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The Equilibration of Technical Objects: Uncovering Normative Layers of Sensorimotor Engagement

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Abstract

In this paper we argue that radically embodied approaches to cognition can be expanded to show that: (a) our sensorimotor engagements with technical objects can be normatively shaped in a direct manner (i.e. not necessarily involving symbolic processes), and that (b) this normativity is not only anchored in the agent but also partially supported by technical objects themselves. We depart from the enactive reinterpretation of Piagetian sensorimotor schemes and his theory of equilibration to establish how both agent-sided and environment-sided support structures (including artefacts) contribute to the autonomous self-maintenance of sensorimotor networks. We will then introduce *technical behaviour* as a regulatory transformation of the environment enacted to equilibrate certain sensorimotor structures. We will defend that technical objects, as products of technical behaviour, sediment these normative constraints in their material structure. Then, through the dynamics of assimilation and accommodation, we schematize how different scenarios give rise to canonical or alternative uses in the encounter of agents with artefacts. Finally, we will offer a complexification of the normative entanglement of objects and agents by introducing the sociohistorical notion of activity as developed within Activity Theory approaches as collectively articulating individual actions. Based on all of this, we will have offered a picture of technical objects as also radically embodying normative layers, without submitting to an overly-deterministic picture of artefacts as rigidly prescribing behaviour, or to the purely symbolic or culturalist interpretation of them.

Keywords Technology · Normativity · Sensorimotor scheme · Radical embodiment · Enactivism · Affordances

1 Introduction

Why do we interact with our technological environment in the ways we do? What kind of normative forces shape our interactions with artifacts? Where does this normativity originate? In the agents? The objects? Purely in social convention? Turning against classical internalist readings that situate all meaning or normativity in the agents, relatively recent approaches in philosophy of technology (Verbeek 2005), archaeology (Malafouris 2016), anthropology (Henare et al. 2007), sociology (Latour 2007) or metaphysics (Harman 2002) have proposed a turn to the things *themselves* as bearers of meaning and normativity, endowing artifacts with a much more *active* (sometimes even agential) role in their shaping behaviour.

Within cognitive science, radically embodied theories of cognition (Chemero 2009, 2013) share such a turn away from internalist and rationalist presuppositions in our interactions with the environment, and ground our cognitive lives in our *direct* embodied interactions. Approaches such as ecological psychology (Gibson 1979; Heft 2005; Segundo-Ortin and Raja 2024) and sensorimotor enactivism (Di Paolo et al. 2017; Noë, 2004; Varela et al. 1991), have provided strong theoretical resources, such as the notions of sensorimotor schemes or of *affordances* (the possibilities of action offered by environmental structures that are directly perceived by organisms by virtue of their being specified by ecological information). Meaning, according to these views, is not necessarily mediated by internal representations of objects but emerges from the interaction with them. They thus provide

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a vantage point from which to analyze the question of normativity in technical objects and behaviour.

In fact, radical embodiment has long tried to work out the problem of how to conjugate direct perception with its being permeated by sociocultural norms. A way to frame the problem is exemplified by Heft (2003, discussed in Segundo-Ortin, 2024): according to affordance theory, tables should be perceived as climbable by humans, since the leg-(table) height ratio specifies our bodily possibility of stepping on it. However, we normally do not perceive them as climbable, but instead as a plane surface where we place and manipulate objects. But then again, if a rat was running wild in the office many of us would very directly use the table as a climbable object to the table. So how come we "normally" only directly perceive its affordances for laying objects on top of it, and not for climbing?

Many authors have pointed out the relevance of the situation (Heijmeskamp 2024) to explore this variability in our perception of the *relevant* affordances (Rietveld and Kiverstein 2014; van Dijk and Rietveld 2017). But beyond the idea of relevant affordances, there is a particularly pertinent distinction put forward by Costall (2012) between the general notion of affordance, and what he termed *canonical* affordances, i.e. those that are conventional and normative, particularly present in human artifacts. It is not just the fact that we perceive affordances differently depending on the situation, but that man-made artifacts seem to have the peculiarity of having normative asymmetries between the possible affordances to be perceived (see also Ye et al. 2009). So, how and why do we learn to perceive these canonical affordances in technical objects? Why do we normally engage with tables as affording laying things, or keyboards primarily affording typing? As Muñoz Serrano (2022) states: "Costall does not specify the mechanism that makes general affordances into canonical ones. It seems to be merely a conventional process, some sort of agreement about the meaning of artefacts." (p. 234, translation from Spanish is our own). This is another way to frame the question with which we opened the paper: how should we pursue an explanation of what makes general affordances *canonical* ones, what drives our normative, selective, engagements with objects? We believe that radical embodiment, and in particular the enactive framework of sensorimotor life (Di Paolo et al. 2017),[1] has the resources to explore this normativity as distributed and supported by both agents and technical objects, and possibly (or partially) articulated in non-symbolic, sensorimotor terms.

Surely, a big part of the answer has to do with aspects of the social and shared nature of our behaviour, which is rarely enacted in isolation and usually guided by others. We learn to use artifacts in a specific way through our joint action with others, through instruction, guiding, imitation, etc. Some authors within ecological psychology have advanced explanations in this line; recent examples include Heras-Escribano's (2022)[2] use of Reed's (1996) theory of fields of promoted action, or Segundo-Ortín's (2024) call to shed light on the process of what he terms the *education of intention*. We believe that these accounts go in the right direction, but here we argue that a more complete explanation requires focusing also on technical objects themselves, including their socio-technical environment. We propose to understand technical objects as themselves *radically embodying* certain normative aspects of the interaction too. For this, we will turn to enactivism.

Within the enactive approach, however, normativity has often been tied to the organic body of the cognitive subject, both in terms of its biological embodiment (Barandiaran 2025; Barandiaran and Egbert 2014; Barrett 2017; Weber and Varela 2002) and/or its sensorimotor autonomy (Barandiaran 2017; Di Paolo et al. 2017). We will thus need to expand how the enactive approach understands the technical environment, and particularly technical objects, as well as the behaviour involving it (which has already started to be explored, see the different explorations of sensorimotor enactivism and philosophy of technology in, for example Di Paolo et al. 2023; Mojica In press; Peeters 2019).

Thus, the outline that we will follow to answer the question of whether and how the material structure of objects themselves partially supports the normativity of their use is

[1] Although the compatibility between enactive approaches and ecological psychology (or affordance theory) is disputed (see McGann et al. 2020), we do consider that for our purposes, the problem presented in terms of affordances in our introduction is compatible with an analysis in enactive terms, as will become more evident in Sect. 2.

[2] It is worth commenting on a distinction brought forth in his account between pertinence and normativity. He uses normativity to refer to social shaping that carries sociocultural norms of correctness, while using the notion of "pertinence" to talk about the "combination of the aim or goal to be achieved, the layout of the environment, and the correctness of the action according to the rules being followed for achieving the goal" (p.67). In this sense, our explanation (at least until Sect. 4) would be for him related to this weaker idea of pertinence. We do still however seek to maintain the notion of normativity for the different levels (sensorimotor, sociohistorical) that we touch upon in our account. We are motivated, on the one hand, by the conceptual history of the term normativity around the notion of function (both on the philosophy of biology and technology) and the way it has permeated the enactive terminology. But, more importantly, also because as we will explore in Sect. 4, we believe that understanding different layers of normativity (and not separated concepts) is more illuminating in understanding bodies and artefacts as traversed by them in multiple and sometimes conflicting ways, as well as to unpack the relation between them. For further discussion on this, see García & Barandiaran (2025).

as follows: In Sect. 2 we will introduce the enactive account of sensorimotor schemes, as developed by Di Paolo et al. (2017) and Barandiaran (2008), and their reinterpretation of Piagetian theory of equilibration to zoom in on our sensorimotor interactions with technical objects. Then, in Sect. 3 we will expand the enactive picture to offer an account of technical objects as products of regulatory technical behaviour, sedimenting in their structure part of the sensorimotor normativity that guided their design. This is what will allow us to explain why agents interact with environmental affordances not only selectively, but *canonically*. Finally, in Sect. 4, to fully grasp the socio-cultural and historical dimensions of our interactions, we will turn to a notion of systems of activity as developed within the activity theory tradition (Leont'ev 1978). The articulation of individual actions in collective activities will allow us to relate the sensorimotor layer of normativity in our interactions with objects to the socio-historical layer of normativity that organizes the actions from which we encounter technical objects.

2 The Enactive Theory of Sensorimotor Schemes and Equilibration

In enactive cognitive science, sensorimotor schemes recently came to play a central role in understanding perception, action, and cognition (Barandiaran 2008; Di Paolo et al. 2014, 2017). Originally popularized by Piaget as the basic building block of cognitive development (Piaget 1947), sensorimotor schemes can be defined as organized sensorimotor coordination patterns, i.e., nested sequences of structured (by regularities of the environment and within the agent) variations between changes in motor modulation and sensory variations. Sensorimotor schemes or habits are not internally represented, but sustained by distributed support structures, both agent-sided (neuromuscular, postural, sensory) and environmental (arrays, densities, forces, material compositions, etc.).[3] Think of pouring hot water from a teapot as an example of a sensorimotor scheme, supported by different structures such as all the complex musculoskeletal coordinations that involve the action, the audiovisual and tactile feedback of the teapot and the water hitting the inside of the glass, the material structure of the handle of the teapot… Importantly, these schemes are not isolated but embedded within larger networks (of coordinated activities) that structure an agent's identity and engagement with her world. They are formed and stabilized through repeated interaction and outcome (e.g., different forms of conditioning or reinforcement); this dependance on their own enactment for their existence endows them with an intrinsic normativity (Egbert and Barandiaran 2014).

In the enactive account, the lawful relations between an embodied agent and its environment that are at the base of the idea of affordance are captured through the notion of the *sensorimotor environment* (see Buhrmann et al. 2013 for a more complete account of how this enactive framework treats the sensorimotor environment, habitat, coordination and scheme/strategy; also Di Paolo et al. 2017, p. 74). The sensorimotor environment thus consists of the full landscape of possible affordances that an agent could potentially interact with. Sensorimotor schemes, on the other hand, constitute arrangements of specific patterns of coordination (that is, of specific ways in which the agent engages with this environment). Sensorimotor schemes thus determine which specific affordances are engaged with. It is the fact that we encounter affordances within the backdrop of not only a sensorimotor environment but a specific region of a historically shaped network of sensorimotor schemes, which allows us to explain why we only perceive certain affordances—and not others—in specific action contexts.

But how do networks of sensorimotor schemes get stabilized in an ever-changing environment? Jean Piaget's theory of equilibration (1947) has been adapted within the enactive framework (Di Paolo et al. 2014) as a possible answer, particularly in its description of cognitive development as a continuous process of balancing two processes: assimilation and accommodation. *Assimilation* refers to the process of integrating new environments into already existing schemes, allowing agents to enact familiar arranged coordination patterns that are already stabilized in their sensorimotor repertoire. *Accommodation*, on the other hand, involves the modification or restructuration of sensorimotor schemes that prove inefficient in dealing with a novel or challenging situation. Accommodation can range from relatively small adaptations, such as when facing a new instrument that is slightly different in shape, to deep re-arrangements of existing schemes, or to the creation of new ones through progressive differentiation. In any case, the agent-sided structures that support previous sensorimotor schemes are modulated to engage a novel aspect of the environment that is not yet assimilable, until coherence with the environment is restored.

Equilibration, in this enactive reinterpretation, is the overarching process through which an agent maintains coherence between its sensorimotor repertoire and the environment. It is a dynamic, continuous process of asymmetric regulation (as characteristic of agency, see Barandiaran et al. 2009) in which assimilation and accommodation interact. Importantly, although presented as two different processes,

[3] The enactive reinterpretation of Piaget, by highlighting the co-constitutive role of the environment in sensorimotor schemes, avoids an internist reading of Piaget, and elaborates a world-involving theory that can account for the role of the environment in the stabilization of behaviour (see Di Paolo et al. 2014).

they are better understood as the two dynamical parts of the continuous process of equilibration; our engagement with the environment always requires some sort of assimilation (otherwise we would not be able to engage any novel object at all[4]) into existing previous schemes, that are then gradually accommodated and sometimes create new and different sensorimotor engagements. Equilibration is not simply an internal cognitive process but an embodied, world-involving activity where successful interactions reinforce stability, while breakdowns and perturbations drive adaptation and learning. Note that all of these sensorimotor schemes rely on both environmental and agent-sided support structures. This leads us to the idea that the equilibration of behavioural structures can take place through agent-sided transformations, but also –and this has been less explored–through transformations of the environment itself.

3 Assimilation and Accommodation of Technical Objects

3.1 Technical Behaviour

To understand our relation with technical objects we first have to provide an account of technical objects themselves. We will understand technical objects as those material structures that are a product of *technical behaviour.* As we have defended elsewhere, "*we behave technically when we actively transform and organise elements of our body and environments with the intended effect of constraining or regulating couplings with (or between) other aspects of the environment*" (Pérez-Verdugo and Barandiaran 2023, pp. 83–84). As we have previously mentioned, human agency implies the asymmetric modulation of the coupling with the environment, usually through processes of accommodation through changes in agent-sided support structures of sensorimotor schemes (see Fig. 1A). That would be, for instance, changing the way we lift our arm to achieve an effective pouring scheme. But technical behaviour, as we are defining it, is a specific kind of accommodation that implies the transformation of parts of the environment with the regulatory aim of modulating this coupling (see Fig. 1B). A sensorimotor scheme successfully accommodates the transformed environment when it successfully achieves or regains coherence with the broader network of sensorimotor schemes that compose the activity. That is, when sensorimotor schemes are efficient and "lead to an appropriate transition to another sensorimotor scheme according to the conditions of viability of the network" (Di Paolo et al. 2017, p. 155).

Let us unpack this. When engaged in a particular action (in enactive terms: a particular network of schemes arranged in a specific manner to achieve a task), an agent in the face of perturbations might transform the environment to facilitate the enactment of certain sensorimotor schemes that can sustain the network. Take the example of wooden spears for hunting; an agent engaged in the action of hunting might try to do so with her bare hands, or with branches and sticks that she finds around. However, when encountering certain animals these schemes may not be able to sustain a successful hunting network, and so she might then sharpen one of the branches to accommodate a more efficient scheme of stabbing.[5] This is a regulatory intervention upon the environment, and it follows the sensorimotor normativity of equilibration processes that strive to maintain coherence between a specific network of schemes and (the rest of) the environment. Let us present a different example: in order to transport hot liquids, an agent may add a rudimentary handle to a jar that allows her to grab the jar comfortably and, crucially, to not burn herself. A teapot thus becomes a clear example of a technical object, here defined as the material product of technical behaviour. In its evolution, all of its features (weight, shapes) become highly concretized

[4] We thank Gabrielle Jackson for pushing us to clarify this point.

[5] We are aware that even this simple example is an abstraction of technical behaviour, and that these transformations of the environment usually involve many very minimal modifications along many different generations (and sometimes radical discontinuities and innovative jumps) to end up with a spear. However, our point is that those modifications—even if done progressively by many different agents—follow the sensorimotor norms of stabilization of a certain network of schemes. This raises a related worry: it might seem like we are presupposing that there exists a hunting action that, prior to the existence of the transformed spear, already *requires* it. In this sense, our explanation would amount to saying that an agent *invents* a spear in order to fill a preconceived need of the already formed action. We agree that this would go against embodied intuitions (see Malafouris 2016) that technical actions emerge in the encounter with materiality (in the context of a social organisation that constraints and makes possible this encounter), and are not a response to a preformed need of modifying the environment in a specific way. However, we do not think that our account is to be understood in that way; while the equilibration dynamics might occur relative to the sensorimotor norms that emerge from an existing sensorimotor network, the newly equilibrated sensorimotor scheme is always re-organizing said network. With any slight transformation of the environment, sensorimotor schemes are transformed through processes of accommodation, and with them, the whole network, bringing about new normative constraints. In this sense, we are not necessarily "inventing" a spear (as an intellectualist, pre-figurative, representational action), but successively accommodating the environment—according to the emerging sensorimotor norms of our continuously changing engagement—in a way that ends up stabilizing a spear. And this is not at odds with saying that the active transformation of the environment followed the sensorimotor norms derived from the existing hunting sensorimotor schemes, even if later transformed. We thank Alva Noë for pushing us to discuss both of these points.

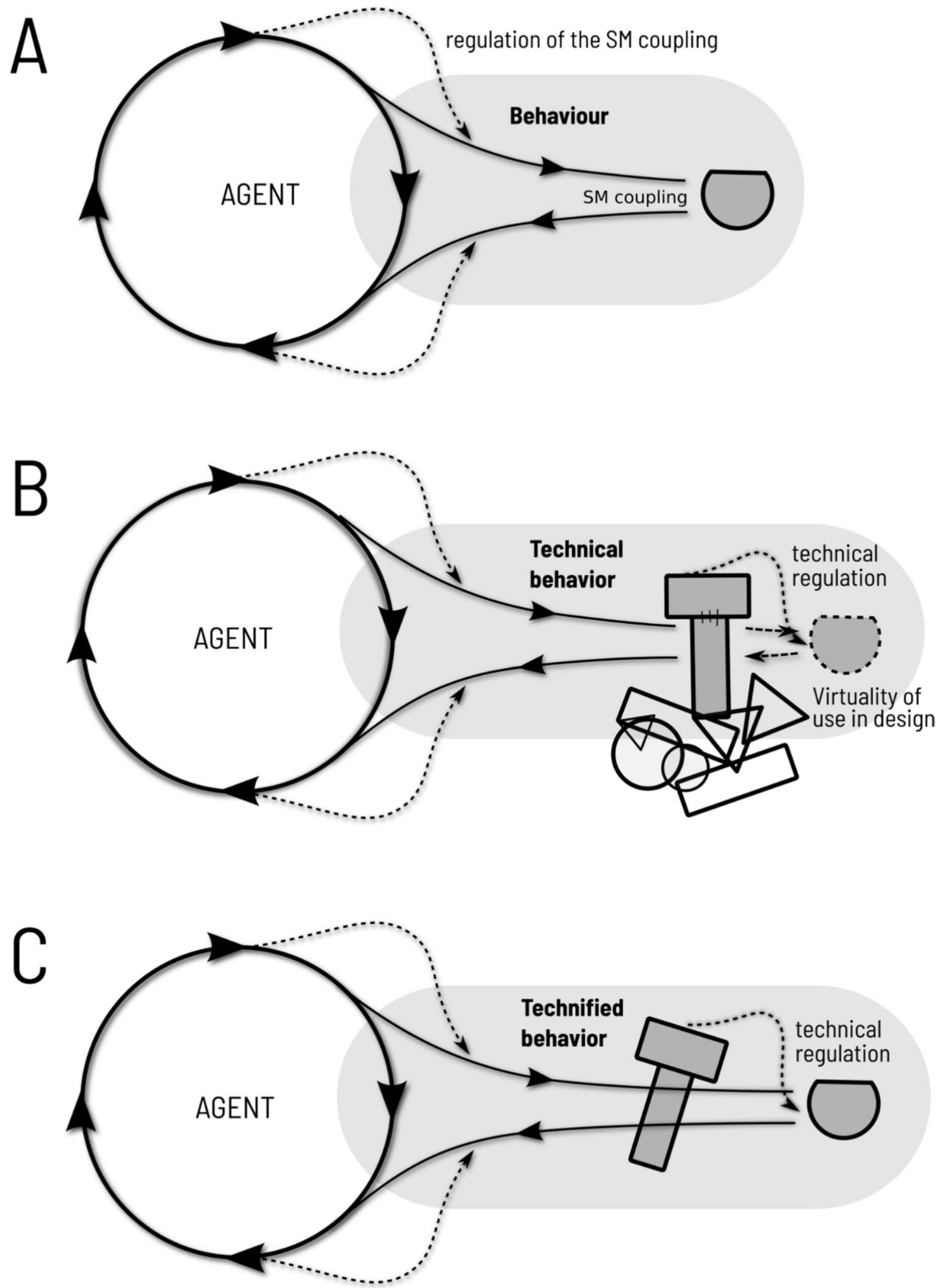

Fig. 1 Three diagrammatic descriptions of agency; **A** showing an abstract representation of agency as modulation of the coupling between agent and environment, **B** depicting technical behaviour involving the development of artefacts (that includes both the direct interaction with the tool and the potential, virtual, uses that will be given to the tool), and **C** showing the specific form of agency that we are referring to as technified behavior (involving the use of artifacts to carry out a task) [**A** from Barandiaran et al. (2009), diagrams **B** and **C** by Pérez-Verdugo and Barandiaran, all under CreativeCommons-by-sa licenses]

(Simondon 2017) to regulate the sensorimotor possibilities of an agent, constraining the degrees of freedom of movement of the wrist and the liquid for an effective pour. It is also important to note that technical objects do not exist in isolation, but in a *constellation* (Costall 2012; Muñoz Serrano 2022) of other technical objects. A teapot in the context of the activity of making tea relates to flat surfaces for resting the teapot on (such as tables) and to other containers of liquid (such as glasses).

A crucial feature of technical objects is that they typically survive the interaction that they are intended to regulate, while retaining in their structure the effects of the transformations they have undergone.[6] The sharpened stick (now

[6] As an anonymous reviewer correctly points out, this is a crucial aspect of technical objects. Technical objects persist after the agent has interacted with them, and also crucially can long outlive them. An analysis of the different timescales in the relation between agents and artifacts has been provided by Mojica (In Press), and it becomes a central aspect in the *historical*, potentially intergenerational character of artifacts.

a spear[7]) that lies in the ground after being used to hunt by our original agent can be encountered by another agent, but it retains a material structure (its having one pointed end, but also maybe a specific diameter and length) that had been transformed to regulate the sensorimotor interactions of that other, maybe now long gone agent. As such, they carry with themselves a *regulatory* character that goes beyond the original regulator; a certain normativity is sedimented in their material structure. These objects enable specific sensorimotor schemes that, in the context of a particular action, are more effective in sustaining certain networks; by facilitating the transition to the following sensorimotor schemes, investing less energy, facilitating stabilization by expanding the range of assimilable objects or providing more opportunities for accommodation, reinforcing habits by intensifying reinforcing outcomes…

The extent to which this object (now a technical object by virtue of its being a product of technical behaviour[8]) manages to stabilize sensorimotor schemes similar to what the original agent intended will depend then on how similar the network of sensorimotor schemes that lead each agent to the engagement with the object is. We will explore this in the next subsection, but we can already see how technical objects do carry with themselves a normative load in sensorimotor terms; if a similarly bodied agent is immersed in a similar hunting action and encounters this object as part of her environment, the spear itself will seem to be calling to be held in a specific orientation.[9]

When this new agent uses the spear, their behaviour becomes *technified*. The agent is not involved in an instance of technical behaviour as per our definition, since they are not actively transforming the object, but their action is mediated by this technical object and its *techniques*. Similarly, an agent is engaged in technified behaviour in their skilled use of an (already built) teapot; gripping, arm lifting and wrist turning to just the right degree to pour the liquid into the glass. Technified behaviour involves the use of techniques; the assimilation of the object in an action with the intended use of achieving a goal, but without implying a further transformation of the environment (see Fig. 1C). This technified behaviour involving technical objects[10] is usually enacted without an explicit awareness of the object, but it potentially inherits, as we have discussed, the normative constraints of the original regulator. In other words, technical artefacts (as a product of technical behaviour) can equilibrate *certain kinds* of technified behaviour.

Let us recapitulate the key takeaway: since (1) technical behaviour is a *regulatory* kind of behaviour that transforms the material structure of objects with the intent of stabilizing specific schemes, and (2) these objects retain this structure in their encountering by other agents, we can see how technical objects retain a regulatory character that intervenes in the stabilization of other agents' technified behaviour.

3.2 The Equilibration of Technical Objects

We now want to offer a systematization of how agents encounter already-existing technical objects through the Piagetian theory of equilibration. It is important to stress that technical objects are always encountered by an agent who is *already engaged* in a specific network of sensorimotor schemes, which can be more or less similar, or radically different, to the one the technical object was intended to regulate.[11] As such, the normativity sedimented in the technical object enters in relation to the sensorimotor normativities currently at play in that particular agents' network of sensorimotor interactions. So, let us explore the equilibration

[7] The relation between specific actions and the technological artifacts that allow their stabilization is sometimes beautifully echoed in the identity between tool names and action verbs, such as in the verb 'to spear'.

[8] This characterization echoes Ingold's (1993) distinction between tools and artifacts, where the former are found material objects that are used instrumentally while the latter are characterized precisely by their having been designed or modified to serve a task (see Heft 2005, p. 341 for a discussion). Thus, when we talk of technical objects we are referring to something close to Ingold's conception of artifacts as distinct from mere tools. However, in our text we stick to the term technical object, instead of artifact, as what we have conceptually sketched is the most basic kind of technical object. Artifacts, or technologies, require a much more systemic account. Such an account has recently been provided within the same enactive framework by Laura Mojica (In Press).

[9] The claim that the material structure of the object elicits particular actions can be echoed in some classical empirical literature, such as developmental studies that explore how infants, when presented with a variety of objects with different material properties, perform distinct exploratory behaviors (shaking, banging, squeezing, etc.) that are appropriate to the affordances each object offered, rather than random or uniform exploration (Palmer 1989). We can also look at comparative cognition studies; for instance, Visalberghi et al. (2009) depict how capuchin monkeys were able to select the "correct"—in terms of its functional features—tool to crack nuts (see also Chappell & Kacelnik 2002 for a study on crows directly using the adequately lengthed stick for a specific task). The relevance of these studies is that, even in cases where there is no direct instruction, there is a

Footnote 9 (continued)

selective deployment of tools that relate to how the material structure of the objects are able to stabilize successful sensorimotor schemes.

[10] Technified behaviour can also occur without technical objects; the human body itself can become an object of *techniques*; think, for instance, of athletic sports, dance, military… The notion of technified behaviour is also, we believe, a gradual notion, a continuum, modulated by the complexity of techniques. An exploration of this idea of technique, training, or skill, is out of scope of this paper, but is partly being carried out by Prokop & Barandiaran (Forthcoming).

[11] This echoes Sepúlveda-Pedro's (2023) assertion that, when agents encounter their environment, they are not (or rarely) producing new normative interactions, but rather actualizing a field of normativities already at play.

process (as described in Sect. 3.2) of an agent encountering a technical artefact, depending on the similarity of the current agent's network of schemes to that which the artifact was intended to regulate.

It is often the case that when we encounter a technical object, we already have a stable repertoire of sensorimotor schemes able to engage with it; even from our first encounter with a particular object, we already know how to use it in a relatively stable way. In these cases, as we have already mentioned, we equilibrate our encounter with these novel objects mainly through processes of *assimilation*. If we look at child development, we can see how these processes of assimilation play a big role in learning to use technical objects; for instance, studies have shown that the ability to use handled tools for hammering is rooted in earlier percussive behaviours (Lockman and Kahrs 2017). These authors offer evidentiary support that "young humans, like the young of other species, adapt and refine available action patterns for new instrumental ends" (p. 333). But think also of when you immediately know how to use the teapot in your friend's kitchen when preparing tea, even though it is a different model from the one you own. You know to grab it by the handle, and its shape allows you to pour the tea with an array of coordination patterns that is already stable in your sensorimotor repertoire.[12] Similarly, I immediately know how to write on the QWERTY keyboard of my new laptop. In these cases, I am engaged in the action that the technical object intended to regulate; and as such, it maintains this original regulatory power. The object prompts me to engage in a *specific* familiar network of sensorimotor schemes that already involved similar support structures.[13] When assimilation processes dominate the encounter with objects, we can face cases of what has been described in the literature as *functional fixedness*, where the canonical or designed use of objects seems to inhibit to some extent their other possible uses (German and Barrett 2005; German and Defeyter 2000; see also Ye et al. 2009 for a discussion around affordances).[14] In any case, what is relevant for our purposes is that when an agent is able to assimilate the technical object, then, she will engage in what we have previously defined as *technified* behaviour; she deploys a specific *technique* that she is already familiar with.

But an agent may encounter a technical object and not be able to successfully assimilate it right away, as no previously existing sensorimotor schemes are successful in the context of a specific action. As such, a process of *accommodation* needs to take place. In many cases, accommodation takes place through changes in the agent that lead to the stabilization of new sensorimotor schemes. Whether the resulting schemes are those that the artefact was designed to enable, will depend on the activity that the agent is engaged with when encountering the object. We can identify two scenarios:

(A) The sensorimotor network that the agent is engaged with is sufficiently *similar* to the one the artifact was intended to regulate. As such, the posture, bodily orientation and, crucially, the classes of sensorimotor schemes that are expected to follow, are similar. In this case, the agent will end up interacting with the object in a very similar way to what the designer intended. This is what we usually describe as an agent learning to use an object in the way it was designed to be used. Following our example, think of a person who encounters a teapot for the first time (or a very differently designed teapot) while serving tea. If the teapot is situated in a table or an equally firm surface, and the agent is making tea in such a way that she has visual access to the table and the teapot from a perspective that allows her to distinguish the handle and the pouring end, the agent will grab the teapot by its handle and pour water. At first, she might get the angle wrong and spill some water, but quickly enough she will stabilize a successful sensorimotor scheme for pouring from a teapot. Equally, when one encounters a computer keyboard for the first time, it can take some time to unreflectively learn how to write on it. But, after a while, if a person uses it with the computer on a table in front of her while sitting on a chair and able to rest both hands on the keyboard, a sensorimotor scheme of writing with most of the fingers splayed upon the keyboard horizontally, gets stabilized. This importance on how the agent faces the novel object can also be found in developmental studies that look at how chil-

[12] This does not mean that I am mechanically or automatically deploying a set of rigid movements, in the style of a pre-programmed robot. Each specific instance of a sensorimotor scheme is slightly different, accounting for subtle varieties of environmental conditions. That we can still identify it as a certain stable sensorimotor scheme depends on its falling within the same class of sensorimotor schemes, defined by stability and transition conditions (for more detail on this, see Di Paolo et al. 2017, p. 92).

[13] This is a key aspect of many digital designs, that rely on the user being familiar with a specific interaction feature to prompt them to engage with it (e.g. the keyboard popping up automatically to respond to a question in a survey, or a full-screen video coming up as you open an app, intended to scroll down).

[14] An even more extreme condition could be seen in the case of the neurological condition of utilization behaviour, where patients automatically have to use an object when they see it, independently of what they were doing (see Iaccarino et al. 2014). Exploring this condition within the equilibration framework we are here presenting could potentially be illuminating. We thank Menno van Calcar for pointing us towards this.

dren learn to use mealtime tools; among many other crucial aspects of the interaction between caregiver and infant, one of the key roles of the caregiver at a certain point is the structuration of the environment regarding the children's posture so that the appropriate tool-using schemes can appear (Nonaka and Goldfield 2018).[15]

(B) The sensorimotor network that the agent is engaged with is *different* from the one the artifact was intended to regulate. In this case, the sensorimotor schemes and coordinations that precede and follow the encounter with the object are quite different, and the object will likely be accommodated *in a different way*.[16] The sensorimotor schemes that it will give rise to will be different from the ones that the object was designed to accommodate. This case is what we would usually describe as alternative uses of an object. For example, in Ayurvedic practice, teapots are repurposed for nasal cleansing with warm (but not boiling hot) water. What made the handle be perceived as a canonical affordance was an activity that is not the one the current agent is engaged with. This would also be the case that we presented in the introduction, where running away from a rat in an office gives rise to directly perceiving the table as climbable.

As we mentioned, however, yet another possible type of accommodation is the *environment-sided* accommodation that we have termed *technical behaviour*. That is, a further transformation of elements of the environment. This is relatively rarer due to the materiality of the objects usually making them less amenable to modifications in shorter time-scales. Nevertheless, some instances of technical behaviour upon existing artefacts in our everyday lives are not so strange. Think, to continue with our examples, of a teapot that has a slight crack in the pouring end, that makes water flow out in an uncomfortable angle. An agent may put some strong tape in the crooked end to craft a different shape that makes water flow in a more constrained direction; that way, the agent can now engage in her habitual pouring sensorimotor schemes. Another interesting example of object-sided accommodation can be seen in the case of keyboard layouts. Most keyboards use a QWERTY layout that is however not optimal in terms of comfort and possible typing speed. People engaged in intense writing actions end up aiming to optimize their writing sensorimotor schemes to better sustain their action, and do so by changing the keyboard layout to, for instance, a DVORAK layout that is much more comfortable and ergonomic (more on this example in the following section).

What this schematized exploration of equilibration involving technical objects provides is a sensorimotor analysis that can ground a description of how technical objects can directly shape users' behaviour towards conventional uses, while also leaving room for an explanation of the emergence of alternative uses. Accounting for this "multistable" character of technology is central for a philosophy of technology, as shown by postphenomenologists, particularly Ihde (1999) (see also de Boer 2023 for an analysis in relation to affordances). But although adjacent (technical) possibilities for an object are potentially infinite and beyond newtonian or dynamical scientific grasp (Kauffman and Roli 2023), they are not homogeneously distributed on the space of the possible, nor equally accessible; the constraining regulatory effect of their materiality is virtually effective and yet open to unpredictable innovations. For the purposes of our discussion what becomes central is that we can account for how technical objects *can* prompt conventional uses when engaged in the contexts of certain actions, while retaining their multistable character. The object retains in its structure what in Fig. 1B we have termed the virtuality of use in its design; the fact that the object is designed to regulate virtual (as in non-actual) uses (or sensorimotor schemes, in our terms). This virtuality is not a deterministic imposition on the object, but connects with what in analytic philosophy of technology has been discussed as intentionality-bearing functions (Kroes and Meijers 2006) or dispositions (Roberts 2024). Our framework allows to ground this intuition in a flexible way by connecting it with the regulatory aims in the design of the object, that can remain virtual or be actualized depending on how other agents encounter the object. As such, this allows us to claim that technical objects embody at least a certain normative character cashed out in sensorimotor terms; and a normativity that we can uncover without resorting to representational or intellectualist approaches.

4 Socio-Historically Articulated Activities

Through the Piagetian accommodation/assimilation scheme, we have shown how technical objects can either guide behaviour in intended directions or elicit creative, unprecedented uses, depending on the sensorimotor schemes from which they are encountered. However, this analysis has deliberately simplified the full complexity of technical behaviour. We were aiming to uncover the sensorimotor-level normativity supported by technical objects before we add the complex social interactions that also continuously shape our behaviour and our relation with objects in a recursive manner (that

[15] We thank an anonymous reviewer for pointing us to this literature.

[16] It is true, however, that the motivation behind pursuing this accommodation remains underexplored up to this point. We believe that the next section opens up the necessary complexity to account for an explanation that goes in line with Mojica's (2021) exploration of the role of sociality in addressing this question (see also Sepúlveda-Pedro & Mojica 2024).

only conceptually can be split as we just did). As mentioned in the introduction, for instance, our behaviour is always shaped by other agents that promote, regulate, motivate, indicate, instruct, or otherwise educate our actions as the correct ones. Our analysis conceptually isolates a triadic relation between an original agent, a technical object and a novel agent. The actual dealings of human beings are always much more complex and multilateral, and many other agents and objects can play a role in this process, adding extra and sometimes conflicting layers of normative use. But even within the triadic relation, we have been overlooking an obvious point: in order to underline the regulatory character of technical objects, we have been focusing on cases of technical behaviour where an agent transforms the environment to regulate her *own* sensorimotor schemes. But it is evident that in many cases, we directly transform the environment to regulate *others*' sensorimotor schemes. As we learn that certain modifications of the environment can regulate our own sensorimotor engagements, we also learn that we can regulate those of others.[17] We are also aware that there are many complex symbolic and instructional processes that direct our learning of how to use complex technologies and that shape technified behaviour (think of how manuals become second-order technical objects that regulate the use of the technical objects that in turn regulate behaviour). Through our conceptual analysis we do not mean to say that there exist beings who encounter objects in a "purely" individual way, stripped of all this complex social shaping of their behaviour. In human beings, these processes are always entangled and inseparable. We merely want to bring forward how part of this entanglement has to do with the ways in which agents accommodate and assimilate technical objects at the, sometimes neglected, sensorimotor embodied level of cognition (without necessarily involving complex symbolic rationalizations).

Our analysis, so far, has then grounded the intuition that objects that are a product of technical behaviour (as opposed to other objects that are not technical[18]) support some normative constraints of behaviour. This explanation can help make sense of what makes certain uses *conventional* in the context of a network of sensorimotor schemes, beyond explanations based on mere agreement. There is room, however, to say something more and point towards how this layer is entangled with other layers of social and historical normativities. In fact, our explanation has made the regulatory character of technology (in agents different than the designer) possible only insofar as the novel users encounter an object while engaged in a similar enough action as the original regulator. But it is not just a contingent, fortuitous matter that different agents would encounter a particular object while engaged in similar actions.

So far, we have been using the concept of "action" and "activity" in a relatively limited sense, focusing on them as networks of structured sensorimotor schemes. But we can use a more robust account of activity (that is still compatible with our enactive analysis) by drawing from the *activity theory* approach that was developed by Leont'ev (1978, 1981) and Engeström (1987), among others, taking Marxist and Hegelian thought and Vygotsky's psychological theory as inspiration. These approaches center their analysis in human *activity* as the meaningful psychological unit of analysis, viewing it as deeply socially and historically constituted, and guided by a normativity that is collectively determined.[19]

One main contribution of the activity approach, mainly articulated by Leont'ev (1978, 1981), is the structural analysis of activities; human activities are composed of a series of individual actions whose normativity is dependent upon but distinct from the broader normativity of the activity, and individually articulated. Leont'ev (1981, discussed in Engeström, p. 53) exemplifies this through an analysis of hunting; the goal of the activity is collectively determined (to kill an animal to feed the group) but the individual actions that compose the activity may have different goals (e.g., a specific individual's goal might be to successfully scare away the animals in a specific direction for others' to actually kill it). Furthermore, Leont'ev shows how these actions are concretely carried out through operations that respond to the actual material conditions of the environment. This nested characterization of activity that proposes to merge sensorimotor, individual and collective norms is, we believe, compatible with the enactive picture that we are using. What we, in enactive terms, consider the "arranged coordination patterns" that compose sensorimotor schemes, are amenable

[17] A detailed analysis of how this leap can be made is still to be provided, but we want to point to a discussion in Di Paolo et al. (2018, pp. 146–149) around mutual influence and co-regulation as precursors of linguistic behaviour, where they explore how children come to deal with the fact that others can manipulate their environmental support structures to regulate their behaviour. The discovery of social agency through technical behaviour that can occur not only with regards to your own behaviour, but also to others', is an important step in the entanglement between technical and social behaviour (very much in line with Vygotskyan thought).

[18] Even though it is difficult for the contemporary human being to find environmental elements that are not a product of technical behaviour.

[19] Given space limitations, we cannot lay out a comprehensive introduction of the approach and of all the ways in which it can illuminate radically embodied cognitive science, but it is worth noting that the compatibility of the Activity Approach with radically embodied accounts of cognition has already been explored, both in relation to enactivism (Di Paolo & Potapov 2024; Drain & Ave 2018) and to ecological psychology and affordance theory (Albrechtsen et al. 2001; Bærentsen & Trettvik 2002; Borrajo Reinaldo 2021; Pedersen & Bang 2016).

to the operations that Leont'ev describes, and the specific habits (understood as arranged sensorimotor schemes) that these end up establishing correspond to the normative level of the individual action in activity theory.[20] The articulation of these actions in supra-individual activities is what activity theory approaches contribute to the analysis. And activity theory—as heir to Vygotsky's theory of mediation—crucially emphasizes how tools (technical objects in our account) mediate all these levels, from the activity level (collective in nature) to the actual encounter with the material object through individual operations, which is what we have analyzed in the paper so far. We could thus say that technical objects (as well as sensorimotor bodies), given their material character, are traversed by all these various layers of normativity; they embody the normative layer of the collective organisation of activity but engage users at an operational level with its associated sensorimotor norms (through processes of accommodation and assimilation). From this perspective, technical objects are not only a sedimentation of individual regulatory behaviour, but integral components of historically evolved activity systems (which are composed of mediating artefacts or instruments, but also subjects, objects, communities, explicit and implicit rules and practices, and division of labor, see Engeström, 1987).

Beyond tying different levels of normativity through a nested conception of activities, activity theory has also focused on how tensions and contradictions between levels lie at the heart of activities and, importantly, drive them to change (Engeström, 1987, pp. 66–73). In our discussion above, we have already seen this contradiction in play through the keyboard layout example. The QWERTY layout was established long before computer keyboards, as a layout for early typewriters, where material constraints in the form of frequent typebar clashing made QWERTY an effective layout (David 1985). But soon, with improvements in design, those initial constraints went away and alternative layouts appeared, such as the DVORAK–more ergonomic in its design and thus affording better quick typing possibilities (Dvorak 1943). However, the QWERTY layout is still the standard. If we understand the use of keyboards as evolving within the context of activities of writing, we can see that assimilation dynamics, but also other norms that pertain to the historical character of the activity, make the QWERTY keyboard and its sensorimotor engagements stable enough to maintain themselves, even if they may enter into conflicts with sensorimotor norms. But when the nature of the activity changes (a change that cannot be understood at the individual level of actions, as it requires a different organisation of subjects, labor and outcomes altogether), the relation of subjects to tools changes as well, the tension between normative layers widens and assimilation is no longer sufficient to successfully equilibrate relations with the keyboard in the new activity. A process of object-sided accommodation (of technical behaviour) takes place in the changing of the layout to a more efficient DVORAK layout. These kinds of breakdowns of historically sedimented activities and their mediating artifacts and the subsequent accommodations that bring about novel forms of the activity, are ubiquitous in human experience.[21]

5 Conclusion

We opened the paper by questioning where the normative forces that shape our behaviour reside. We are now in a position to provide a nuanced answer to this question. Our analysis has revealed that normativity in technological use is not merely a function of abstract intellectualist rule following or of internalized social convention. Rather, we have shown that objects themselves partially support and stabilize interactions in normative ways as part of deeply historical and social activities. Taking seriously the idea that sensorimotor schemes crucially depend on both agent-sided and environmental support structures, we can see how the latter—and not only the former—can be transformed (*designed*) to equilibrate behaviour in specific, *canonical* ways. Normative layers are, in this sense, doubly *radically embodied*; in agents and in technical objects. This does not commit us, however, to endowing objects with an overly-agential nor an overly-deterministic role that neglects the variety and culture-dependency of technological use; our account rather allows us to underline the flexibility of engagement. In this sense, we have grounded a view of normativity in technological use that goes beyond an opposition between human-anchored normativity and artefact-anchored determinism. We have shown that radically embodied cognition can offer a picture of technical objects not as the passive content of cognitive processing, but as dynamically equilibrated support structures for nodes of a complex web of sensorimotor normativities. Technical objects both shape and are shaped by the embodied interactions they afford and support, constraining action while remaining open to transformation and reappropriation within wider networks of historical socio-technical activities.

[20] A finer analysis of the exact equivalence of terms is out of scope of this paper; for the purposes of our use of activity theory, we believe these rough equivalences are illuminating.

[21] In this regard, if we aim to tackle the complexity in human activity and its evolution, we would need to attend to what Noë (2023) terms *reorganizational practices*, as characteristically human ways of relating to activities that bring about their change.

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Declarations

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