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Towards a Radical Constructivist Understanding of Science

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Abstract. Constructivism is the idea that we construct our own world rather than it being determined by an outside reality. Its most consistent form, Radical Constructivism (RC), claims that we cannot transcend our experiences. Thus it doesn't make sense to say that our constructions gradually approach the structure of an external reality. The mind is necessarily an epistemological solipsist, in contrast to being an ontological solipsist who maintains that this is all there is, namely a single mind within which the only world exists. RC recognizes the impossibility of the claim that the world does not exist. Yet, RC has the potential to go much further. I claim that RC provides the foundation of a new world-view in which we can overcome hard scientific problems. Thus, the paper is urging us to carry RC further, not just on philosophical grounds, but also into the domain of science.

Keywords. Epistemology, instrumentalism, scientific realism, truth, solipsism.

Introduction

Radical Constructivism (RC) is the insight that we cannot transcend the horizon of our experiences. Experiences are all we can work with; out of experiences we construct our world. Thus, there are no mind-independent entities on which our cognition is based. This does not imply that Radical Constructivists deny the existence of such an objective world populated by mind-independent entities, the reality. Neither do they assert its existence. RC is agnostic. Clinging to an external reality would make us acolytes in a cult of claiming something which we can never know, and which—this is the constructive aspect of RC—we also don't even need in order to explain cognition and what we commonly refer to as 'the world'. The present issue sheds more light on the consequences of this, what is for many people still an unusual and—understandably—hard to accept insight. In the 'traditional Cartesian world-view', we see ourselves as entities among other entities in a reality that is independent of us. We are separated from that reality by the classical subject–object dichotomy. Here the I, on the other side the Everything-else, to which the I makes reference. White snow is white because it *is* white, as Tarski's (1944) Semantic Theory of Truth claims. What the new world-view, RC, says is the following. Although we can at anytime *assume* perception and experience in general to be the result of the impact of the reality on the I, we cannot prove this in *any* way. We are '*epistemological* solipsists' rather than God-like creatures equipped with the omnipotence to recognize reality—cf. Putnam's (1990) "God's Eye point of view": "Realism is an impossible attempt to view the world from Nowhere" (p28). Nor are we *ontological* solipsists who want to negate something (or claim its non-existence) which cannot be proven anyway[1].

So simple this insight may seem, yet so difficult it is to find acceptance. It is therefore not surprising that much of the ongoing discussion in and at the periphery of RC is still concerned with the basics of RC—defending itself against attacks from the realists' camp who accuse RC of being solipsist—instead of being devoted to developing RC further. Book titles like "How real is real?" (Watzlawick 1976) seem to suggest that RC would be concerned with questions of ontology, i.e., with the existence (or non-existence) of reality. But it is exactly this epistemological question which is strictly speaking not part of the RC discourse. It is faintly reminiscent of 'Kant's Scandal' according to which it is a scandal that philosophy hasn't been able to falsify idealists' claims, and Heidegger's response that the true scandal is that philosophy has never given up attempting to find such a falsification. As Searle (1999) rightly comments, "the biggest single obstacle to progress of a systematic theoretical kind has been the obsession with epistemology". Asking What is knowledge?, is meaningless and does not lead anywhere. What *plays* an important role is the question: How do we gain knowledge? As a consequence, RC is interested in investigating the mechanisms of knowledge construction. Therefore, RC has the constructive opportunity to transform from a purely philosophical-argumentative framework into a scaffolding for science.

In order to explore the dimensions of its impact on science, I will first provide a short sketch of the surprisingly long history of RC which shows that it is more than just a temporary fashion. Along its historical evolution, RC has developed a variety of interpretations amongst authors. We are therefore challenged to extract the main principles which lie at the bottom across all variants. Equipped with the basic claims of RC, we will again pick up the question to what degree RC and realism opponents and whether this schism can be bridged. Furthermore, I will investigate how science and scientific activity can be understood from a RC point of view, and what the main differences with scientific realism are. An overview of the contributions to the present issue follows. Finally, the conclusions summarize the main arguments and implications, and point at the fact that with RC science has the opportunity to expand in new realms.

An Abridged History of Radical Constructivism

The notion "radical constructivism" was originally coined by Ernst von Glasersfeld in the early 1970s. However, modern RC is a condensate which brings together key ideas of historical thinkers, and merges them with contemporary findings[2]. Glasersfeld traces the history of RC many centuries

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1 The constructivism propagated here is to be distinguished from the *social* constructivism movement, e.g., Knorr-Cetina (1981), Latour (1987). The latter claims that (scientific) knowledge does not arise within cognizing individuals or within nature but is *socially* constituted.

2 See http://www.univie.ac.at/constructivism/ for a collection of papers and other RC-related material that is available on the world wide web.

back, even back to the Greek sceptics. While the sceptics clearly recognized one of the basic tenets of RC—namely that there is no proof for an external reality—they failed to provide any constructive solution to this sudden lack of an ‘anchor’. Many authors of previous centuries can be considered precursors of RC as long as their statements are interpreted in a non-ontological manner. George Berkeley’s “esse est percipi” (to be is to be perceived) read in a realist context of course doesn’t make sense. Also Giambatista Vico, whose dictum “verum ipsum factum” (the truth is the same as the made) already points in the direction of knowledge construction, belongs to the long term history of forerunners to RC, as well as Hans Vaihinger, whose “philosophy of the as-if” bears remarkable similarity to other constructivist features (for more details see Glasersfeld 1995). Putting emphasis on the construction of knowledge in infants, Piaget contributes to the history from a psychological point of view (see e.g., Piaget 1954).

In the strict sense, however, the history of modern radical constructivism starts in the 20th century. Apart from its philosophical roots, RC also has cybernetic ones which are closely linked to Heinz von Foerster and what is called *second order cybernetics*. While traditionally, cybernetics is the science of communication and control in animal and machine, its second order version focuses on self-referential systems (the “observation of observing systems”) and the importance of *eigenbehaviors* for the explanation of complex phenomena. The term refers to the behavior through which a system asserts its autonomy from other systems. Eventually, this idea would give rise to the concept of ‘operational closure’: any cognitive system is semantically independent (and impenetrable). From the late 50s to the mid 70s, Foerster had been running a lab, the Biological Computer Laboratory (BCL), at the University of Illinois at Urbana-Champaign which was a wellspring of people thinking along similar lines (for an overview see Müller 2000). Among others, prominent members of the BCL were

- Humberto Maturana and Francisco Varela who, as the founders of the theory of autopoiesis, focus on the central role of the observer. Autopoiesis is the process whereby a system constitutes and maintains its own organization—see also Ziemke’s contribution in this issue.
- Gordon Pask who developed a conversation theory—see the contribution by Scott.

In German-speaking countries, an avalanche was triggered in the late 80s by translations of major works by the above authors, plus original contributions in German by Siegfried J. Schmidt, Hans-Rudi Fischer, Gerhard Roth, Gebhard Rusch, and others (e.g., Schmidt 1987).

What are the challenges of RC which attract so many scientific writers and readers; what can we find behind the stir RC created? The rather long history of RC suggests that it is an interdisciplinary melting pot of critical thoughts that have been congregated as principles under its label. In the next section we will look closer at these fundamentals.

Basic Claims of Radical Constructivism

As the previous section has shown, a variety of authors have left their fingerprints, making RC a somewhat heterogeneous field, but what lies at its core is the following.

The **Radical Constructivist Postulate** says that the cognitive system (mind) is operationally closed. It interacts necessarily only with its own states. The nervous system is “a closed network of interacting neurons such that any change in the state of relative activity of a collection of neurons leads to a change in the state of relative activity of other or the same collection of neurons" (Winograd & Flores 1986, p. 42). This is a consequence of the neurophysiological *principle of undifferentiated encoding*, as already formulated by Johannes Müller in the 19th century. "The response of a nerve cell does not encode the physical nature of the agents that caused its response." (Foerster 1973/1981, p. 293). Maturana (1978) suggests that we can compare the situation of the mind with a pilot using instruments to fly the plane. All he does is "manipulate certain internal relations of the plane in order to obtain a particular sequence of reading in a set of instruments" (p. 42). In other words, the pilot doesn't even need to look 'outside'.

Since the mind is operationally closed, i.e., semantically impenetrable, we cannot know any 'external semantics'; thus we arrive at the **Epistemological Corollary**: Reality is neither rejected nor confirmed, it must be considered irrelevant[3]. Any explanation within the RC framework forgoes recourses to a mind-independent reality. As mentioned above, it is this postulate which draws a sharp distinction between RC and solipsism which explicitly objects to reality on grounds which are as obscure as any grounds to assert reality.

As an immediate result, any correspondence theory of representation is rendered impossible (Peschl & Riegler 1999). In neurophysiology, it is useless to search for neuron clusters whose activations correlate with external events in a stable referential manner. Understanding representation from the perspective of constructivism gives us a clue as to what we have to look for in the representational substratum; namely, mechanisms which allow the generation of adequate behavior. Traditionally these mechanisms have been thought of in terms of manipulations of referential representations. However, there is neither neuroscientific nor epistemological evidence in favor of such a view. As the representational structure is the result of a system-relative construction process, it is no wonder that we are experiencing difficulties identifying (traditional referential) representations in natural and artificial neural systems. It seems that it is simply the wrong thing to search for. Likewise, it is useless to implement agents in artificial intelligence or artificial life with an *a priori* defined set of concepts, and to claim they were 'intelligent'. This is what I call the *PacMan Syndrome* (Riegler 1997). Artificial agents interact with anthropomorphically defined entities, such as "food" and "enemy", which make sense only to the programmer of the system[4]. No attention is paid to questions like: How have organisms arrived at

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[3] However, this does not say that our constructions are arbitrary. See the "Limitations of Construction Postulate" below.

[4] Let us not forget that the word 'fact' derives from Latin 'facere' = 'to make'. In this regard, the aforementioned motto "verum ipsum factum" of Vico gains distinctness. An agent, natural or artificial, has to be the artificer of the concepts used. While we—as designer of artificial life models— would like, let's say, the upper left pixel on the computer screen to be a food pill for the pixel in the lower right corner representing the cognitive creature, this is not necessarily the case from the perspective of the creature and its cognitive apparatus. Likewise, the relevance for RC-based education becomes evident. The teacher cannot expect the student knowing facts in the same way as she does; a fact has to be 'made', i.e., constructed from components of the existing conceptual network. Finally, Paul Watzlawick (1990) applies this insight to family therapy. While a realism-based therapy would want the patient to adapt to the true matter of affairs, his approach focuses on a viable consensus among all participants. This consensus has to be constructed by the patients (by 'reframing' a habitual situation) rather than specified *a priori*.

the idea that something is a source of food? How do they ‘know’ that another creature is a dangerous opponent? Predators do not have signs on their backs saying “I’m your enemy”. Even if this were the case—how would cognitive beings have learned to understand the meaning of those labels? The RC view offers the opportunity to investigate the phylogenetic and ontogenetic emergence of system-relative representations, i.e., “meanings” for the cognitive systems.

Such insights also have impacts on communication and language. (a) Meaning is a human construct. It does not reside somewhere else and is not independent of the person who makes it. (b) Meaning cannot be transmitted as an entity. It is not in the words, gestures, symbols with which we express ourselves. Language therefore, must be seen as a behavioral system which triggers orienting actions within the cognitive domain of the interlocutor. Thus language is an ongoing process of interpretation and mutual adaptation. As Glasersfeld (1991b, p. 25) puts it, “[t]o find a fit simply means *not* to notice any discrepancies”. This is in contrast to *matching* something against something else; there are no ways to validate a ‘correct match’. For Glasersfeld, the main characteristic of a cognitive system is to stay *viable* in the above sense of fitting, of displaying adequate behavior.

The operational closure results also in a **Methodological Corollary**: Explanations are necessarily circular since there is no outside point of reference[5]. Experience is thus a form of self-reference[6]. “Cognition serves the subject’s organization of the experimental world, not the discovery of an objective reality”, as Glasersfeld (1988, p. 83) points out. The radical constructivist world-view is only then consistent *iff* it gives rise to the world which generates it. In contrast to *trivial* constructivism, RC does not propose that differently constructed world-views gradually converge towards a knowledge system which represents the world: “those who merely speak of the construction of knowledge, but do not explicitly give up the notion that our conceptual constructions can or should in some way represent an independent, ‘objective’ reality, are still caught up in the traditional theory of knowledge” (Glasersfeld 1991b, p. 16). Thus, RC is necessarily complete, i.e., *radical*, with its claim to uncompromisingly apply the idea of constructions on all levels[7]. While the inescapable self-referential circularity of knowledge is a threat to realist world-views, it is a logical consequence within RC. It requires scientific disciplines to acknowledge their own roots, and thus be open to critical re-examinations and proper integration of new insights.

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5 This is to be contrasted to formal logical systems in which a set of axioms is introduced *a priori*, and which serve as a truth criterion. Postulated statements are *logically* true if they can be derived from the axioms.

6 This does not mean that RC is in favor of tautologies. Rather, the conceptual network in the mind is considered to be without a ‘beginning’ or ‘ending’ since its relational structure has developed with a bootstrapping process that allows only self-referential links. In the absence of external references other criteria for checking the validity of proposed theories must be pulled up. Such yardsticks are consistency, coherence, and richness of referential concepts involved. Tautologies are thus to be rejected on grounds of these criteria.

7 The adjective ‘radical’ (lat. *radix* = root) is used in the sense of ‘thoroughly consistent’ (rather than ‘extreme’). In this sense, RC is also different from other constructivist movements in science such as the ‘Erlangen Constructivism’ (Janich 1993) which wants to avoid the RC-typical circularity. It tries to explain science from the perspective of unconditional linguistic constructions. Its proponents maintain that science can be reduced to a ‘proto-science’ which, in turn, is defined in terms of a pre-scientific common-sense vocabulary. However, such an argumentation not only drives an (unjustified) wedge between scientific and common-sense reasoning, it also cannot account for the construction of common-sense knowledge.

Finally I want to point at an important issue which I call the **Limitations of Construction Postulate**. One of the most frequent arguments against constructivism consists of a mere question such as "Surely, you still believe that when the door is closed you cannot walk through it don't you?". It seems that an adverb inevitably sneaks in: Constructing our own world is equated with *arbitrarily* constructing our own world. However, RC is far from confusing both versions. Experiences are made subsequently. As such, they are connected with each other in a historical manner and form a network of hierarchical interdependencies (Riegler 2001). The components of such a network are therefore mutually dependent; removing one component may change the context of another component. In this sense they impose constraints on each other. Let us compare the situation with a traffic network consisting of different means of transportation. By car, you can reach only those points which are connected to the road network. By foot, all the points (such as mountain peaks) in between can be accessed, but only if they are within walking distance. The basic component in both cases is the means of transportation which restricts the availability of reachable destinations. Free arbitrariness is not possible since different means of transportation have different degrees of flexibility and speeds. Similarly, the construction network of the mind is also necessarily non-arbitrary. It follows the canalizations which result from the mutual interdependencies among experiences. Once a certain path is taken relating experiences to each other in a particular manner, the mind uses previous constructions as building-blocks for further constructions. The expectation that the mind is free to construct whatever it wants is as illusionary as the idea that natural evolution could bring forth pigs with wings. Although we can have fantasies about such a hybrid being, physiological constraints within the animal would result in a lethal mutant (Riedl 1977)[8]. Likewise, the idea of a door, the mental construct, and the experience of bumping into something one has decided fits the mental construct are constructs which are mutually dependent. On a meta-level, we can reflect on the components of the compound constructions and do *as if* we could deal with each component separately, or change the features of isolated entities *as if* those features would not depend on other elements. However, there are cases in which we can deliberately change constructions to different degrees. Our capacity to solve problems is restricted by factors that are commonly referred to as the 'set-effect' in cognitive psychology, a mental 'laziness' which prevents us from looking for alternative solutions once a workable solution has been found (Duncker 1935/1945, Luchins 1942). Such constructions can be revised rather easily. Already more difficult are problems related to human relations. Such problems have a longer history and thus involve more dependent factors. Watzlawick's family therapy (1990, see also footnote 4) aims at finding alternative constructions (reframing) which *can* make the previously existing problem disappear. From constructs with an even longer history and/or bigger number of mutually dependent components we can expect even more insuperable obstacles in somebody's attempt to change them, such as our idea of doors and bumping into them. Usually we hold an outside reality responsible in such cases.

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[8] Note that such a mutant is lethal not because of environmental selection—again, we could imagine that pigs with wings have an edge over normal pigs—, but because of interferences among physiological structures during early developmental stages (i.e., the *epigenesis*) of the animal.

However, the different degrees of changeability of constructs suggest that we find the reasons rather in the constructs and their mutual relations.

While RC is consistent and well thought through, people (and among them, scientists) have sometimes problems committing themselves to RC and its consequences. In the following I will further investigate this apparent gap.

Constructivism vs. Realism?

From a common-sense perspective there seem to be good reasons for opposing the RC view. Appealing to reality as the ultimate arbiter of (scientific) disputes gives rise to the belief that there exists a mind-independent reality (MIR) which defines what is true and what is not. What is the sense of clinging to such a concept which is the metaphysical extrapolation of our experiences (or observations)? Clearly, many psychological and social reasons can be put forward to account for this way of reasoning, among which we can find: (R1) Claiming authority by referring to an external truth makes one's own point of view unassailable (Mitterer 1994). (R2) Justifying research expenses, as the true description of reality "…is what we are working for and what we spend the taxpayers' money for" (Weinberg 1998). (R3) In more general terms, claims of objectivity are for the purpose of forcing others to do what they would not otherwise do themselves (Maturana 1988). (R4) Finally, realism is equated with seriousness and rationality. As Searle (1995) puts it, maintaining 'external realism' is a "first step in combatting irrationality" (p. 197). However important such pressure from outside science is, no *logical* reason could seriously challenge the strict sceptical foundation of RC. Quite on the contrary, it seems that the belief in MIR is the *un*scientific alternative. Here, the ultimate reason for any phenomenon is reality, the metaphysical transcending of the realm of our experiences. If data doesn't fit the theory realists claim an almighty reality responsible. This resembles religious argumentations in which inconsistencies or unexplainable phenomena are due to an ultimate divine instance far beyond human accessibility. René Descartes could escape the consequences of his fundamental scepticism only by referring to the ultimate instance of God, since the "faculty of knowledge which God has given us can never disclose to us any object which is not true" (quoted after Osler 1970). In times before modern science started to become a dominant factor, people believed in God as the source and engine of all phenomena. "Then faith shifted from God to science and the world that science was mapping was called 'Nature' and believed to be ultimately understandable and controllable" (Glasersfeld 1991a, p. 237). Paradoxically, realism-based science sets out to uncover this real Nature. We have to wonder whether this is not a major yet unavoidable foundational flaw. The description of so-called *scientific realism* (SR) reads as follows: "Science aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true." (Van Fraassen 1980, p. 8). Metaphysically, this means to claim the existence of MIR with a definite structure. Epistemologically, SR maintains that we can gain knowledge about that world and that the aim of science is to comprehend its structure. It is the "success" of science which is held up as evidence of the validity of SR by its advocates. Their "miracle"-argument says that the evident success of science would be a miracle if things wouldn't exist ontologically. Such an argument is logically inconclusive. Furthermore the claimed "comprehensiveness" of reality would require us to find a correspondence between the real entity and its representation in the mind of the scientist. But as Franklin (1995) tersely says, "things don't come labelled". There is no label attached to the object I recognize as tree which would say that it is a tree.[9] Foerster (1973/1981) reminds us to strictly separate *confirmation* (realism) from *correlation* (RC): "My sensation of touch is *confirmation* for my visual sensation that here is a table… My sensation of touch in *correlation* with my visual sensation generate an experience which I may describe by 'here is a table'" (p. 295). The table itself, the Kantian *Ding an sich*, in no way says that it is a table. It is our experience which makes us construct the concept of 'table' out of ongoing interactions of various modalities over a longer period of time (e.g., Piaget 1954; see also the Limitations of Construction Postulate above). Therefore, not the question "What is knowledge?" but "How is knowledge generated?" ought to be the subject of investigations. RC, stressing the mind-dependency, and SR, clinging to the idea of ontological objectivity, are incommensurate—at least on this level. Foerster (quoted from Glasersfeld 1995) summarizes the crucial point in a single statement, "Objectivity is the delusion that observations could be made without an observer".

The gap between realism and constructivism seems to be unbridgeable. Defining science as an instrumentalist enterprise in which we attempt to find regularities among our experiences in order to arrive at useful predictions, is hardly acceptable for a realist. It is just as difficult to imagine finding a solution to this schism on philosophical grounds since the conception of RC appears to be so hard to accept. Nevertheless, I don't think that this is necessary. There appear to be at least two solutions.

Recalling Bohr's *complementarity principle*, the rupture can be cemented. The principle says, "Any new theory should reduce to the old theory for those cases in which the old theory is known to hold" (Umpleby 1990). And indeed, as Maturana (1988) convincingly shows, we embed our common-sense understanding of reality—or 'objectivity–without–parenthesis' in Maturana's terms—within a constructivist framework—the 'objectivity–in–parenthesis'. In our daily lives, we work with a realist concept of the world around us. For an understanding of simple mechanical phenomena neither relativity theory nor RC is necessary. In such cases the—for us still—unusual context of constructivist concepts is more of an obstacle than a help. But when it comes to explaining cognitive or quantum phenomena, for instance, we leave the familiar domain of the simplifying Cartesian world, and we have to take the observer into the theory.

The second solution to bridging the apparent gap between realism being so strongly anchored in our thinking and RC is to transcend purely philosophical discourses. RC has to prove its usefulness with working applications. Following Pagels' imperative (1988)—which he accidentally called 'strict constructivism'—"You have got to design and build, not just talk about your philosophical fantasies" is more than a sagacious recommendation. Glasersfeld, one of the main proponents of RC, does not hesitate to agree to Pagels' imperative when he says, "Ultimately, of course, a way of thinking must not only be claimed feasible but, in order to become attractive, its advantage be shown in action" (1991b, p. 12). His primary target is early education, a domain in which the consequences of epistemological solipsism become very clear (Glasersfeld 1995): The pupil as well as the teacher are mutually closed systems with regard to their experience. Both sides

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9 See arguments against the correspondence principle in the previous section.

have established their own world, but now the teacher wants to enrich the world of the pupil. No direct transfer of new ideas is possible, no royal road to learning is available. Instead the whole problem of interpersonal communication becomes evident. Scott's paper in this issue is devoted to aspects of this problem.

After having outlined the relationship between RC and SR in detail, we will take a closer look at the link between RC and scientific practice in the next section.

Radical Constructivism and Science

One of the goals of science is to *explain* phenomena. Another is to make *predictions*. Usually, instrumentalists abandon the idea of being able to explain and focus on predictions instead. At its core, an explanation is the attempt to set the explicandum in relation (e.g., scientifically by employing the covering-law thesis) to another phenomenon which in turn is related to yet another phenomenon etc.… ad infinitum? Ad reality? Or to what Latour (1987) labels 'black boxes': successful experiments, procedures, devices etc. which are taken for granted and treated as an unquestionable fact? Naturally, there is no need to look inside the black box again as it is thought to be the safe rock, the reality upon which the scientific building is erected. Be it because we get tired of stepping increasingly deeper into the explanatory circle—like the curious child who stops asking question after question because it becomes increasingly difficult to receive further answers—, or be it that we are afraid of asking further as this may reveal inconsistencies within our own world-view. In any case, equating black boxed explanations with reality is but the motor that keeps spinning off scientific revolutions. Differently made-up black boxes are incompatible with each other, even though they might focus on a similar class of phenomena.

Clearly, both facets—prediction and explanation—make use of cognitive capabilities. We can safely say that the cognitive mechanisms underneath common-sense reasoning and science are the same. Both are brought forth by a mind. However, science must be considered as the *systematic investigation* of experienced phenomena subject to further processing. These investigations are based on the idea of reproducibility in order to eliminate fraudulent subjective "It happens just to me"-claims.[10] This means to expose one's ideas to rigorous examinations through others and their potential refutation. A second means to avoid fraud is explicitness when quoting other scientists, or observers in general. None of these mechanisms of science is sufficient in its own.[11]

In scientific textbooks, however, the aspect of explicit citations seems to fall short. History of science is smoothed out by re-writing it.[12] Textbooks provide students with the impression that

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[10] Evidently, this makes it difficult to understand subjectivity as a cognitive phenomenon when the only way to investigate certain phenomena is introspection. From this perspective the claim seems to be justified to say that not all our experiences can be tackled by science. See also Peschl's paper.

[11] For postmodernist authors, for example, to whom 'text' is everything, explicitly quoting others seems to be enough rigor. See the 'Sokal affair' (Sokal 1996) as a demonstration.

[12] Already Thomas Kuhn (1962) claimed that it is not desirable to teach future scientists accurate history. As Martin Klein (1972) points out, philosophers and historians of science on the one hand and science teachers on the other hand don't have necessarily common purposes. However, leaving out all history doesn't solve the problem either since an ahistorical perspective even reinforces the impression of a mind independent existence of natural laws.

natural laws exist (ontologically) as described, rather than pointing out that these are statements/findings of a certain person[13], acclaimed by the scientific community. This is a psychological trick, of course, to win the competition among other world-views which claim to be the correct one. The more students learn perspective A the more likely they will, as later scientists, consider A true. I think we have to look at this from a historical point of view. Science, after all, has helped us to get rid of many forms of superstition and literal beliefs in legends and myths.[14] Without doubts, by insisting on rigor when observing phenomena, science lets us arrive at more reliable results with a wider range of applicability. Reliable in the sense that we have encountered less exceptions to rules and laws proposed by science than to rules established by different world-views. Living organisms are *conservative* systems[15], they seek confidence in phenomena which are repeated rather than getting cognitively overloaded in chaotic environments. From this perspective, we can unroll the objective of the aforementioned 'competition' among different world-views as a competition in order to establish confidence rather than to get closer to an objective truth. Traditionally, the search for viable solutions has been equated with *instrumentalism*—and indeed several RC authors write in this line.

Instrumentalism holds that theories are just tools or calculation devices for useful predictions rather than representations of an external reality. But I think there is more to it as the instrumentalist conception cannot account for why science has always been considered to be looking for the absolute truth while at the same time blessed us a greater degree of confidence in established natural laws and insights than other *anschauungen*. Let's look at an example. Early encyclopedias such as 'Natural History' by Plinius the Elder in the first century AD didn't manage to distinguish between fact and legend (de Camp 1974). For Plinius the story that elephants could be taught to write appeared plausible because he was not exposed to what is commonly referred to as the scientific method. Modern science sets out to eliminate such views by providing a rigorous procedure, the scientific method. It rests basically on the idea of reproducibility (i.e., try to teach elephants writing) and being explicit when referring to other authors. In his contribution, de Zeeuw argues that observation has to get 'detached' in order to eliminate prejudices, social influences, etc. But the price to pay for weeding out other, potentially more attractive—because easier to obtain—ways of gaining knowledge was to claim that the scientific method indeed reveals reality. Science became the only legitimate form of knowledge. It is a matter of *claiming* to be superior compared to others if you want to win acceptance in a world of arbitrariness. One had to ascribe to such a strong claim mainly due to sociological factors. The 'uninformed' audience is not an ideal, neutrally biased

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[13] Maturana reminds us that "everything said is said by an observer to another observer that could be him- or herself." (Maturana 1988, p. 27).

[14] This is not to say that the scientific world-view is 'more true' than others. To claim that something is more true than something else means to neglect a basic principles of RC, namely the self-applicability of its findings. As Glasersfeld (1991a, p.13) puts it, "I would be contradicting one of the basic principles of my own theory if I were to claim that the constructivist approach proved a true description of an objective state of affairs… [I]ts values will depend mainly on its usefulness in our experimental world".

[15] "A living system, due to its circular organization, is an inductive system and functions always in a predictive manner; what occurred once will occur again. Its organization (both genetic and otherwise) is conservative and repeats only that which works." (Maturana and Varela 1980, p. 26–27)

audience without any other need and biasing factors they are exposed to. Especially in former days, the life of people was situated in a much less free society and depended on very down-to-earth issues which wouldn't forgive mistakes. Hence we owe much to science as it enabled better organized investigations into the world of experienced phenomena—even though it has been a realist enterprise. However, the time may now be ripe to climb up the ladder into a new, RC-based era of science, as the contributions in the present issue suggest.

The Contributions

RC has already gained great influence in literature, media and educational science. However, there is little (if any) attention paid to RC in other disciplines. The contributors to these two issues on "The Impact of Radical Constructivism on Science" set out to provide arguments for the usefulness of RC in other domains. These arguments may be related to already existing applications of constructivist ideas, may give reasons to import these ideas to currently realist-dominated branches of sciences, or may point out the success of RC in 'traditional' areas. The goal is to increase the acceptance and plausibility of constructivism outside its 'classical' domains. Therefore, typical questions addressed may encompass: What is the impact of RC on science? What has RC changed so far in scientific disciplines?

Having a constructivist background certainly changes the way of thinking (for a sceptical thought on this see Schwegler's contribution). This also applies to scientists and the way science is carried out. In literature, e.g., there once was a dominant view that focussed on the communication signal itself rather than on the reader. Thus, transformations of meanings were differently explained than within a constructivist framework (Spivey 1997). In physics, to mention another example, the concept of science, its goals, and functioning are mostly non-constructivist. Despite results from research in quantum physics, which urges us to give up the objectivist perspective, physicists are (still[16]) indoctrinated to believe that they are generating an ever more accurate picture of physical reality. Many base their whole sense of profession and self on the notion that they are generating absolute truth (e.g., Weinberg 1998; for a popular overview see Horgan 1996). For them, if physics is not that, then why bother? Getting to the 'truth' is the whole reason why they went into physics. To question the notion of knowing 'truth' is for them a direct attack on their self-understanding. So what would change if physics became a constructivist-biased discipline? It could give an answer to Penrose's (1986) remark that although quantum mechanics exhibits "marvellous agreements… with every experimental result" and is of "astonishing and profound mathematical beauty", it "makes absolutely no sense" (p. 129)—apparently when trying to link it to a common-sense conception of reality.

Or, on a more general level we can continue to ask: How could RC be applied in all domains of human scientific activity? Or are there reasons to exclude RC as a methodology and background epistemology in some disciplines? Since some disciplines seem to contain a higher dose of constructivism than others, we have to provide a representative overview and ask: What is the

[16] Already in 1957, Max Jammer demanded: "As a result of modern research in physics, the ambition and hope […] that physical science could offer a photographic picture and true image of reality had to be abandoned." (p. 2)

(detailed) picture of the current situation in various disciplines? By comparing the application in different branches of science we might finally get answers to the question of how to carry RC to those domains in which RC is still neglected.

Yet another issue is that many scientists who have heard of RC and postmodernist tendencies lump them together and see them as a very serious threat to their profession. Searle's (1995) call for realism as a first step in combatting irrationalism expresses this very clearly. In response, the reply of RC is also clear. As a discipline that is centered on the processes of how knowledge is generated, it lends itself naturally to the purpose and goals of scientific activity. There is nothing from RC that would lead us to question the fit of current theory to experience. RC suggests that scientists re-examine scientific activity and their ideas about the nature of theory. For example, the theory of Autopoiesis (Maturana and Varela 1980) does not involve any fundamentally new biology. The authors were reinterpreting existing biology and so arrived at new insights without appealing to 'esoteric' knowledge. In this sense, RC sets out to find a better understanding of scientific activity in order to increase its efficiency. Of course, such a claim can only be cashed in by bringing forth convincing arguments in favor of the usability of RC in order to distinguish it from postmodernist 'cargo cult science' (Feynman 1985).

To sum up, the goal of this special issue is to come up with an overview of the rela tionship between RC as an epistemology/methodology and various scientific disciplines as target domains. This implies both examples where RC has already been successfully merged with disciplines and strategies of how to proceed in those domains which still neglect RC or even oppose it.

Science consists of many facets, many areas of investigations. Naturally, the contributions to this special issue focus on various disciplines. In the beginning, three articles are concerned with the paradigm of RC itself. They investigate the content of the RC-movement from the perspectives of philosophy of science and pay also heed to sociological aspects.

Ernst von Glasersfeld starts with a general exposition of RC. Quoting Einstein who once said that all science is the enterprise of coordinating and arranging our experiences, Glasersfeld points out that all scientific rationality can work with experiences. There is no 'going beyond'. There is no fanciful retreat into the realm of objectivity possible. Likewise, a 'phenomenon' does not connote a mind-independent entity. Instead, it refers to an isolated part of the experience. A possible objection goes, experience is a common feature of common-sense and scientific reasoning. What makes science so unique is, among others, exact measurement and quantifying, which does not allow for 'subjective interpretation'. But again, to measure means to compare two phenomena with each other, one of which already assigned with a dimension. Assigning a scale or units to a phenomenon means to compare it with yet another one, etc. Therefore, the act of quantifying does not save the realists' argument either. By introducing the notion of 'functional fit', von Glasersfeld clearly defines what it means to 'know' in a RC context. It is to possess ways and means of acting and thinking that allow one to attain one's own goals, rather than to posses a true representation of 'reality'.

Ranulph Glanville's contribution is concerned with the possible reconciling RC and realism. He urges us to distinguish between the 'as is' and the 'as if' of our experiences. Being all our life encouraged to belief in the mind-independent existence of things, we tend to confuse 'as is' and 'as if'. Glanville also makes it clear that our understanding of the world depends on how well we understand the processes which enable us to understand. See also the paper of Schwegler.

Also the paper of **Gerard de Zeeuw** tries to bridge the gap between RC and SR. He outlines a solution of how to resolve the dilemma that the justification of RC is obvious from its own perspective but not from the position of SR, and vice versa. The solution can be found in clarifying the historical development of observation and knowledge. De Zeeuw identifies two methods to combine and systematize publicly reported observations: 'attached' and 'detached' observations. Attachment sorts observations in terms of time, direction, viewing position, etc. Detaching observations (recognizing observations as closed classes) from situated interests is important in order to make them resist societal influence. Only this 'standardization' of observation has made the development of modern science possible (see also the example of Plinius the Elder above). De Zeeuw notes that detachment does not require an (assumed) reality—contrary to the common-sense expectation. This is in line with Glasersfeld's skeptics argument. On this basis he is able to conclude that certain extensions of SR converge to RC, in particular combinations of attached observations. As collectives, they prove detachable themselves. This convergence allows for the development of concrete research designs for RC, as shown by examples. It also suggests a possibly fruitful communication between RC and SR.

Important areas of application for RC are biological sciences and artificial intelligence. Unfortunately, RC has had little impact on them to date. This is somewhat surprising. Firstly, the evolution of RC has largely been influenced by biological cybernetics (such as Foerster's BCL) and Maturana and Varela's theory of 'autopoietic systems' even explicitly refers to a 'biology of cognition' (Maturana and Varela 1980). And secondly, in the case of artificial intelligence and artificial life, one could expect that through adaptive learning artifacts necessarily construct internal 'knowledge' structures which are not a priori provided by the designer of the system. In order to investigate the reasons why so little attention has been paid in these disciplines to RC, and how RC might contribute to progress, three papers are devoted to this topic.

John Stewart provides us with an overview of how RC changes the world-view in biology and cognitive science. In the context of realism vs. constructivism, he discusses the relation between the two opposed views of the organization of the living. The currently dominating neo-Darwinian world-view is portrayed as timeless and ahistorical. The alternative paradigm of autopoiesis deals with processes of self-construction and is thus historical. This classification parallels the distinction in cognitive science between classical cognitivism and enaction. Cognitivism plays an important role in the explanation of cognitive capabilities and their implementation in artifacts. Symbols are placed at the root of computational processes. Meaning is imposed on these symbols by the designer of the artifact through the fact that symbols are representations of some states in the outside world. Enaction, on the contrary, focuses on the self-creation of meaning through the system itself. The conclusion Stewart draws from his investigations is that constructivism rehabilitates realism as a pragmatic possibility in cognitive science which points at an even-handed reciprocity between these apparently contrary world-views. Regarding the little impact of constructivism in mainstream biology, Stewart claims that while authors take the constructivist theory of Autopoiesis as granted not much effort has been spent in the mechanisms of autopoiesis itself. This is a clear call for further research in this area.

Markus Peschl steps deeper into the problem of representation. In particular he investigates the relationship between cognitive and scientific processes for which 'knowledge representation' is a key concept. By relating the notion of 'representational spaces' to 'theory spaces', Peschl applies concepts from neuroscience and genetics. Representation can now be described as trajectories in activation and synaptic weight spaces, and genetic drift accounts for the creation of scientific knowledge and its paradigmatic changes. Such a cognitive foundation of science characterizes scientific activity as extracting regularities from experience, predicting and manipulating. However, in an epilogue, Peschl is sceptical about whether a purely quantitative–functionalist view can indeed tell the 'full story' and explain the intellectual satisfaction of doing science. He attributes this lack of a 'deep' understanding in traditional science to the fact that by measuring and computing the effects of a phenomenon under investigation, the description of these effects are confused with the phenomenon itself. One possible answer to this fundamental question is provided by RC and Glasersfeld's notion of 'function fit'. In contrast to a pure instrumentalist perspective, RC emphasizes that whatever theory is able to 'fit' the 'data' must also be embedded in the conceptual network of the scientist. As solutions to (scientific) problems arise from this network, they not only allow for predictions but also for explanations which are characterized as relations to the conceptual network.

Finally, an important potential area of application of RC are technical disciplines which heavily borrow from natural sciences, such as artificial intelligence (AI) and artificial life. In Riegler (1992) I have provided early sketches of how the design of artifacts can or should be guided by principles of RC. **Tom Ziemke**'s paper furnishes an extensive account on this topic. The lengthy paper unrolls the problems of AI on the backdrop of realism which is somewhat surprisingly the mainstream view in this field. The difficulties arise from the fact that AI has focused on human-constructed formal-computational devices which can be interpreted as models of cognition only through an observer. But they cannot be considered cognitive on their own stand. In order to overcome those problems, Ziemke introduces the concepts of 'situatedness' and 'embodiment', as they have been defined within the alternative 'New AI' movement. The basic idea here is that artifacts (robots) are in direct interaction with their environment, such that their actions are part of a dynamic with the world. Ziemke argues with Uexküll, Maturana and Varela that even a New AI cannot fulfill the goal of creating cognitive artifacts as long as it is committed to heteronomous computationalism.

In part two of these journal issues (*Foundations of Science*, volume 6, number 2), three authors discuss the relevance of RC to physics. Since the early days of modern science, physics has played a dominant role and has been a model for other disciplines as it is the incarnation of exact science. Physics is about measuring exactly, and applying the strict framework of mathematics to solving problems. However, when it comes to re-examining the physical world-view, one has to notice that physics fails to recognize the constructivist content of any human-erected cognitive scaffold, including physics. So writes Weinberg (1998), "What drives us onward in the work of science is precisely the sense that there are truths out there to be discovered, truths that once discovered will form a permanent part of human knowledge." And although physics is no longer in the state of employing a mechanist world-view with rigid causal relationships, the insights gained in quantum physics have not led to an acknowledgment of its constructivist nature. Why, thus, is physics still a domain of realists?

Indeed, in his article, **Helmut Schwegler** expresses a certain amount of skepticism about whether RC can also address the domain of exact and objective science. He argues that all science including physics is basically a language game in the sense of Wittgenstein, i.e., scientists communicate via language and work via these communications. But in order to play this language game correctly one doesn't need to adopt the RC world-view. This calls for a deeper inquiry into scientific activity. Certainly, Schwegler mainly addresses the social aspects of the scientific community. It is clear that the support within the community obeys entirely different laws than the ways a single scientist comes up with a new idea. One may come up with a bad idea and nevertheless find acknowledgment within the community simply because one is a good 'language-player'. Therefore, the article triggers a series of interesting questions which still have to be solved. Does the old distinction of Reichenbach between context of discovery and context of justification (in Schwegler's case: within the community) still hold? Is science about satisfying the needs of the prevailing community, or is it a tool of self-*erkenntnis*, as Peschl asks in his paper? As for the influence of the epistemological background on scientific practice, Stewart vehemently negates its irrelevance. He argues that this dimension of reflexivity is not just metaphysically, but also scientifically relevant. Following a proposal by Schwegler (personal communication), we could draw the analogy of a shoemaker before and after having read RC literature. In the 'realist mode' the shoemaker will stick to the principles of shoemaking which are believed to be true. The RC shoemaker, on the contrary, will more flexibility adopt alternative approaches as for him the commitment to a hypothetical truth is no longer an essential criterion (Dewey Dykstra, personal communication). If this analogy is correct, then one of the advantages of an RC-biased science certainly has more potential to come up with new solutions.

Science is a form of cognitive activity. Thus one should expect to find similarities between the evolution of both. **Gerhard Grössing**'s contribution is the attempt to parallel the development of cognition, and the progress of physics in general. His paper takes us into a domain which attracts an increasing number of scientists, the problem of consciousness, and how it relates to the evolution of physics. His arguments are largely based on the work of Roland Fischer who presented a cartography of states of consciousness some 30 years ago. Grössing argues that the emergence of new invariants in reality and physical theory construction correlates with moving towards increasing arousal (measured as the desynchronization of EEG amplitudes) on the perception–hallucination continuum onto which states of consciousness are mapped. Moving along the continuum means to go from the I of the objectified physical world to the Self of personal experience—a hint of how to reconcile realism and RC. Certainly further research has to be undertaken on this promising subject.

The main idea in Grössing's paper—the perceived non-classical structure of space and time in relativistic cases is not objective in the sense of realism but rather a human specific artifact based on neurophysiological processes—links directly to the last paper in the physics section. **Olaf Diettrich** offers us a reinterpretation of physical results in the light of the theory of cognitive operators, and delivers as such support for a non-trivial constructivism from a physics point of view. Diettrich's theory starts with the insight that "properties are defined as invariants of measurement devices", i.e., that certain notions in physics can no longer be defined independent of the measurement. Diettrich now claims that structures of observations also have to be seen as results of measurements of the cognitive operators in the mind. The crucial point is that observation can only be understood as invariants of these cognitive measuring devices. Therefore, they are strictly human-specific, and do not represent independent ontological elements of an outside reality. The notion of truth can no longer be used as a criterion to evaluate physical theories. Instead theory-building must seek for consistency. This leads to the RC-typical circularity as mentioned above. Furthermore, the fact that different set of cognitive operators brings forth a different cognitive phenotype makes it virtually impossible to communicate with beings equipped with that alternative operators. However, such beings do not necessarily have a less consistent or efficient world-view. Diettrich goes even a step further when drawing the conclusion that there is a homology between the mechanisms generating mathematical terms and those generating observational ones. That mathematical equations fit physical observations so well would then no longer be surprising. Diettrich also vehemently rejects the view of evolutionary epistemology according to which to evolutionary success of a species is linked to a match between reality and the body-plan or cognitive capabilities of the species in question (cf. Glasersfeld's distinction between 'match' and 'fit'). The concept of 'reality' is only brought about as a 'shortcut' in order to secure observations against doubts in situations when quick action is required. It may thus be regarded as 'cognitive burden'.

In Schwegler's paper the topic of science education was already briefly mentioned. Certainly, science education shapes the reasoning of the later scientist. Revealing the processes by which we 'gain knowledge' is of outmost importance if we want to improve the working of science in total. The contribution by **Bernard Scott** devotes space to this topic and focuses on a domain-independent theory of conversation which was originally developed by Gordon Pask, and further elaborated by others. From an RC point of view, communication—especially between a teacher (someone who has learned already) to a student (someone who starts to learn or is still learning)—deals with the apparent paradox that we as epistemological solipsists living in our 'bubble of experiences' have to communicate with others who are in the same situation. RC denies the possibility of exchanging information like pieces of chocolate, as von Glasersfeld puts it. Likewise, science education cannot be built on the royal road to learning either. Scott's 'constructivist learning' is taken to depend on the relation between what is to be learned and what is learned. This relation may take on different forms. It may be of a representational nature (both are structurally the same), or of an analogical nature (in which case what is learned has to be 'coherent'), or both may serve to effectuate the same tasks or actions.

The last contribution of this issue is concerned with the question of how we can explain knowledge-growth from an RC perspective. The SR point of view teaches us that the boundaries of what is thinkable is determined by the structures of (classical) logics. As Gardenförs (1994), among others, shows, this classical logical approach to rational reasoning cannot account for everything. The critique addresses foremost the traditional distinction between the context of discovery and the context of justification as introduced by Hans Reichenbach (1938) and further elaborated in the writings of Sir Karl Popper. While for Popper justification could be handled by logical deductions (falsification) he failed to find an explanation for discovery. **Hans Rudi Fischer**'s contribution picks up the critical opinion regarding the limitations of classical logics. He argues that the attempt to exclude illogicality must necessarily be illogical itself. By 'illogical reasoning' he refers to Charles Sanders Peirce's formulation of abduction. Fischer argues that, from an RC perspective, only through abduction scientists may arrive at new insights. Abductive inferences also change the semantics of a conceptual system by introducing new relations amongst the entities of the conceptual network that could not be seen before. Fischer ties this insight to the event of scientific revolutions which take place when new hypotheses erected through abduction are confirmed by induction.

Conclusion

The contributions make clear: From a RC perspective the purpose of science is not to seek for truth or to map out 'reality'. There is no justification for an exclusive claim of objectivity. As I have shown this isn't necessary anyway. Glasersfeld points out that science is the attempt to make sense in the manifold of experiences, to look out for regularities. As scientists we do this with greater rigor than in everyday situations, but this is a gradual rather than fundamental difference. At both ends of the continuum of common-sense and scientific cognition we employ a set of mental scaffolds. Scaffolds guide us in what we perceive and how we reason. Since "neither problems nor solutions are ontological entities, but arise out of particular ways of constructing" (Glasersfeld 1991b, p. 27), experiences must fit into the current web of knowledge in order to make sense—a fact which is stressed by the constructivism movement in education. And it has consequences for questions of representation, communication, and language. Words can no longer be considered carriers of informations but triggers of a mutual interpretation and communication process. Clearly, this has profound implications for scientific language as well. To speak of a universal scientific language which anchors in an external reality cannot be justified.

RC also suggests that we move away from epistemology, i.e., asking What is knowledge?, to the mechanisms of knowledge construction. We are not passively flooded by information from the outside. Rather, as RC suggests, we actively construct our world. Therefore, we can expect deeper insights in scientific model building from advanced findings in the cognitive sciences.

The constructivist view of science goes beyond the conception of instrumentalism which acknowledges only the utility of theories as science as sole *raison d'être*. The mental constructions in a scientist's mind form an operationally closed system. No semantics from an outside reality intrudes upon them. Rather than referring to the metaphysical (and possibly science–impeding) concept of a mind-independent reality, these mental constructs create meaning by relating to each other. Finding appropriate pieces in this puzzle game is the ultimate drive to go on with scientific inquiry.

Critics of RC often conclude that because knowledge is constructed, the mind is in principle free to construct anything it wants. We must not forget that constructions are historical assemblies. The historical aspect imposes a hierarchical organization in which more recent additions build on older ones. Such a hierarchy causes mutual dependencies and thus canalization among its components. It severely restricts the degrees of freedom in the way constructions can be accomplished, as described by the Limitations of Construction Postulate. Therefore, the constructions of the mind cannot be arbitrary.

It would be wrong to say that RC was an already fully developed theory. The contributions show that there are still many open questions which are subject to further investigations and argumentations. In this sense, RC does not only offer a new world-view which—propelled by the problems of realism in many recent developments in science such as cognitive science and quantum physics—has the potential to lead to *significantly* better results in science (not to mention science education as well). Radical constructivism is, as its name suggests, consistent in its claim of applying the idea of viable constructions also to itself rather than proposing a dogmatic world-view. Borrowing the best from both sides—the rigor of the scientific method and the undogmatic characteristic— radical constructivist science is equipped with the possibility of carrying research into new and promising realms.

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References

de Camp, L. S. (1974) *The Ancient Engineers*. New York: Ballantine.

Duncker, K. (1935) *Zur Psychologie des produktiven Denkens*. Berlin: Springer. Translated: (1945) On Problem Solving. *Psychological Monographs* 58 (270): 1–112.

Feynman, R. (1985) *Surely You’re Joking, Mr. Feynman!* New York: W. W. Norton & Company.

Foerster, H. von (1981) On Constructing a Reality. In: H. von Foerster, *Observing Systems*. Intersystems Publications, pp. 288–309. Originally published in: F. E. Preiser (ed.) (1973) Environmental Design Research, Vol. 2. Dowden, Hutchinson & Ross, Stroudberg, pp. 35–46. Also available at http://platon.ee.duth.gr/~soeist7t/Lessons/ lesson2_2.htm

Franklin, S. (1995) *Artificial Minds*. Cambridge: MIT Press.

Gardenförs, P. (1994) The Role of Expectations in Reasoning. In: M. Masuch & L. Pólos (eds.) *Knowledge Representation and Reasoning Under Uncertainty*. Springer-Verlag: Berlin, pp. 1–16.

Glasersfeld, E. von (1988) The reluctance to change a way of thinking. *The Irish Journal of Psychology* 9(1): 83– 90.

Glasersfeld, E. von (1991a) An Exposition of Constructivism: Why Some Like it Radical. In: Klir, G. J. (ed.) *Facets of System Science*, New York, London: Plenum Press, pp. 229–238.

Glasersfeld, E. von (1991b) Knowing without Metaphysics: Aspects of the Radical Constructivist Position. In: Steier, F. (ed.) *Research and Reflexivity* (Inquiries into Social Construction).

London: Sage Publications, pp. 12–29. Also available at http://www.mcgill.ca/douglas/fdg/kjf/17-TAGLA.htm

Glasersfeld, E. von (1995) *Radical Constructivism. A way of knowing and learning*. London: Falmer Press.

Horgan, J. (1996) *The End of Science*. Reading: Addison-Wesley.

Jammer, M. (1957) *Concepts of Force. A Study in the Foundations of Dynamics*. Harvard University Press: Cambridge.

Janich, P. (1993) *Erkennen als Handeln. Erlangen*. Jena: Palm & Enke.

Klein, M. (1972) The use and abuse of historical teaching in physics. In: Brush, S. G. & A. L. King, A. L. (eds.) *History in the Teaching of Physics.* Hanover, NH: University Press of New England, pp. 12–18.

Knorr-Cetina, K. (1981) *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science.* Oxford: Pergamon Press.

Kuhn, T. (1962) *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Latour, B. (1987) *Science in Action.* Cambridge: Harvard University Press.

Luchins, A. S. (1942) Mechanization in Problem Solving. In: *Psychological Monographs* 54/248.

Maturana, H. R. (1978) Biology of Language: The Epistemology of Reality. In: Miller, G. A. & Lenneberg, E. (eds.) Psychology and Biology of Language and Thought: Essays in Honor of Eric Lenneberg, New York: Academic Press, pp. 27–63. Also available at: http://www.enolagaia.com/M78BoL.html

Maturana, H. R. and F. J.Varela, , (1980) *Autopoiesis and Cognition: The Realization of the Living.* Boston Studies in the Philosophy of Sciences. Vol. 42. Boston, Dordrecht: D. Reidel Publishing

Maturana, H. R. (1988) Reality: The search for objectivity or the quest for a compelling argument, *The Irish Journal of Psychology,* Vol. 9, no. 1, pp. 25–82. Also available at http://www.univie.ac.at/constructivism/papers/maturana/88-reality.html

Müller, A. (2000) Eine kurze Geschichte des BCL [A short history of the BCL]. *Österreichische Zeitschrift für Geschichtswissenschaften* 11 (1): 9–30. Also available at http://www.univie.ac.at/constructivism/papers/mueller/ mueller00-bcl.html

Osler, M. J. (1970) John Locke and the Changing Ideal of Scientific Knowledge. *Journal of the History of Ideas*,. 31 (1).

Pagels, H. R. (1988) *The Dreams of Reason: The Computer and the Rise of the Sciences of Complexity*. New York: Simon & Schuster.

Penrose, R. (1986) Gravity and state vector reduction. In: Penrose, R. & Isham, C. (eds.) Quantum Concepts in Space & Time. Clarendon Press, Oxford, pp. 129–146.

Peschl, M. & Riegler, A. (1999) Does Representation Need Reality? In: Riegler, A., Peschl, M. & Stein, A. von (eds.) *Understanding Representation in the Cognitive Sciences.* New York: Kluwer Academic / Plenum Publishers, pp. 9–17. Also available at: http://www.univie.ac.at/cognition/books/representation/peschlriegler.pdf

Piaget, J. (1954) *The Construction of Reality in the Child.* New York: Ballentine.

Putnam, H. (1990) *Realism with a Human Face*. Cambridge: Harvard University Press.

Reichenbach, H. (1938) *Experience and Prediction: An Analysis of the Foundations and the Structure of Knowledge*. Chicago: University of Chicago Press.

Riedl, R. (1977) A systems-analytical approach to macro-evolutionary phenomena. *Quarterly Review of Biology* 52: 351– 370.

Riegler, A. (1992) Constructivist Artificial Life, and Beyond In: McMullin, B. (ed.) *Proceedings of the Workshop "Autopoiesis and Perception"*, Dublin City University. Also available at ftp://ftp.eeng.dcu.ie/pub/autonomy/bmcm9401/riegler.ps.Z

Riegler, A. (1997) Ein kybernetisch–konstruktivistisches Modell der Kognition. In: Müller, A., Müller, K. H. & Stadler, F. (eds.) *Konstruktivismus und Kognitionswissenschaft. Kulturelle Wurzeln und Ergebnisse*. Wien, New York: Springer, pp. 75–88.

Riegler, A. (2001) The Cognitive Ratchet. The Ratchet Effect as a Fundamental Principle in Evolution and Cognition. *Cybernetics and Systems*32 (3–4), in press.

Schmidt, S. J. (ed.) (1987) *Der Diskurs des Radikalen Konstruktivismus*. Suhrkamp: Frankfurt a. M.

Searle, J. R. (1995) The Construction of Social Reality. The Free Press.

Searle, J. R. (1999) The Future of Philosophy. Philosophical Transactions: Biological Sciences (The Royal Society) 354 (1392): 2069–2080.

Sokal, A. (1996) A Physicist Experiments with Cultural Studies. Lingua Franca, May/June 1996, pp. 62–64.

Spivey, N. N. (1997) The Constructivist Metaphor. Reading, Writing, and the Making of Meaning. San Diego: Academic Press.

Tarski, A. (1944) The Semantic Conception of Truth and the Foundations of Semantics. *Philosophy and Phenomenological Research* 4: 341–375.

Umpleby, S. A. (1990) The Science of Cybernetics and the Cybernetics of Science. *Cybernetics and System 21 (1):* 109–121.

Van Fraassen, B. (1980) *The Scientific Image.* Clarendon Press, Oxford.

Watzlawick, P. (1976). *How Real is Real?* New York: Random House.

Watzlawick, P. (1990) *Munchhausen's Pigtail: Or Psychotherapy & "Reality"—Essays and Lectures.* New York: W.W. Norton & Company.

Weinberg, S. (1998) The Revolution That Didn't Happen. *The New York Book Review*, October 8, pp. 48–52.

Winograd, T. & Flores, F. (1986) *Understanding Computers and Cognition.* Norwood: Ablex.