsbury Publishing USA.

Pedersen, S., & Bang, J. (2016). Historicizing affordance theory: A rendezvous between ecological psychology and cultural-historical activity theory. *Theory & Psychology, 26*(6), 731–750.
Popper, K. (2005). *The logic of scientific discovery*. Routledge.
Prinz, J. (2009). Is consciousness embodied? In P. Robbins & M. Aydede (Eds.), *The Cambridge handbook of situated cognition* (pp. 419–437). Cambridge University Press.
Rączaszek-Leonardi, J., Krzesicka, J., Klamann, N., Ziembowicz, K., Denkiewicz, M., Kukiełka, M., & Zubek, J. (2019). Cultural artifacts transform embodied practice: How a sommelier card shapes the behavior of dyads engaged in wine tasting. *Frontiers in Psychology, 10*, 2671.
Rączaszek-Leonardi, J., Nomikou, I., Rohlfing, K. J., & Deacon, T. W. (2018). Language development from an ecological perspective: Ecologically valid ways to abstract symbols. *Ecological Psychology, 30*(1), 39–73.
Richards, G. (2002). The psychology of psychology: A historically grounded sketch. *Theory & Psychology, 12*(1), 7–36.
Richardson, M. J., Shockley, K., Fajen, B. R., Riley, M. A., & Turvey, M. T. (2008). Ecological psychology: Six principles for an embodied–embedded approach to behavior. In P. Calvo & A. Gomila (Eds.), *Handbook of cognitive science: An Embodied Approach* (pp. 159–187). Elsevier.
Rietveld, E. (2019). *The affordances of art for making technologies*. University of Twente.
Rietveld, E., & Kiverstein, J. (2014). A rich landscape of affordances. *Ecological Psychology, 26*(4), 325–352.
Robbins, P., & Aydede, M. (2009). *The Cambridge handbook of situated cognition*. Cambridge University Press.
Robbins, P., & Aydede, M. (2009b). A short primer on situated cognition. In Robbins, P., & Aydede, M. (Eds.) (2008). *The Cambridge Handbook of Situated Cognition*, pp. 1–10. Cambridge University Press.
Rolla, G., & Novaes, F. (2020). Ecological-enactive scientific cognition: modeling and material engagement. *Phenomenology and the Cognitive Sciences*. https://doi.org/10.1007/s11097-020-09713-y
Rorty, R. (1980). Pragmatism, relativism, and irrationalism. In *Proceedings and addresses of the American Philosophical Association*, *53*, 717–738.
Rorty, R. (1991). *Objectivity, relativism, and truth: Philosophical papers,* (Vol. 1). Cambridge University Press.
Roth, W.-M., & Jornet, A. (2013). Situated cognition. *Wiley Interdisciplinary Reviews: Cognitive Science, 4*(5), 463–478.
Sanches de Oliveira, G. (2016). Gibson's reasons for realism and Gibsonian reasons for anti-realism: An ecological approach to model-based reasoning in science. In A. Papafragou, D. Grodner, D. Mirman, J. Trueswell (Eds.), Proceedings of the 38th annual conference of the cognitive science society (pp. 1373–1378).
Sanches de Oliveira, G. (2022). From something old to something new: Functionalist lessons for the cognitive science of scientific creativity. *Frontiers in Psychology,* 12:750086. https://doi.org/10.3389/fpsyg.2021.750086
Sanches de Oliveira, G., & Chemero, A. (2015). Against smallism and localism. *Studies in Logic, Grammar and Rhetoric, 41*(1), 9–23. https://doi.org/10.1515/slgr-2015-0017.
Schoggen, P. (1991/2014). Ecological psychology: One approach to development in context. In *Context and development*, pp. 291–312. Psychology Press.
Shapiro, L. (2014). *The Routledge handbook of embodied cognition*. Routledge.
Shapiro, L. (2019). *Embodied cognition* (2nd ed.). Routledge.
Shapiro, L., & Spaulding, S. (2021). Embodied Cognition. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Fall 2021 ed.). Metaphysics Research Lab, Stanford University.
Silver, S. (2016). Hooke, Latour, and the history of extended cognition. *The Eighteenth Century, 57*(2), 197–215.
Simis, M. J., Madden, H., Cacciatore, M. A., & Yeo, S. K. (2016). The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science, 25*(4), 400–414.
Solomon, M. (2007). Situated cognition. In *Philosophy of psychology and cognitive science*, pp. 413–428. Elsevier.
Stewart, J. (2010). Foundational issues in enaction as a paradigm for cognitive science: From the origin of life to consciousness and writing. In J. Stewart, O. Gapenne, & E. Di Paolo (Eds.), *Enaction: Toward a new paradigm for cognitive science* (pp. 1–31). MIT Press.
Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge University Press.

Sutton, J. (2006). Distributed cognition: Domains and dimensions. *Pragmatics & Cognition, 14*(2), 235–247.
Thagard, P. (1993). *Computational philosophy of science*. MIT press.
Thagard, P. (2012). *The cognitive science of science: Explanation, discovery, and conceptual change*. MIT Press.
Thompson, E. (2004). Life and mind: From autopoiesis to neurophenomenology. A tribute to Francisco Varela. *Phenomenology and the cognitive Sciences 3*(4), 381–398.
Thorén, H., & Persson, J. (2013). The philosophy of interdisciplinarity: Sustainability science and problem-feeding. *Journal for General Philosophy of Science, 44*(2), 337–355.
Trasmundi, S. B. (2020). *Errors and interaction: a cognitive ethnography of emergency medicine.* Pragmatics & Beyond New Series, Volume 309. John Benjamins Publishing Company.
Trasmundi, S. B., & Steffensen, S. V. (2016). Meaning emergence in the ecology of dialogical systems. *Psychology of Language and Communication, 20*(2), 154–181.
Tweney, R. D. (1985). Faraday's discovery of induction: A cognitive approach. In D. Gooding and F. James (Eds.), *Faraday rediscovered: Essays on the life and work of Michael Faraday, 1791–1867*, pp. 189–209. Springer (Stockton Press; Macmillan).
Tweney, R. D. (1989). Fields of enterprise: On Michael Faraday's thought. In D. W. H. Gruber (Ed.), *Creative people at work: Twelve cognitive case studies* (pp. 91–106). Oxford University Press.
Tweney, R. D. (2014). Metaphor and model-based reasoning in maxwell's mathematical physics. In L. Magnani (Ed.), *Model-Based Reasoning in Science and Technology* (pp. 395–414). Springer.
van Dijk, L. (2021). Psychology in an indeterminate world. *Perspectives on Psychological Science, 16*(3), 577–589.
van Dijk, L., & Myin, E. (2019). Ecological neuroscience: From reduction to proliferation of our resources. *Ecological Psychology, 31*(3), 254–268.
Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. MIT Press.
Wilson, A. D., & Golonka, S. (2013). Embodied cognition is not what you think it is. *Frontiers in Psychology, 4*, 58.
Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.
Wilson, R. A. (1994). Wide computationalism. *Mind, 103*(411), 351–372.
Wilson, R. A. (2004). *Boundaries of the Mind: The Individual in the Fragile Sciences*. Cambridge University Press.
Zahidi, K. (2014). Non-representationalist cognitive science and realism. *Phenomenology and the Cognitive Sciences, 13*(3), 461–475.