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Science process skills and education for sustainable development competences: A review through the lens of critical realism

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Abstract
This review is developed as a treatise on how scientific process skills and the associated competences are currently inscribed in the curriculum. It is developed around the developing imperatives for the curriculum sciences to take up education for sustainable development around global concerns for biodiversity loss, environmental pollution and climate change. It draws on critical realism as a vantage point on scientific processes to open up some tools for reinscribing science process skills and competences as pertinent necessities of curriculum-activated processes of transformative learning.

Keywords: critical realism, education for sustainable development, in-service teachers, logic of scientific discovery, science process skills

INTRODUCTION

Environmental education (EE) has long been hailed as (and still is [cf. Uddin, 2023]) a means to not only develop humanity's awareness and concern about the environment in a broader sense, but also *skills*, *motivations*, and *commitments* essential to solving current and future problems (Carter & Simmons, 2010). In addition, Imran et al. (2024) eloquently show the synergy between it (EE), education for sustainable development (ESD) and knowledge, *attitudes* and *values*. In South Africa, EE developed with a wider focus than the earlier field of conservation education. Science and geography became fields that put an emphasis on knowledge, *skills* and awareness and the addition of a concern for *sustainable development* (SD) in all learning areas. This change was in line with the declaration of the United Nations Decade of Environmental Education of Sustainable Development (2005-2014) (Reddy, 2011).

As the world embarked on this fundamental and significant shift towards a sustainable future, the subtle shift to SD cannot be overemphasized. After all, it (SD) has evolved into what is better–it is now about present humanity and a quest to make the change that will ensure that civilization in its entirety has a future (Muller, 2018). That said, Africa's agenda 2063 calls for urgency on climate change and the environment and catalyzing of, among others, skills revolution and active promotion of *science (education)* (African Union Commission, 2015). United Nations Educational Scientific and Cultural Organization (UNESCO), with its 'a new social contract for education' (see UNESCO, 2021a), has since called for reimagining education itself as the basis for reshaping sustainable futures and achieving the 2030 goals. Reimagining science education to champion ESD has been a slow process. It developed with a search for synergies across scientific knowledge, associated competences and *methods* (they entail science process skills [SPS]). For Özdoğru (2022), the 21st century problems and challenges call for skills and competences proposed by scholars and organizations, and a dynamic and flexible education systems that could nurture them. Such systems, from Moroye's (2009) long-standing perspective, might entail complementary curricula whose efforts could be a catalyst for holistic EE consciousness. Amid the quandary of what should work, cross-disciplinary collaborations and research partnerships (see Das et al., 2024), and specifically, inquiry-based learning, which develops SPS, are also proposed. Sadly, it has not been an easy matter to reconcile SPS and competencies in the current science curriculum.

The challenge thereof about SPS nudged us to ponder on a philosophical approach that could be a catalyst for

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Contribution to the literature

- The review opens up how science process skills (SPS) and critical realism (CR) function as mediating tools for scaffolding real-world learning within school curriculum settings.
- Specifically, SPS are portrayed as an essential part of a process of inquiry for mediating the acquisition of real-world knowledge, while CR serves as a platform for apprehending environmental risk (e.g., climate change, biodiversity loss, and environmental pollution) as genuine problems that can be attributed to absences that can be resolved through corrective change.
- The review effectively bridges the gap between contested perspectives, thereby providing a realistic onto-epistemic framing for education sustainable development within curriculum settings.

understanding complex global issues enshrined in EE hence transformative action–critical realism (CR) (cf. Huckle, 2024). Indeed, Price (2023) shows the synergy between EE (with special reference to climate change) and CR. She leverages Bhaskar's (1998) enlightened common sense to argue that endorsing a transcendental realist perspective can mitigate arguments from climate change sceptics who challenge the scientific accuracy of climate models. For her, "understandings of *structures* and *mechanisms* [synonymous with *CR*] can be trustworthy–such as the understanding of the greenhouse effect which is in fact" rooted in scientific principles, although not at a global scale; that can help teachers deepen the understanding of environmental aspects (p. 12; emphases added). That said, we acknowledge that, as it shall be discovered, our review echoes, among others, interconnectedness, and sustainability and balance (*ecological paradigm*; see Klarić & Jovičić, 2025); brings out what Tokay (2024) calls "agentic assemblages" essential for addressing ecological problems (*new materialism*); and portrays transformation within the context of climate change, which is enshrined in systemic, reflective and participation in teacher professional development and teacher resources (*participatory paradigm*). Nevertheless, we have chosen to center it (this review) on SPS and competencies in curriculum settings and draw on CR after Bhaskar (2010) for insights into how science education can be realigned to meet the challenges of ESD and transformative learning. We propose that science (education), by virtue of being a communal practice in search of congruent knowledge, could be an exciting and creative process of discovery that broadens our scope of knowledge of SPS, competencies and deliberative experience. To examine competences or skills (SPS) in a teacher education setting, we draw on the DREI(c) schema for scientific processes after him (Bhaskar, 2010). This served to deepen an understanding of the logic of scientific discovery and an understanding of the sustainability competencies frameworks specified for ESD. Our engagement with these process skills and competencies is rooted in an overdue need to review the SPS specified in the science curriculum (see Department of Basic Education [DBE], 2011) and to interrogate how they may relate to the UNESCO ESD competences for climate and sustainability-based teaching and learning programs.

The new era of the sustainable development goals (SDGs) challenges us to rethink our place in the world, hence the increase in the mobilization of green life skills in the 21st century (Kwauk & Casey, 2021). Indeed, Le Grange et al.'s (2024) theoretical framework enshrined in a post-humanistic perspective, points to a *relational ontology*: "We live in a posthuman condition, with issues such as *ecological destruction*, the ever-present economic crises, ongoing poverty, and social injustice, and this calls for curriculum studies that is attuned to a post-anthropocentric world" (p. 40; emphasis added). Their argument points to a need for educators and scholars alike to reimagine a curriculum that emphasizes awareness of ecological realities and, most importantly, advocates for sustainability (cf. Reid, 2018). As sustainability starts with teachers (UNESCO, 2021b) - the agents of change–it is imperative that science teachers and the study of science shape meaningful learning processes in relation to the challenges of climate change and future sustainability (cf. Facer et al., 2020). It should be noted that science and SPS assume even greater importance in this era of technological and scientific advances in knowledge that are intertwined with green economy globalization and transformative learning. These changes (advances), according to UNESCO (2021a), are increasingly influencing what and how students learn. That said, it should further be noted that the synergy between the acquisition of scientific knowledge, and teaching and research (they both have philosophical basis hence intertwined), as unified community practices assume even greater importance here (see Sfard, 1998). Indeed, Sfard's (1998) eloquent debate on conversations of learning championed by Piaget and Vygotsky, which are enshrined in concept development gave way to relevant terms such as *schema* and *representation* within the acquisition metaphor (the *having*) and to the continual flux of the *doing* synonymous with participation metaphor, such as *teacher reflections*, *learning in community of practice* and *communities of inquiry*.

Against this prelude, the purpose of this review, in its quest to contribute to the field of environmental and sustainability education, is to portray, with special reference to *keep it cool* case study[1], how CR (with its potential to develop critical scientific literacy [see Ferguson, 2022]) can inform the integration of in-service teachers' SPS and ESD competencies.

A CALL FOR LOGIC OF SCIENTIFIC DISCOVERY: REVIEW OF SCIENCE (EDUCATION) WITHIN ESD CONTEXT

Kyle (2020) alludes to Brundtland's (2019) argument that SD has increasingly become the modern holy grail to address environmental and social disasters amid efforts to tackle global (climate) change, increased population patterns and the associated consumption, and the inevitable and fast-paced changes in global technology advancements. For Giangrande et al. (2019), despite its tag as a vehicle towards pursued aspirations for the future, SD has its challenges. The associated SDGs have tensions and contradictions, and there are concerns about their framing. On the other hand, sustainability scientists, in their efforts to alleviate the global challenges of our time, have limited expertise and experience to provide practical and effectual solutions (Wiek et al., 2012). The challenges thereof are amid the impending *ESD for 2030 framework*'s vision of achieving all these goals and envisaged just and sustainable world by 2030 (see UNESCO, 2020). Thus, it is reasonable that science (education) itself has not escaped criticism. Hogan and O'Flaherty (2021) argue that "in order to provide appropriate learning spaces to engage in issues central to ESD … [science education should reconsider prioritizing] content and procedural scientific literacy at the expense of epistemic scientific literacy" (p. 17 of 22). For Muller (2018), science education, by being fact-based and divorced from spiritual or intangible component, has slowed down advancement in solving modern complex problems. Interestingly, Bhaskar (1998) had long argued about science education's lack of scientificity and that it should not be a transitive object of inquiry. He subsequently posited on science and the associated theories, methodologies, *mechanisms* and the need for a reimagined approach:

> Current metatheories and methodologies of science encourage an actualist and reductionist, monodisciplinary approach to phenomena such as climate change. Conversely, such phenomena can only be understood in terms of the indication of several distinct explanatory mechanisms, operating at radically different levels of reality, including four-planar social reality, and orders of scale … From a philosophical point of view … the situation of a multiplicity of mechanisms operating at radically different levels of reality and orders of scale presupposes that the systems in which the mechanisms act are open and that some of these mechanisms operate at levels which are emergent from others. This necessitates, at the very least, a *multidisciplinary* approach (Bhaskar, 2010, p. 10; emphasis included).

The present review follows from the arguments thereof, and it places ESD and SPS through the lens of natural sciences in teacher education at the heart of the matter. We draw from the *keep it cool* case study to question how in-service teachers reconcile SPS and ESD competencies. The reconciliation thereof is enshrined in the framing of the teachers' science education pedagogy in response to how scientific knowledge has become an essential basis for addressing environmental problems in light of the emerging processes of climate change. We argue that this can raise the question of how we (educators and teachers) can best work with established and emergent scientific knowledge to activate SPS in ways that are relevant to our teaching of science for ESD as a knowledge-mediated process of social change in curriculum settings.

It was important that we put the present scope of in-service teachers' *science education* pedagogy under a microscope. Science education provides a springboard for the exploration of SD under its inquiry-based pedagogical approaches, which also promote the development of SPS (Hogan & O'Flaherty, 2021). Most importantly, the SDGs themselves can provide a framework for teachers to structure problem- and project-based interdisciplinary learning in their quest to reimagining suitable pedagogical approaches in the 21st century (cf. Espino-Díaz et al., 2025; UNESCO, 2021a). Here, a solution-focused teaching approach can be tailored to the principles of ESD and the associated competencies (Hoffmann, 2021). That said, we acknowledge Muller's (2018) philosophical perspective enshrined in curbing regenerative development. While we also acknowledge that Bhaskar (1998, 2010) questioned science, from the point of a philosopher, his subsequent publication (Bhaskar, 2016) portrays *science (education)* as our hope–a new vision. Amid the perception of the world as compartmentalized and

[1] See VVOB's (n. d.) link, in references, for an overview of the associated project, which was focused on the professional development of in-service teachers and school leaders within the context of climate change education. The project epitomized Tokay's (2024) *agentic assemblages* within the context of environmental education by bringing into the fore, among others, a special technology-based presentations and teachers' activities that tapped into use of classroom and school environment resources, climate related-data, ecological ethics in a quest to shape the stakeholders' (i.e., school leaders and teachers) environmental awareness, with special focus on global climate change. Thus, the project, by focusing on the material aspects of the phenomena investigated, including the agentic capacities of the material entanglements (see Hein, 2023, p. 304), thereby entangling matter and meaning, has leveraged a *new materialist* perspective.

Table 1. Ontological stratification of CR (adapted from Bhaskar, 2016)

Description (Mirzaei Rafe et al., 2020, p. 59)	Domains		
	Real	Actual	Empirical
	Mechanisms and structures with enduring properties	Events (and non-events) generated by the mechanisms	Actually observed and experienced events
Mechanisms	*		
Events	*	*	
Experiences	*	*	*

individuated, the future is now envisaged from the vantage point of science (education) as wonderful again–an enterprise that better reveals the workings of our world. Learning science is seen as "an exciting, creative process of discovery that expands our knowledge rather than producing (inevitably, in open systems, increasingly complicated) redescriptions of our everyday knowledge and ordinary experience" (p. 30). Most importantly, it has illuminated the characteristic logic of scientific discovery, which entails what Bhaskar (2016) articulated as *DREIC schema*–a vantage point on scientific processes to open up some tools for reinscribing *SPS* and *ESD* competences as pertinent necessities of curriculum-activated processes of transformative learning. In our view, the argument therefore underscores the significance of intersecting CR, SPS and ESD.

REVIEW

The Overview of Critical Realism

CR, which gained prominence through Bhaskar's (1998) renowned works, is one of some post-positivism paradigm's perspectives intended to address its (positivism) apparently defective nature in ontology and epistemological terms (Zachariadis et al., 2010) to show that reality exists beyond awareness of it (reality). It is thus reasonable that Fletcher (2017) portrays CR as a solution to what Denzin and Lincoln (2011) once termed positivist/constructivist "paradigm wars" by reconciling their (positivist/constructivist) ingredients to address such defective nature. We also contend that, in the contemporary context of EE and sustainability, CR can be a viable solution when integrated with the *ecological paradigm* (through ecological and posthuman lenses) to address global challenges. CR forms the basis for real-world interventions, such as *keep it cool*. The ecological paradigm invites us to explore the intricate relationship of humanity and the environment as a single socioecological entity (Loonstra et al. 2025). Indeed, this paradigm emerged out of the need to assess philosophical perspective of humanity concerning the sustainability of the planet, the connection with nature and the reduction of the impact of human activities on the environment (Escolà-Gascón et al., 2023; para. 4). The latter (environment), materiality and ecologies form part of the posthuman perspective (Koro & Cannella, 2023).

CR's quest for causation has enabled researchers to make sense of and explain events and put forward pragmatic policy recommendations to address social problems, including that (social problem) of climate change. CR's critical component–DREI(c)–which has since been expanded to RRREIC, points to scientific discovery. In this review, we argue that DREI(c) sheds new light on scientific knowledge production processes. Bhaskar (2016) also uses the latter (RRREI[c]) as a reflexive process in the social sciences where the re-describing of things is an initiation of SPS for learning across what we know (scientific knowledge) and the complex conditions that confront us in problem-solving settings in relation, for example, to climate change. In light of these, we have chosen to tap into Bhaskar's (2016) philosophical perspectives to contemplate an alignment of SPS, DREI(c) and the key competencies for ESD in science education curriculum settings of teaching and learning transactions concerning climate change. As a point of departure, we illuminate CR–a philosophical system by Bhaskar (2016)–that has since gathered force in the contested terrain of paradigm rhetoric.

Bhaskar (2016) passionately dissected CR - a doctrine to which (apparently) ontology and non-human ontology subscribe. Apart from the distinction between philosophical and scientific ontology, transitive and intransitive dimensions (the latter lends itself to ontological realism, epistemological relativism and judgmental rationalism), he provided the basis for CR in which reality is stratified into three nested domains (see **Table 1**). Fletcher (2017) eloquently elaborated on these domains. Fundamental to the **real** level are causal *mechanisms* and structures with inherent properties that act as causal forces to produce *events* (we *experience* and observe) at the empirical level. At the **actual** level, *events* take place regardless of whether or not "we *experience* or interpret them, and these true occurrences are often different from that is observed at the empirical level" (p. 5; emphasis added). The **empirical** level accommodates empirical measurement of events, with logical explanations. The logic aspect is evident in this level of reality being transitive and people are at the domain of events as they *experience* them. In short, CR is all about the explanation of events through the identifying of emergent causal mechanisms (inherent properties in a structure acting as causal forces, for instance, the *greenhouse effect* and *the laws of ecology* [see Huckle, 2024]) and their consequences throughout the three nested domains of reality.

On the other hand, Sharon-Baker (2016) discussed the hallmark of CR as a stance. CR–also viewed as an all-inclusive scientific philosophy (Lawani, 2021)–is characterized by a belief that the world is constructed through people's stances and perceptions (*constructivist epistemology*) and that there are realities that transcend our knowledge (*traditional realist ontology*). The latter explains why critical realists usually tap into theories but, at the same time, acknowledge that they (theories) cannot portray the complete picture of reality. Sharon-Baker (2016) goes further to argue that its (CR) usefulness is not only in accommodating mental insights and *reflections*, facilitating theoretical debates (or reviews) but also in emphasizing the "*context* in which an intervention is implemented; the *mechanisms* of that intervention, as well as its outcomes" (p. 330; emphases included). Thus, it is reasonable once again that, in CR, the empirical, actual and real domains form the basis for the stratification of reality (**Table 1**) (Haigh et al., 2019).

Enacting Critical Realist Case Study: Ontological Construct and DREI(c) Schema and the Logic of Scientific Discovery in Natural Sciences

South Africa is ranked in the top three countries with rich biodiversity; this brings into focus issues of economic and social development (Maze et al., 2016), and the environment and climate change. Trott et al. (2023) suggest that climate change–a primarily scientific, technical, and/or environmental issue–requires rethinking education systems to accelerate awareness and action about it. After all, (science) education remains the fundamental tool in addressing environmental and development issues entangled and embedded in SD, which, itself, is shaped by teachers' pertinent competences and praxis (Agbedahin, 2018). That said, although South Africa has made significant progress in integrating environment and sustainability education at all levels of education, its socio-economic and environmental issues have rendered it vulnerable to the impacts of climate change. There has long been a conglomerate of barriers to the inclusion of environment and sustainability education, which are related to teachers, curriculum, and teaching and learning (see Kimaryo, 2011). Indeed, more recently, Damoah et al. (2024) concluded that, in South Africa, "teachers' and learners' perceptions and understanding of the integration of EE into teaching and learning are limited and uninspiring" (p. 13). Kimaryo's (2011) and Damoah et al.'s (2024) arguments are illuminated by VVOB's (n. d., para. 3) argument that there is "a fragmentation of climate change knowledge and education at all policy levels, and a lack of alignment of climate change education (CCE) with new science and policy directions". It is, therefore, reasonable that there have been calls for norm support structures at the school level for efficient implementation of ESD and, most importantly, pertinent policy documents (see Læssøe & Mochizuki, 2015). In this review, we add that the adoption of scientific-realistic *perspectives* and enacting critical realistic *approach* are also reasonable (cf. Vogel et al., 2015). The latter, in particular, is rooted in what Shoolman (2017) posits as Bhaskarian's promulgated worldview marked by ontological and epistemological credo.

Our discourse in relation to the perspectives and the approach thereof is twofold. First, they are enshrined in the *ontology* of CCE in tandem with SPS. In other words, what CCE-SPS should be like amid the calls for developing climate change literacy; the need to align it with the country's relevant policy directions; and disrupting the natural sciences curriculum, as we know it, in our quest to teach environment and sustainability education, with special reference to climate change. For instance, a curriculum that leverages SDGs to provide an all-inclusive framework for social change, and CR is applied to investigate the real, actual and empirical domains where climate change is explored from multidiscipline perspectives that include natural sciences (cf. Mirzaei Rafe et al., 2019). The latter (disrupting natural sciences curriculum) is at the heart of the second point–developing ways to learn about CCE-SPS through the lens of scientific discovery.

Bhaskar (2008), within the context of a realist theory of science, eloquently argued for an explanation of events around us. For him, "if science is to be possible, the world must be open; it is men that experimentally close it. And they do so to find out about structures, not to record patterns of events" (p. 115). This brings us to the rationale for the ontological construct. For Shoolman (2017, p. 3; emphases added), as "nature does not simply reveal the finished blueprint of an infinitely stratified structure … our *ontological constructs* must therefore embrace the concepts of '*change*' and '*process*' as well as those of *structure* and *complexity*". This means working beyond the reductionist cause-and-effect dialectic of people and problems to a grasp of the complex relational dynamics across time of people, natural, living landscapes and climate. Bhaskar's (2008) and Shoolman's (2017) arguments, collectively, suggest the need for researchers to view reality as more complex with multiple layers that point to a need to apply appropriate philosophical stances and theories (see **Figure 1**). They point to the need for researchers to go beyond just experimental observations synonymous with, for instance, positivism and understand mechanisms that produce them that are usually not directly observable (Lawani, 2021), hence 'practically adequate' designs that 'fit for purpose' (Haigh et al., 2019). Evidently, CR is fundamental. Nevertheless, we acknowledge that it has its challenges that are not only based on its tenets (e.g., Elder-Vass et al., 2023) but also epistemological (e.g., Zhang, 2023).

Figure 1. *Keep it cool–Fundisa for change* theory of change (Source: Authors' own elaboration)

Table 2. Scientific skills stipulated in the South African science curriculum

Science process skills
Accessing & recalling information
Observing
Comparing
Measuring
Sorting & classifying
Identifying problems & issues
Raising questions
Predicting
Hypothesizing
Planning investigations
Doing investigations
Recording information
Interpreting information
Communicating

As referred to earlier, we argue that CR can provide the springboard for an appropriate approach to scientific discovery. That said, we further argue that our methodological approach–mapping *SPS* and *ESD* competences onto a CR schema–has the potential to contribute to our review's theoretical impact on the field of environmental and sustainability education. The related examples provide a case for applying *CR* to educational outcomes (such as *SPS* [**Table 2**]) enshrined in heritage practices, *ESD competences* and scientific inquiry within the South African science curriculum, and pertinent teacher praxis-based training.

DISCUSSION

Science Process Skills and Critical Realism Within the Context of Environment and Sustainability Education

In South Africa, Reddy (2011, 2021) eloquently articulated the advent of EE in 1997. That significant period saw the lobby for awareness of *environmental issues* in, for instance, science curricula. Most importantly, the lobby is enshrined in developing knowledge and understanding, *skills* (e.g., SPS) and awareness of *SD* in subjects such as science. The present review thus follows from the arguments thereof in terms of ESD and science through the lens of SPS stipulated in the South African science curriculum (**Table 1**) (DBE, 2011).

SPS have long been hailed as the basis for *scientific endeavors* (Coil et al., 2010). They could be developed within the context of scientific inquiry intertwined with ESD (with a special focus on SDGs based on a particular ecosystem) (see Molefe & Aubin, 2023) and EE itself today (Sa'adah et al., 2024; Ute et al., 2025). Thus, they could be effective in the acquisition of environmental concepts (see Melesse, 2025). Conversely, leveraging scientific principles intertwined with appropriate EE-based methods can prove beneficial in fostering environmental consciousness and, most importantly, the development of SPS (Ute et al., 2025). ESD, by drawing on extensive research (cf. Baidya & Saha, 2024) and cross-disciplinary scholarly discourse on complex global challenges in a quest to come up with innovative solutions that transcend disciplinary boundaries, has assumed status as both a multifaceted and *scientific endeavor* (see Das et al., 2024). Thus, it is imperative that it (ESD) is also understood through the lens of SPS. However, we also argue that the weakness here is the lists of SPS (**Table 2**) for mediating learning and assessment have been developed as distinct processes are, within scientific inquiry, far more situated, emergent and intermeshed. Bhaskar (1998) provides an RRREI(c) schematic model of applied scientific inquiry in a social learning context. This can be useful for mediating some of the key relational dynamics within learning through scientific inquiry in curriculum settings as shown in **Figure 2**. We selected RRREI(c) over the basic CR DREI(c) processual tenets for scientific inquiry, as it has the extra step necessary for resolving complex phenomenon into components for explanatory redescription with retrodictive[2] analysis that then carries forward into verification and correction. **Figure 2** further brings together African heritage knowledge and the disciplinary concepts of the natural sciences.

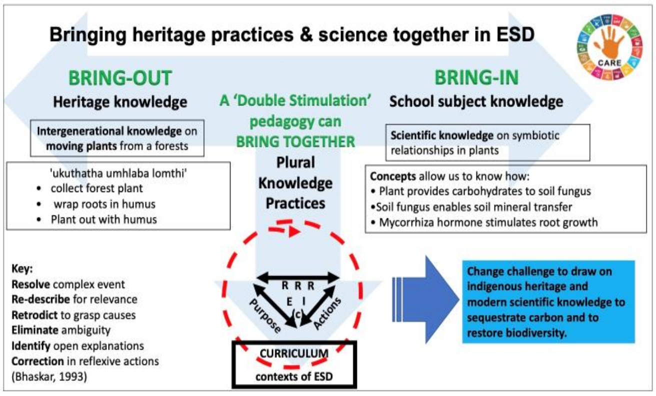

Figure 2. Merging heritage practices, ESD, and scientific inquiry (Source: Authors' own elaboration)

We found that the RRREI(c) schema was useful for making SPS explicit as shown in **Figure 3**. In the planning, mediating and assessment of this learning progression, we realized that we could map SPS onto a learning task sequence. For instance, accessing/recalling information and the identification of ambiguity for resolution concerning a purposeful inquiry activates a conglomerate of other SPS that are associated with making observations/comparisons, raising questions,

[2] Bhaskar points to how retrodiction involves the use of a hypothesis for identifying causal events, whereas reproduction involves a process of looking back to identify generative mechanisms. This distinction is particularly relevant for identifying omissions or earlier blind spots that have produced risk that Bhaskar referred to as a process of 'absenting absences' in Dialectical CR.

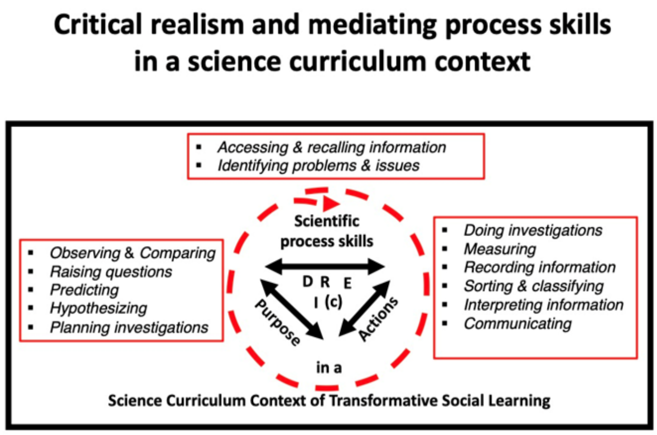

Figure 3. How CR mediates SPS stipulated in the South African science curriculum (Source: Authors' own elaboration)

making predictions and/or formulating hypotheses in a planned investigation.

It should also be noted that the enacting of this purpose can further involve SPS that include an investigation with measurement, the gathering of information, sorting and classifying towards interpreting information and communicating outcomes for the realization of a shared purpose in actions so as to approach the resolution of some of the risks associated with climate change through tree planting for increased carbon sequestration. Worked in this way, the SPS specified in the curriculum can be inscribed within an environment and sustainability program in the natural sciences as part of a process of problem-based learning. Not only does CR allow us to make the SPS specific in a curriculum process but the mapping process also challenges us to make ESD process skills explicit and open to inclusion in formal assessment processes. This insight came in *fundisa for change* work with teachers who were struggling to work with the learning outcomes (competences) specified in the curriculum and the ESD competences identified by Wiek et al. (2012).

Figure 4 is a graphic summary of how the inclusion of ESD competences were mapped out in relation to a learning progression in the natural sciences. The weakness here is that, although question 2 and question 3 were focused on skills development, the significant SPS were not explicitly stated.

Nevertheless, in this case, we approached a problem-based learning progression in the sciences as a four-quadrant progression from identifying the problem that needed to be understood, to conducting research to generate data to inform the question at hand. This was followed by deliberate analysis of data towards clarifying what could be done to resolve the risk. Working with a number of concerns related to biodiversity loss, pollution and planning for climate change-induced drought, it was useful to note how the mediating of critical thinking, systems thinking with

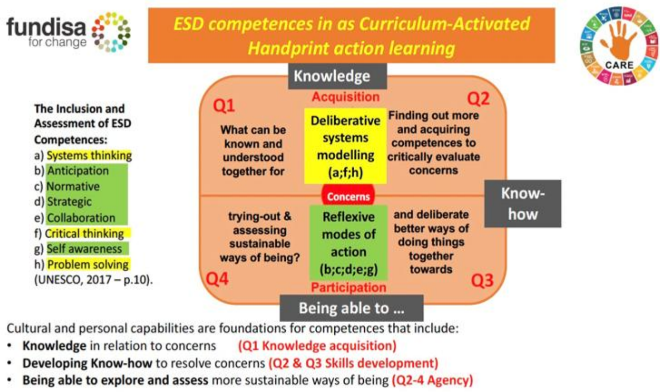

Figure 4. ESD competences within the context of *fundisa for change* teacher training (Source: Authors' own elaboration)

available evidence and the hypothesizing of possible ways to resolve the problem at hand needed work with the knowledge necessary for informing research or investigative work. As the research work was enacted then the teachers were able to support and assess the development of process skills that developed anticipation, the framing of new norms alongside strategic and collaborative skills with the requisite self-awareness for working towards the resolution of a concern. This has two characteristics that are invaluable for informing key dimensions of the scientific inquiry necessary to derive informative insights as new environmental knowledge to inform transformative learning towards more just and sustainable futures together.

CONCLUSION

In contrast to church/state institutions, Harari (2024) notes how scientific institutions:

> gained authority because it had strong self-correcting mechanisms (enabled by SPS) that exposed and rectified the errors of the institution itself. It was these self-correcting mechanisms (and associated competencies), not the technology of printing that were the engine of the scientific revolution. (p. 103; our brackets)

The review suggests that the enactment of SPS in curriculum settings must amplify them (SPS) and associated competences in ways that enable students to engage the sustainability concerns of the times in ways that the curriculum plays out as self-correcting mechanisms of transformative learning.

The reframing of the current somewhat narrow SPS and competences will have to be undertaken in ways that the sciences re-emerge as sites of transformative learning that enable our learners to develop the networking them (SPS) and competences to be part of the change to more just and sustainable futures.

Most importantly, we have provided a commentary on the practical application of the critical realist paradigm in a project addressing CCE in education policy, guidelines and materials. The review not only highlights the possible value of SPS but also emphasizes the development of critical competences essential for interdisciplinary research and ESD. It provides a practical case study through the lens of CR, showcasing the integration of SPS, competences, and ESD principles into the paradigm for possible enhancement of its accessibility and application, further empowering researchers to tackle complex global challenges effectively.

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