an implant. The cochlear implant is not itself producing a sensory experience. What it gets connected to, the mind, is what is producing sensory experience.

« 16 » At the end of §10, a list of "inspiring perspectives of the 20th century" is given. While I cannot here speak to all of these perspectives, I can point out that Piaget and von Glasersfeld were radical constructivists, but Vygotsky was certainly not (Fuller et al. 2009: 191–199). It is also the case that when "discovery learning" was the latest thing in science education (I taught in a Discovery Learning program in the mid-1970s as a graduate student for three years in the Physics Department at the University of Texas at Austin), it was practiced by realists, rather than proponents of radical constructivism, which had not been defined yet, and Piagetians who were known by at least a few at the time. Just these aspects of the list of perspectives leads me to question the strength of the role of radical constructivism in the work described in the target article.

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Dewey I. Dykstra Jr. has been studying and testing the work of Jean Piaget as it relates to cognitive development and learning since 1976 and, likewise, with the work of Ernst von Glasersfeld, since 1990. He has developed learning materials based on the theories of Piaget and von Glasersfeld on motion, force, electric circuits, thermal phenomena, images from lenses, and light and color for use with non-science majors at the university level. Where there are established diagnostics of understanding from Physics Education Research, students in these courses do noticeably better on conceptual understanding at the end of the courses than Physics and Engineering students at the end of their first courses in physics at the university.

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Authors' Response

Becoming Makers Through Continuous Practice: Learning to Deal With the Uncertain

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> Abstract • We address the following three questions that summarize the concerns of commentators: (a) Is the metaphor of creativity as catching the big fish useful? (b) What is the relationship between radical constructivism and the 4E approach? (c) What do we understand by teaching from the 4E approach?

« 1 » We appreciate the contributions and thoughtful insights brought up by the commentators, which suggest ways to refine and broaden the research reported on in our target article. We address below the main four themes we discern in our target article's commentaries.

Is the metaphor of creativity catching the big fish useful?

« 2 » The suitability of the metaphor proposed in our target article to understand the phenomenon of creativity as "catching the big fish," is discussed by Francisco Parada and Wendy Ross. In Parada's (§3) view it is a "realist argument" because "even in an infinitely deep ocean, the number and nature of these fish would be independent of the nature and history of the catcher and her bait." We agree with Parada that without the catcher, the metaphor is inconsistent with the 4E approach that we adopt to refer to creativity as a skilled experience embodied and distributed among materials and people. However, in the target article, we briefly refer to the metaphor of filmmaker David Lynch, who is recognized for his creative potential reflected in films, paintings, music and furniture design. In an interview[1] he explains that his creative process is meticulously constituted by movements and gestures. Lynch (2006) affirms that his ideas appear like fish in the infinite ocean of his consciousness, but are associated with emotions that are irrelevant in the sense that they make it impossible for him to immerse himself into these ideas. When an idea is accompanied

1 | In the interview Lynch is asked about his creative process in which he refers to the origin of the first idea as "catching the bis fish," https://www.youtube.com/watch?v=YAL52dL5K3Q. In addition, in his book entitled "Catching the big fish" (Lynch 2006), his personal vision of his creativity in his continuous practice with music, painting and furniture making is evidenced.

by relevant emotions, they can "catch the attention" and lead to the creation of images of situations that shape the unpublished script of a film (i.e., create something in the ineffable flow of sensations). In other words, scenes from a film in progress sprout from sensations that give shape to ideas, through attentional anchors[2] that contribute to restricting the action of perceiving a set of emerging opportunities.

« 3 » Parada (§4) argues that "the 4E approach indicates that there is no a priori masterpiece […]. Its status may come and go from a humble effort to a timeless masterpiece depending on context and observers." We agree with Parada that there is no such masterpiece. Quite the opposite, "catching the big fish" is not about taking an available fish, which would otherwise allude to the cognitivist metaphor criticized by Humberto Maturana as "obtaining information from the environment and constructing a representation of it" (Maturana 2006: 37). Paraphrasing Lynch (2006), the big fish can only arise in the sensorimotor engagement with things and people, in which "catching" is to restrict the field of opportunities for action, attending to an unprecedented thought that translates into creative actions. This onto-epistemological adherence allows us to understand creativity as an emerging phenomenon that is embodied and distributed, since intertwined at different levels (brain, mind, and environment). This view distances us from the dualistic perspective (processes and products) that fundamentally contradicts the 4E approach.

« 4 » Ross (§5) affirms that "if we are to take the 4E perspective seriously and its focus on the process and dynamics of creativity, the role of usefulness requires more consideration than it is currently given." We agree with Ross about the argument in favour of the usefulness of the created prototypes, however, in our article, we pay attention to the "making of ideas" through kinetic knowledge of sense-making. In relation to this, Ross Q1 invites us to reflect on whether our metaphor does not characterize creativity "as something fixed and external to the creator rather than a collaborative and emergent effort." We agree with Ross that the metaphor could be interpreted as an individual creation. However, in the target article, we emphasize the collaborative experience, i.e., the phenomenon of creativity arises from a relational ontological matrix (organism–environment) in which the individual and the social are determined by mechanisms that are co-specified. Therefore, the metaphor does not undermine our argument. The historical contingencies of individual sensorimotor activities generate plastic changes within the organism, which, in turn, determine its capacities at different times and contexts (Rojas-Líbano & Parada 2020).

« 5 » Ross (§3) claims that "creativity cannot be understood as a fixed object or process but is rather an act that changes meaning at different times." However, Parada wonders (§3) "[h]ow can an emergent understanding be caught? Catching something seems more of a one-way action imposed by the catcher on whatever is being caught […]." From our theoretical perspective, we consider that we do not allude to dualisms and objective representations of a fixed and immutable world. On the contrary, in our empirical example (§29ff), the emerging ideas that give shape to the prototype of the buoy are carried out through ongoing experience (Ingold 2014), the product of creative actions co-determined by sensorimotor engagement (Di Paolo, Buhrmann & Barandiaran 2017), in which the organism, materials and tools co-evolve (Penny 2022). The prototype changes as a result of contingent actions and not based on a priori established goals.

« 6 » In order to maintain our theoretical perspective, we adhere to a relational ontology, in which the emergence of creativity as skilfully situated experiences depends on the maintenance of its structural coupling with/in the environment (Maturana & Varela 1992: 75). Our metaphor, "catching the big fish," is part of the foundations of the notion of "optimal grip," which is defined as a restriction of the field of action that shapes creative thoughts during a cumulus of ineffable sensations. It was first enunciated by Maurice Merleau-Ponty (2002) to explain the skillful flow of actions in response to a sense of the situation. This notion was taken up by Hubert Dreyfus, alluding to the "tendency to refine its responses so as to bring the current situation closer to an optimal gestalt" (Dreyfus 2002: 367). Along the same lines, Erik Rietveld and Anne Brouwers show how expert intentionality in architectural design activities depends on, "how the self-organisation of this system contributes to the reduction of dis-equilibrium or dis-attunement between the individual and the dynamically changing landscape of affordances" (Rietveld & Brouwers 2017: 547).

« 7 » So, how does this address the criticism we received from Ross and Parada? We maintain that "catching" refers to restricting the field of action opportunities during the ineffable flow of sensations, the product of emerging sensorimotor patterns that stabilize action, opening new ways of perceiving and acting with materials, which, in turn, maximize skilful performance, enriching the prototype design. This becomes clear in §34 of our target article, where we report on students who work on the contingent opportunities distributed with 2D materials and manage to make a sketch in the form of a restriction of perception and action that can be observed later in the resulting design. Simultaneously, the perception–action loop is reconfigured, so that its anticipatory capacities (Kirchhoff 2015) shape new ways of perceiving and acting in 3D material environments, creating unprecedented forms expressed as design restrictions. These ideas have deep roots in the concept of enactive cognition of Francisco Varela, Evan Thompson & Eleanor Rosch (1991: 172f):

- perception consists in perceptually guided action, and
- cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided.

« 8 » Ross Q2 wonders whether we give "greater precedence to ideation than implementation." While we assume that the proposed emphasis on creativity is a form of ideation, we reveal in each phase of the buoy construction project that artifacts are ways of thinking rather than products of thought. This opens up new ways of thinking about

2| "Attentional anchors productively hone and channel attention during perception–action couplings, thus functioning as enabling constraints on action" (Hutto, Kirchhoff & Abrahamson 2015: 7). When participating in tasks or situations that involve clusters of thoughts, attentional anchors reduce operational complexity, by restricting the field of action for perception.

the status of created artefacts in relation to sensorimotor engagement.

« 9 » Parada Q2 challenges the usefulness of the extendedness dimension of the 4E perspective when it comes to creativity in STEAM education. Also from our perspective, extended cognition seems to contribute little to understanding creativity in STEAM environments, and we agree with Parada (§9) that the greatest contribution is made by embodied, enacted and embedded cognition alone. In contrast to his allegation in §3 that our fish-catching metaphor appears to be a realist argument (see also §2 above), we maintain that our argument is constitutively dialectical, given the relational ontological foundations mentioned in §13 of our target article. Indeed, in the enactivist perspective, all living organisms are cognitive. The metaphor of creativity, "catching big fish," consists of restricting relational dynamics from a foundation of circular causality and not from a unidirectional logic (Bateson 1979). In this sense, we agree with Ezequiel Di Paolo that –

> "organismic boundaries are dialectical processes and not immanent walls, therefore bodies can extend by incorporating parts of their environment as in the case of insects that use trapped air bubbles to breathe underwater." (Di Paolo 2020: 37)

In §32 of our target article, we show how the initial idea for the manufacture of the prototype begins with the individual sketch of a buoy on a napkin. Subsequently, the idea is shared among people, and it mutates in the course of participation with materials and technological tools, so that "we have two sense-makers, who by engaging in interaction modulate each other's sense-making and in doing so sustain an autonomous relational domain of coordination while the interaction lasts" (Cuffari, Di Paolo & De Jaegher 2015: 1099).

« 10 » Parada Q1 invites us to reflect on how to "better incorporate interaction processes in understanding creativity without subscribing to interactionism." This question is essential, since it reveals a limitation of our study. It alludes to the unique approach of the descriptive dimension in the third person, through the participant observation technique. A way to improve the understanding of the phenomenon of creativity from the 4E approach could be completing this type of study with micro-phenomenological interviews that reveal individual experiences based on first-person reports (Petitmengin et al. 2009). Given the multimodal nature of cognitive dynamics, techniques from cognitive neuroscience could be used, such as the Mobile Brain/Body Imaging (MoBI) framework, which allows real-time modeling of the cognitive system along with natural behaviors in the environment (Parada & Rossi 2022). In favor of the research design used in our study for understanding interactive processes, we agree with Tim Ingold who affirms –

> "if its method is that of the practitioner, working with materials, its discipline lies in the observational engagement and perceptual acuity that allow the practitioner to follow what is going on, and in turn to respond to it." (Ingold 2013: 4)

Are the 4E and radical constructivism research programs incompatible?

« 11 » Dewey Dykstra and Hugh Gash are concerned about whether the 4E approach and radical constructivism (RC) are "in tune" (Dykstra §11). While we cannot offer a detailed analysis of their mutual relationship here, let us nevertheless make a few remarks. Clearly, both approaches have been historically influenced by each other. So, while there is no isomorphic relationship between them, which would make it possible to reduce one to the other, one should expect at least a certain "harmony." The harmony is due to two core elements:

a Any reference to a mind-independent reality must remain metaphysical speculation (Riegler 2005), which means that, as enunciated by Alexander Riegler (2001) and mentioned in our target article (Footnote 4), "reality is neither rejected nor confirmed, it must be considered irrelevant."

b As Ernst von Glasersfeld and Francisco Varela emphasized in their jointly written paper, "the knower constructs the world he knows and, in doing so, he determines his way of knowing," which makes it clear that "the age-old dichotomy between the knower and an ontological reality-to-be-known was a rather dangerous illusion" (Glasersfeld & Varela 1985: 22).

« 12 » So, we can establish a harmony between radical constructivism and the 4E approach, especially with enactivism, on the idea that according to them, the "thinking subject has no alternative but to construct what he or she knows on the basis of his or her own experience" (Glasersfeld 1995: 1).

« 13 » However, a fundamental difference might be the concept of knowing as "for enactivists, knowledge is not in the subject nor in the environment but emerges in the dynamics of interaction between each" (Proulx & Simmt 2016: 102). Radical constructivists emphasize that reality construction happens in the subject's mind, while for enactivists it seems to be based on a sort of relational constitutive ontology that includes both the organism and its environment.

« 14 » Addressing Gash's Q1 of whether the propensity of RC for conceptual analyses and computational modeling fit with the rejection of formal mechanisms or logical rules in 4E cognition, as we pointed out in §11 of our target article, we must repeat that, indeed, the computational models of conceptual analysis typical for RC are at odds with the 4E approach. A large part of the studies in the 4E approach use holistic research techniques that incorporate participant observation reports such as ethnography and techniques that combine third-person data obtained from electroencephalograms, magnetic resonance imaging, mechanical and physiological biomarkers, and first-person techniques such as the microphenomenological interview.

« 15 » Volkan Sevim Q2 wonders to what extent posing|solving (i.e., explanation) could be useful for understanding creativity. As said above, in the 4E approach, it is assumed that the organism and the environment co-evolve in a dynamic and continuous process of transformation. Thus, the posing and the solving agent co-evolve together. For this, it must be considered that closed problems that involve unique answers, obtained from the automation and memorization of procedures, do not favor the understanding of creativity, because reproduction is prioritized over the creation of possible relationships. By contrast, when a problem is open, it is possible to observe different skills that emerge and provide new

solutions as a result of the creation of new relationships. This opens a fertile field for the investigation of creativity and provides an answer to Sevim's Q1, asking how creativity and problem solving are related to each other. We would like to add that creativity requires educational environments that invite the deployment of a set of skills with materials and people, in order to generate solutions to problems that encourage imagination and manufacturing.

« 16 » Regarding the relationship between Piaget's constructivism and the 4E approach, Dykstra Q2 wonders whether the interviews Piaget and his collaborators conducted could exemplify the dynamic sensorimotor environments as described in our target article. Our answer must be no, since the 4E approach emphasizes relations, while Piaget's approach focuses on the individual subject. The interviews seek to identify invariants in the subjects in interaction with the apparatus, while the ethnographic description through participant observation in the 4E approach seeks to describe the processes of skill formation based on contingent relationships situated in material and social contexts.

What do we understand by teaching from the 4E approach?

« 17 » In this section, we are interested in exploring some ideas about teaching as a phenomenon that has been scarcely explored in cognitive science in general. Theories in education have always come from psychology, therefore, the focus has been on learning. In his §4, Dykstra refers to the folk theory that defines teaching as "the presentation of the established canon by approved methods for the benefit of the deserving." From our theoretical lens we, too, disagree with such a definition, since we consider that the "approved methods" that found the "teaching theories" are characterized by a strong commitment to the transmissive approach to teaching. For us, the dialectical-materialist paradigm of Paulo Freire (2013) has a great appeal. Among other aspects, his pedagogy of the oppressed is about a critique of banking education, understood as a transmissive approach in which content and values are deposited in passive minds. We emphasize a pedagogy that highlights experience and the different ways of learning that contribute not only to reproducing knowledge, but also to making us creative and aware of the lived world in order to transform it. This emphasis is consistent with Maturana's claim that "education is a process of transformation in coexistence, in which freedom and self-determination are the goal of educational work" (Maturana & Pörksen 2010: 69, our translation).

« 18 » Dykstra (§6) states that "[t]hose instructors who do make some type of permanent change are generally ones who have become disgruntled with the folk-theory results." This raises the question of whether a lasting change can be made while, at the same time, favoring the cognitive inertia of a mind without a body, as we find in cognitivism. Dykstra (§6) warns that qualitative studies with just two students "will not make much of a splash" because two is too small a number and decision makers do not usually listen to qualitative studies. The 4E approach, which is based on situated experience, does not agree with idea of generalizing behaviour, and its emphasis is on contextual relativism. So we can only wish that decision makers would open up to qualitative research to understand cognition and learning in different social and material environments to abandon the idea that cognitive processes can be universally evaluated and pressed into schemata for a general population. The 4E approach explaining the formation of cognition as the intertwining of the brain, mind and environment suggests turning to the constitutive relationship between organism and environment. It is in informal educational situations in which embodied and embedded cognition is revealed.

« 19 » Let us illustrate this with an example from the ethnographic work of Claudio Aporta in which children and young people belonging to an indigenous Inuit community learn early on to deal with uncertainty in the middle of snowstorms, which make it impossible to recognize changes in the environment for decision making (Figure 1). To do so they must see patterns in nature through sensorimotor engagement with the environment, which allows them to reorganize and combine different aspects such as the four primary winds that leave lasting snowdrifts, large masses of tundra, sea ice,

Figure 1 • Igloolik hunters on the sea ice off the coast of Repulse Bay. Retrieved from https://iu.tind.io/record/547

emerging snowdrifts, and how landmarks look at a distance. Indeed, "traveling and orienting are not considered by Inuit to be activities liable to be taught and learned as sums of techniques."[3] Something similar occurs with the indigenous people of Micronesia, who used their specialized knowledge of the movement of the stars, animals, and changes of seasons to move efficiently (Hutchins 1995). In both examples, cognition emerges from sensorimotor engagement with the environment. What we want to highlight here is the learning processes with which the Inuit generate unprecedented solutions, restricting their global field of action, to maximize their performance. While navigating in the midst of storms, the Inuit see patterns in nature without any type of ship instrumentation, only from traces. To do this, the Inuit form attentional anchors during interaction with the environment that arise as their set of skills grows as a result of participating in a task (Ingold 2000). Our examples suggest that informal educational processes do not require teachers filling the heads of students with content, but teachers who help them "educate perception" through continuous practice. In this type of situation, the teaching does not come from the "canon by approved methods for the benefit of the deserving," but rather, from the experience skillfully cultivated in

3| "Inuit Orienting: Traveling Along Familiar Horizons," by Claudio Aporta, retrieved on 16 April 2023 from https://www.sensorystudies.org/inuit-orienting-traveling-along-familiar-horizons

open dynamical contexts in which sensorimotor engagement prevails. This same process can be evidenced in our target article, in which students must deal with the uncertainty of contingent actions during the design of the buoy.[4]

« 20 » So, what can be done to draw the attention of decision makers to new ways of teaching such as 4E pedagogy (Dykstra's Q1)? The OECD 2023 report, "Building the future of education," confirms that new educational policies are advancing to dynamic approaches that promote learning by doing and do it yourself, which decentralize educational processes: "Education is no longer just about teaching learners something but about helping them develop a reliable compass and the tools to confidently navigate through a complex, volatile, and uncertain world."[5] Therefore, the 4E approach could get a lot of interest from decision makers.

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4| Let us emphasize that we do not want to present old wine in new bottles. Providing situations in which the students discover possible "solutions" for themselves rather than exposing them to transmissive instruction is what education based on radical constructivism has been doing all along since the 1980s. Radical constructivist teachers were criticized for being not instructors anymore because they fancied discovery learning instead.

5| https://www.oecd.org/education/future-of-education-brochure.pdf, retrieved on 19 April 2023.