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Review 1

General reply. We thank the reviewer for raising issues concerning Physics Education Research and the teaching of energy. We originally did not think it would be necessary discuss these topics in our paper since it is not a contribution to PER in the traditional sense, but we now seize the opportunity to add a section on the energy issue in PER.

The points raised by the reviewer are very important for Physics Education Research as generally understood. PER started as a field of didactic research dealing with the conceptual difficulties demonstrated by students in physics courses aspiring to a formal scientific level. In contrast, our paper suggests ways in which children and laypersons can deal with their everyday experience of forces of nature (experience is understood as feedback dynamics resulting from organism-environment interactions). We apply research in cognitive science to the most general form of theories of macroscopic physical processes: continuum physics and the physics of dynamical systems.

Since the reviewer raises general points and does not refer to any specific parts and sections

of our paper, we take the opportunity to make changes where they help strengthen the discussion. We combine issues and restrict our actions to two changes and additions made to the paper.

Reviewer: I guess, the article is more an example for a physics textbook than a summary of results of research. The authors make proposals for an alternative access to several topics of physics, which share one connecting background. This is similar to the well known „Karlsruhe physics course“ whose authors are mentioned in the reference twice. However, for a research-based contribution it would have been necessary to include the discussion of this access.

Our comment. Our paper suggests ways in which children and laypersons can deal with their everyday experience of forces of nature (such as wind, light, heat, fluids, electricity, substances, gravity, and motion) in natural and technical settings. As far as didactic research is concerned, these suggestions arise from work with primary school children and with student teachers of kindergarten and primary school who are not scientifically inclined. We have been researching how student teachers can get better access to scientific and technical culture that is generally alien to them (see the papers by Corni et al., listed in

References, and, in particular, Corni & Fuchs, 2020 and 2021). With our paper, we do not contribute to how physics, as a formal science, should be taught in school.

Again, our research deals with how, in all generality, humans respond to the experience of processes in nature and machines. This leads us to suggestions how this response can be transformed in(to) embodied simulations. Therefore, this research belongs to cognitive science in general and cognitive linguistics, narratology, and the philosophy of agency, causation, and imagination in particular (we hope we have sufficiently documented the literature in these areas so an interested reader may dig more deeply into these exciting fields). As far as activity based (embodied simulation based) questions are concerned, our paper is a contribution to this emerging field (it is a position paper based upon our extensive experience, over the last 10 years, with developing and teaching courses for student teachers and applying examples in primary school).

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Therefore, we feel we do not need to include a discussion of the KPC—as important as this might be in PER. Importantly, our approach is not based upon the KPC. We have described

in detail what the scientific bases of our observations and suggestions are (Section 2.1; see also 3.1 and 4.1): continuum physics, the physics of dynamical systems, and dynamical modeling. The KPC is based upon a generalization of Gibb's thermodynamics which is altogether different from continuum physics (Truesdell & Noll: 1965 The Classical Field Theories; Fuchs, 2010: The Dynamics of Heat). However, as generalizations over theories of specific phenomena, continuum physics and the generalized Gibbsian approach share similarities which, in particular, allow for analogical treatment of the various phenomena covered in theories of physics (that is why we have referenced Herrmann et al., 2010).

Our action. With the exception of a more in-depth discussion of the issue of energy in PER (see our next responses and subsection 2.3 added to the text), we do not specifically act upon this part of the reviewer's comments.

Reviewer: Some of the suggestions the authors make must be compared with those of this access and with the ideas of other proposals already existing, for example the idea to imagine energy as something touchable.

For the discussion of the educational or didactical part it is

necessary to include the discussion of the productivity of such access, there already exists empirically based research about that topic. And there is for example research about the idea to make the transport of energy more illustrative (including both advantages and disadvantages).

Our response. We are not 100% sure what “must be compared with those of this access” refers to. For this reason, we restrict our response to the second part of the reviewer’s comment: “the idea to imagine energy as something touchable,” and to the following sentences.

We are well aware that the issue of how to deal with energy in physics education strikes a nerve with physics (education) researchers. For this reason, we have now added a section discussing teaching of energy comparing PER and an approach based upon generalized macroscopic physical science. This does not change the substantive parts of our paper, but it gives physics teachers and PE researchers some background relating to what we do.

Our action. New Sub-Section 2.3 added to the paper.

Reviewer: Finally, in every case of making suggestions for alternative access to well established parts of physics in classes it would be helpful if the authors could give some data

or at least some impressions about their own experience with their own ideas (there is one article mentioned, but just cursory).

Our response. We have added a couple of sub-section plus more extensive references dealing with didactic experience.

Our action. Section 5 enlarged and restructured.