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INCLUSIVE WORLDVIEWS: INTERDISCIPLINARY RESEARCH FROM A RADICAL CONSTRUCTIVIST PERSPECTIVE

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Interdisciplinary inquiry presupposes an open worldview to enable the researcher to transcend the confinements of a specific discipline in order to become aware of aspects that are necessary to satisfyingly solve a problem. Radical constructivism offers a way of engineering such interdisciplinarity that goes beyond mere multi or pluridisciplinary approaches. In this paper I describe epistemological and methodological aspects of interdisciplinarity, discuss typical problems it faces, and carve out its relationship with knowledge and communication from a constructivist perspective. Five implications for interdisciplinary practice and science education conclude the paper.

Keywords: Radical constructivism; black-boxing; knowledge; meaning

1. Introduction

To me, science has always been an interdisciplinary endeavour. When I enrolled at university, I intended to carry over the passion for astronomy I had developed in high school. But taking to the computational approach, I also became intrigued by the idea of building computational models of that which enables human scientists to do their job in the first place: cognition. In those days, I considered artificial intelligence a sort of meta solution to current problems in science. Rather than solving the actual problem, the solution concerns methods that solve a class of problems, e.g. all those scientific problems that arise due to cognitive insufficiencies of the human researcher. Soon I changed to study artificial intelligence and cognitive science and experienced my first "paradigm-switch" from mathematics-based science to computation-based research. Of course, the expectations regarding AI as a meta-solution strategy did not materialize: no genuine AI systems have been introduced in society until now. Rather, as many have always argued (e.g. Dreyfus[1]), the creation of cognitive artefacts is still as hard a problem as it was in the days of Alan Turing some 50 years ago when he published his seminal paper of computing machinery.[2] So after graduating, instead of following the path of AI, I prepared myself for another paradigm-switch and started to work for theoretical biologists. The biologists' worldview has left an equally dominating impression on me, as has the computational approach of AI scientists. During all this time, I never considered the division of science into relatively isolated disciplines to be an advantage (and worse: sub-disciplines such as theoretical biology was always looked at askance by, say, marine biologists working just one floor below me). Quite the contrary: the idea of an inclusive scientific approach seemed more promising to me, i.e., studying a particular phenomenon or topic using methods and insights from peers from various disciplines pertaining to the natural-scientific worldview, to the engineering approach or to philosophy. It is based on the—almost trivial—definition that science (lat. scire = to know) is about enlarging one's knowledge (and skills). It is only "almost trivial" as an exact definition in the sense that what counts as "knowledge" and how to communicate such knowledge in "language" still seems elusive, in spite of the key importance of these terms for the practicing scientist and philosopher. The following will therefore explore the problems of interdisciplinary practice and how they relate to knowledge and communication from the perspective of radical constructivism.

2. Why philosophy and science?

As is well known, Ludwig Wittgenstein defined the philosopher's work in terms of "assembling reminders for a particular purpose"[3]. If one considers this the most general characterisation of how *philosophical* knowledge is enlarged, the question arises whether this does not also apply to knowledge acquisition in general, that is, whether it is accurate to portray scientific activity as the (systematic) collection of experiences.

The philosophy of *radical constructivism* (RC) takes up this idea and examines the question of how knowledge comes about. For example, according to Ernst von Glasersfeld, who coined the notion of RC some 30 years ago, knowledge constitutes a dynamical product of construction processes in the stream of experience. Whether knowledge reflects any mind-independent reality must remain a matter of speculation. What is more, constructivism opposes the notion that different modes of knowledge acquisition can be considered equal. Rather, it is especially the scientific method that lends itself to assembling various experiences into a coherent whole in order to create both explanations and predictions. (For example, in the natural sciences the scientific method consists of, in rather abstract terms, (1) the idea of reproducibility, e.g. in terms of formal descriptions of the phenomenon in question, and (2) building on the work of peers by making explicit references to their publications.)

As the introduction sought to illustrate, scientific disciplines do not progress in a united manner, neither with respect to their methods nor regarding the set of questions they try to account for. Rather, science is split into what philosophers of science have called *Denkkollektive*[4], *paradigms*[5], or (*metaphysical*) *research programs* ([6,7]). Starting from the fact that science is fragmented, I want to pose the following questions. Firstly, do we need interdisciplinary research to counteract this fragmentation; are there already instances of interdisciplinarity; and what are its advantages? As I will point out below, the answer is mainly positive. Yes, we need interdisciplinarity, examples do exist, and there are advantages of interdisciplinarity over narrowly focused disciplinary research. Consequently, I ask the second question: What problems does interdisciplinarity entail, and can we overcome them? In order to find an answer to this second question, I will formulate an alternative perspective of interdisciplinarity based on radial constructivism. The goal of this paper is to stimulate scientists involved or intending to get involved with interdisciplinary research to reconsider central concepts of research such as knowledge acquisition and language communication. These concepts are considered crucial for fruitful interdisciplinarity.

3. Why interdisciplinarity?

"Interdisciplinary" has been a buzzword for at least 60 years. Some consider the development of the atom bomb as the first large-scale interdisciplinary research, other regard even early industrial parks such as Thomas Edison's Menlo-Park as first successful attempts in this direction. The first interdisciplinary conferences took place after World War II, most notably the meetings of the Josiah Macy foundation held to discuss "circular-causal and feedback mechanisms in biological and social systems"[8]. Their goal was to initiate a kind of science that was later to be called "cybernetics" (cf. Norbert Wiener's 1948 book "Cybernetics"[9]). Their participants included neurologists, psychologists, philosophers, anthropologists, mathematicians, engineers and so on. The basic attitude of cybernetics—to approach complex phenomena from different disciplines—has caught on in many research circles. Their common goal was and is to provide environments for extensive collaborations among scientists from various disciplines. The result of such efforts has become visible in various disciplines that call themselves "interdisciplinary." For example, cognitive science[10] is considered a multi-facetted approach to exploring human cognition from a variety of disciplines, including psychology, computer science, philosophy, anthropology, and so on. Biotechnology is another, particularly recent and financially successful amalgam of chemistry, biological and computer sciences. An older example is behavioural science, which late 19th century philosopher Edmund Husserl[11] characterised as interested in a broad and integrated treatise on organisms based on both natural scientific disciplines such as zoology and ethology and humanistic disciplines such as human ethology. Quantum computing is also considered an interdisciplinary effort for combining physics with computer science[12]. The list can be arbitrarily extended.

What is at the core of such interdisciplinary endeavours? The answer, as we will see, concerns mainly methodological and epistemological considerations.

The *methodological issues* relate to the fact that interdisciplinarity is an open inquiry that enables the investigator to escape the confinements of a specific discipline in order to become aware of aspects that are necessary to satisfyingly solve a problem. What do I mean by that? Consider the following example[13]. Suppose that we take a piece of chalk and write on the blackboard "A = A." We may now point at it and ask, "What is this?" Most likely we will get one of the following answers. (a) White lines on a black background; (b) An arrangement of molecules of chalk; (c) Three signs; (d) The law of identity. Regardless whether you are an art critic, a chemist, a philosopher, or a mathematician, it is obvious that the answer will depend on your educational background. There seems to be no harm in that at first sight, but let us consider another analogy. A teacher "who asks a student to measure the height of a tower with the use of an altimeter, may flunk the student if he uses the length of the altimeter to triangulate the tower and obtains the height of the tower through geometry and not through physics. The teacher may say that the student does not know physics"[14]. What this episode suggests is that by focusing on one particular approach only we will quickly get caught in ignorance and denial of other approaches that might turn out much more fruitful. Of course, such is the human psyche: Functionally fixed[15]. Once we have found a viable solution we tend to stubbornly apply the pattern of our solution to all other problems as well. In his famous experiment, Karl Duncker posed the task to support a candle on a door. The items available to the test subjects were matches and a box filled with tacks. Since the test subjects regarded the box as a mere container they failed to empty it in order to tack it to the door where it could serve as a support for the candle. In other words, our thinking is canalised (cf. the "If it ain't broken don't fix it" syndrome[16,17,18]), caught in the momentary situational context as determined by the way we have learned to deal with things.

The *epistemological considerations* refer to our subjective qualitative and shared social conceptual framework, usually called "worldview." According to Aerts et al.[19], a *worldview* can be described as a system of co-ordinates or a frame of reference in which everything presented to us by our diverse experiences can be placed. Such a representational system allows us to integrate everything we know about the world and ourselves into a global picture, one that illuminates reality as it is presented to us within a certain context or society. As human beings, we face the problem of integrating experience every day. Observations that do not fit into an existing network provide a feeling of "uneasiness" that needs to be resolved. If the tension between new fact and worldview is bigger, fundamental problems arise, and if two worldviews collide in a social context we are often facing an unsolvable problem. (In functional terms this can be compared with Piaget's notion of accommodation of cognitive schemata triggered by experiences that cannot be assimilated into the schemata.) Consequently, the question of interdisciplinarity is tightly connected with that of worldviews: We need a better understanding of how worldviews come about, which rules they obey, and how controversial observations can be integrated in order to avoid fragmentation of knowledge among the more than 8000 distinguishable disciplines today. As Klein[20] put it, "The task for philosophers of science is to specify conditions that promote integration and to formulate criteria to evaluate integrations."

4. Problems of interdisciplinarity

While the idea of interdisciplinary scientific activity seems to be attractive at large, it is often hampered by problems in practice. Whenever people come together to participate in a common project, different personalities meet each other with their own educational backgrounds. For collaborating scientists, this has two immediate effects[21]. (P1) there is usually a *mutual information deficit* that roots in a good deal of ignorance of other fields. Such ignorance may have deliberate reasons, including a dim view of the other discipline: “Teamwork has been compromised by the disdain scientists have for engineers, mathematicians for physicists, pure scientists for applied scientists, physical scientists for social scientists and humanists and vice versa”[22] (quoting Klein[23]). However, mutual information deficit can also be caused by the (cognitive) impossibility to deal with details of an unfamiliar discipline. (P2) Connected with the first point is the problem of *not sharing a common terminology* due to specific jargons. These are words and expressions “ready-to-hand” for the specialist and incomprehensible or at least misleading for the rest. They are typical of the *Denkstil* (style of thought[4]) a particular research community uses, which ultimately results in *Bedeutungsverschiebungen* (semantic shifts) when attempts are made to “translate” typical expressions among various groups or to the public. Language problems also affect the transformation of interdisciplinary results into readable publications, for, as the adage goes, “too many cooks spoil the broth.” The traditional way to get around the jargon problem and obtain a proper interface between participants is by creating redundancy through repetition—in much the same way a young child is exposed to repetitions in order to learn her first words. A long tail of philosophical considerations is linked with this, as well as other language and communication problems, which makes it worth looking at them in more details further below.

Further problems address the different ways of scientific work. Some of the basic dimensions are (P3) *Prediction versus explanation*. Mathematically inclined disciplines tend to emphasise the predictive value of their work, or they try to cling to it, as we know from meteorology. In contrast, humanities seek to account for events and data, with historical and literature science at the far end of the spectrum. It is interesting that phenomena whose degree of complexity transcends the threshold of computability cannot be predicted with quantitative deductive rules, i.e. they seem to cease to be scientific problems and become philosophical, religious, and/or common sense problems. Foerster wrapped this insight into his well-known bon mot: “Only the questions which are principally undecidable, we can decide”[24]. In these cases, prediction recedes into the background in favour of the pursuit of explanations, which in the humanities has even led to prediction playing a marginal role. (P4) Very similar to problem P1 is the *hard sciences* *versus soft sciences* contrast, which in many ways corresponds to the distinction between the two cultures introduced by C. P. Snow[25], widespread in philosophy of science. The soft sciences study humans and human societies as opposed to non-living matter, which is explored by hard science. Therefore, they have to rely on different test and evaluation criteria, which impose severe limits on repeatability—the notion so central to the scientific method. Heinz von Foerster[26] once pointed out that the "hard sciences are successful because they deal with the soft problems; the soft sciences are struggling because they deal with the hard problems." This is the case because the "more profound the problem that is ignored, the greater are the chances for fame and success." Of course, Foerster is hinting at the reductionist approach in physics, which made it easy to focus on a particular tiny problem, within a closed framework, and to forget about the rest of the universe, including the views of others. In this regard, reductionist science as the piecemeal advance by tackling picayune though manageable problems is opposed to large-scale systematic approaches. (P5) *Basic research versus applied science*, or: Does science have to answer to needs of society exclusively? Questions like this refer to the importance of worldview creation, as described above. (P6) *Single scientists versus group research.* Of course the border is blurred. As Thomas Kuhn[27] already pointed out, science is carried out by individuals but scientific knowledge is the result of a community. However, the flexibility of the single researcher might be considered higher compared with the necessarily more rigid organisation of interdisciplinary groups and their internal methodological and linguistic co-ordination.

5. Towards a definition of interdisciplinarity

Interdisciplinary research does not occur spontaneously. Rather, it has an "evolutionary" dimension. For example, what begins as an interdisciplinary effort often results in the creation of a new discipline that is narrowly focussed again. As Frodeman, Mitcham and Sacks[28] pointed out, "biophysics has not really united biology and physics but created another and even more narrow discipline; the same goes for fields like biochemistry and paleoclimatology." The same applies to artificial intelligence and cognitive science, which are well-established disciplines today with their own respective methods, vocabularies and journals. (However, some do not consider cognitive science a new discipline but rather an instance of what Bechtel[29] called "cross-disciplinary clustering." Although it has conferences and journals devoted to its programme, its practitioners remain within their original discipline.) In what follows I claim that such disciplinary developments are far from being unnatural.

A typical phenomenon in scientific praxis is what Bruno Latour[30] called "black-boxing." "Once a device or an experiment or finding is black-boxed, it is treated as an unquestionable fact: no one needs to look inside that particular black box again [...] Procedures or devices or equations or facts are taken for granted by future generations of scientists and may be virtually incomprehensible to outsiders." Of course the cognitive basics of black-boxing are easily recognisable as the black-boxing of skill can be applied to many human domains, including writing and music. Musicians, for example, once they have mastered the basics of playing their instruments will feel free to creatively re-arrange pieces of music. They have grown familiar with these chunks to the extent that using them no longer requires conscious reflection. In other words, while being complex enough to make beginning and less skilful players struggle with them, these musical "chunks" have become "cognitively closed" in the cognition of the advanced. Such "higher order compositions' play a central role in musical techniques such as sampling where parts of a song are combined with parts of other songs.

In science, such closures appear at various levels, from simple procedures to methodologies and—extrapolating Latour's claim—entire research groups that wrap them into new disciplines. If my extrapolation is correct, we can predict that "disciplinary" black-boxing takes place in several steps, evolutionarily transforming a set of single disciplines to a single, tightly homogeneous approach. Indeed, in the literature we find such taxonomies of different degrees of interdisciplinarity, e.g. the one proposed by Erich Jantsch.[31]. He distinguishes the following steps of aggregation. At the *multidisciplinary* stage, a variety of disciplines meet up simultaneously and work on several goals without co-ordination and maintaining explicit relations. The respective paradigms of the disciplines remain unaltered by this loose form of co-operation. One may think of informal conference conversations among unrelated scientists or even reading literature outside one's own area of expertise as a form of multidisciplinary collaboration. Evidently, there are also negative forms of multidisciplinarity, as described by Scerri[32], who quotes from an interview: "The philosophy of our lab is to try to steal as many technologies as we can from other disciplines and to apply them to our problem." In some respect, such procedures may also be considered the drawback of what Gibbons et al.[33] called "Mode 2" research, i.e. the fact that scientific knowledge is no longer exclusively produced at universities and that it is primarily problem-focused. The *pluridisciplinary* stage is marked by the juxtaposition of more or less related disciplines which communicate on the same level, but again without changing the character of the participating disciplines. Only at the *crossdisciplinary* level can a tendency of asymmetry be observed. One discipline starts to dominate the others, establishing itself as leading discipline, for example with regard to the predominant methodology. This relegates the other participating disciplines to a merely auxiliary position. The result is one-level, one-goal guidance rather than co-ordination. The programme of the Vienna Circle was characterised by the attempt to make physics such a prevalent science. Another, almost opposing example is psychologism, where the basic foundations of other disciplines are explained in terms of psychological laws (e.g. Ernst Mach[34]). On the "serving" side we find eminent disciplines such as philosophy. From the perspective of empiricist John Locke, philosophy is the under-labourer to master-builder science in the building of knowledge, sweeping away the debris of erroneous and other traditional ways of thought in order to clear the way for unhindered scientific investigation. The self-assessment of analytical philosophy confirms this view, e.g. Searle[35], who considers philosophy a scout exploring the unknown terrain before science moves in. Also cybernetics, which began as an interdisciplinary effort, soon started to presume a leadership role in the 1960s. Eventually, however, with the exception of some incorrigible researchers who still think they can tackle science's hardest and other philosophical problems with simplicistic cybernetics, this crossdisciplinary presumption led to its decline in the 1970s.

According to Jantsch[31], it is only at the level of *interdisciplinarity* that disciplines are emancipated enough to enter a collaboration characterised by extensive cross-communication and mutual co-ordination against a common perspective. The ultimate stage is the state of *transdisciplinarity*, in which the borders between disciplines have faded and scientists have lost their discipline-specific identities due to a maximum of cross-communication and co-ordination. As mentioned above, this may result in the creation of a new methodologically and terminologically independent discipline.

To sum up, interdisciplinarity is the attempt to overcome the tendency of crossdisciplinarity to subordinate participating disciplines to a single prevailing discipline, resulting in scientific reductionism. The systems-orientation of interdisciplinarity offers many opportunities, including the avoidance of scientific impasses, which are a consequence of cognitive canalisation[17,18]. However, it may also lead to pitfalls if there is insufficient reflection on central notions such as *knowledge acquisition*, *understanding*, *cognition* and *communication*. In the following section, I will embark on these conceptions from the perspective of radical constructivism. My goal is to provide a more thorough apprehension of these notions, especially in relation with interdisciplinary research, where the formation of interfaces between participating scientists very much hinges on mutual *co-ordination* in *knowledge* and *language*.

6. Why radical constructivism?

Generally speaking, science is a directed, constructive approach to knowledge acquisition. It assures the credibility of its results by developing a methodology and tests of the "truth" of its conclusions. In order to put forward a methodology that is sound for a purpose, one necessarily rejects everything that is not covered by this methodology. If one values the systematic recording of observations, anything resembling random observation and the unsystematic gathering of impressions will appear a waste of time, even if it is considered important against the background of another discipline's methodology. Furthermore, it has been recognised for quite some time that predispositions and biases affect the result of a scientific inquiry, but they have been considered distortions of rational judgment. An alternative perspective, however, calls for a revision of this understanding and new light on the role of biases in the process of research and knowledge acquisition. Does it make sense to suppose that carrying out scientific inquiry is to record regularities and systematicities as an objective state of affairs? Or are these systematicities only apparent in one's consciousness within the framework of certain perceptibility and a sense of their significance in the light of this framework? If we are to profit from working together with people from *different* backgrounds, despite potential disagreements, the question arises of how we are to surpass this "framework problem" in order to gain new knowledge? As Frodeman, Mitcham and Sacks[28] rightly recognised, it is necessary to reopen "negotiations about what counts as information or knowledge" in order to extend the epistemological limits of interdisciplinary research. Radical Constructivism (RC) provides the basis for such negotiations.

A cognitively motivated access to RC is its notion of *organisational closure*. It is a necessary quality of cognitive beings based on the *Principle of Undifferentiated Encoding* of nervous signals. Heinz von Foerster described this ubiquitous neurophysiologic insight as follows. "The response of a nerve cell does *not* encode the physical nature of the agents that caused its response. Encoded is only "how much" at this point on my body, but not "what"[36]. Think of the behaviour of young birds that open their beaks whenever the parent bird comes along with some food. As numerous ethological experiments have shown, this also works when the parent bird is replaced by a dummy made of paper. Apparently, the nervous signals in the young birds in no way convey the information of seeing a dummy (or the genuine parent bird it substitutes). One can argue that the cognitive system is in a *Matrix*-like (or, philosophically speaking, brain-in-a-vat) situation, as it has no independent reference to what has caused the incoming electro-chemical signals. With Humberto Maturana and Francisco Varela[37], we can compare the situation of the cognitive system with that of the navigator in a submarine. He avoids reefs and other obstacles without looking even once through the portholes of the vessel (which corresponds to the alleged scientific verification with an absolute reality). All he needs to do is maintain a certain (dynamic) relationship between levers (i.e. carrying out experiments) and gauges (i.e. reading results).

Radical Constructivism (e.g. Glasersfeld[38]) is the conceptual framework that builds on this insight. According to the *Radical Constructivist Postulate*[39], the cognitive system (mind) is organisationally closed. It necessarily interacts only with its own states. Or, as Terry Winograd and Fernando Flores[40] put it, 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." Cognition is, therefore, a continuously self-transforming activity. There is no purpose attached to this dynamics, no goals imposed from the outside relative to the cognitive apparatus. It is also in line with the *dreaming-machine argument* of Rudolfo Llinás[41]. Since the nervous system is able to generate sensory experiences of any type, we are facing the fact that "we are basically dreaming machines that construct virtual models of the real world." His closed-system hypothesis argues that the mind is primarily a self-activating system, "one whose organization is geared toward the generation of intrinsic images." The global picture is that cognition acts independently of the environment. It merely requests confirmation for its ongoing dynamical functioning and works autonomously otherwise: "although the brain may use the senses to take in the richness of the world, it is not limited by those senses; it is capable of doing what it does without any sensory input whatsoever."

Evidently, in closed systems, "meaning" cannot refer to a mapping between external states of affairs and cognitive structures. Following Ernst von Glasersfeld's characterisation of RC, meaning must not be considered to be passively received but rather to be actively built up by the cognising subject as the "function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality"[42]. Thus, the emphasis is placed on mechanisms of knowledge construction in humans, and on the fact that cognitive systems actively construct their world rather than being passively flooded by information from the outside. Consequently, "meaning" is a construct. It does not reside somewhere else and is not independent of the scientist who generates it embedded within her worldview.

RC leads to an alternative understanding of knowledge that refrains from assuming that differently constructed worldviews gradually converge towards a knowledge system that ultimately represents the "objective world." Glasersfeld emphasises the necessarily complete ("radical" in the sense of "thoroughly consistent") character of the constructivist endeavour. "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"[43]. Therefore, the co-ordination among scientists that subscribe to a particular interdisciplinary endeavour cannot be adjusted to an "objective" goal, since its definition would require the recursion to a cognitively inaccessible absolute reality. Instead, discipline-specific goals retain their full applicability as they formulated with regard to the coherent and consistent knowledge structure of the respective discipline. The process of co-ordination becomes that of "*structural coupling*."[44] In general terms, the structure of a system changes as a result of both its internal dynamics and its interactions with other systems, including its environment. This applies to systems that can change their structure without losing their identity, e.g. living systems but also scientific communities. Of the latter it could be said that it is indeed their goal to change, i.e. evolve with regard to knowledge structures, while staying the same discipline. For such systems there are only two options. Either they manage to plastically change their internal relations among constituent components in such a way that no dynamics harms them, or they are crushed under the influence (perturbations) of their environment and vanish. If two such plastic systems meet and they both manage to change their respective structural make-ups such that each of them generates appropriate changes of state triggered by the perturbations of the other system, they will change congruently and, consequently, undergo structural coupling. It is important to stress that this form of mutual adaptation is not specified by the other system (or environment) in the sense that the other system determines the changes that have to be carried out in order to undergo successful coupling. In this perspective, interdisciplinarity is the structural coupling between participating disciplines such that their identity is preserved but plastic "interfaces" are created that enable the exchange of "knowledge." However, not knowledge *structures* are exchanged (the structure remains private to the respective discipline) but rather perturbations are generated that trigger appropriate changes of state ("orienting action") in the fellow scientist.

In how far do these insights affect interdisciplinary practice? The fact that meaning is not transmitted as an "entity" hampers in particular the "exchange of information" among disciplines. It is not in the words, gestures, symbols with which we express ourselves to others. Rather, communication means re-construction. Language is to be seen as a behavioural system that triggers orienting actions within the cognitive domain of the interlocutor. Thus language is an ongoing process of interpretation and mutual adaptation. As Glasersfeld puts it, to "find a fit simply means *not* to notice any discrepancies"[45]. This is in contrast to *matching* something against something else; there are no ways to validate a "correct match." Linguistic co-ordination among participants of an interdisciplinary project has thus to be *viable* in the above sense of fitting.

What will facilitate the process of communication is an attitude of *openness* and expectation to making discoveries. This openness is basically a willingness to extend one's own horizon by accepting the new. It is the opposite of a "haughty" attitude—characterised by the position we take when we think "we know already", when we regard our views as superior and expect nothing enlightening to come. Holding on to the claim that a mind-independent reality plays the ultimate arbiter when it comes to judge our theories in an interdisciplinary environment does nothing but foster such attitudes. Too seducing is the temptation to turn it into a claim of authority. Instead, we should proceed with the realisation of the contingency and contextual dependence of our own views and a readiness to revise them and improve on them.

There are also impacts on scientific inquiry in general. First of all, the alternative perspective means liberation from the usually lopsided application of methodology, i.e. a willingness to go for many different ways of approaching a phenomenon of interest. Secondly, the constructivist approach to scientific inquiry means increased emphasis on the methodological aspects, such as consistency and coherence of our models. That is, rather than try and close the gaps between our models and "reality" in the Popperian sense we should aim to fill up the holes in the patchwork of theories and models and increase its coherence and consistency.

7. Conclusion

The central goal of this essay is to make researchers aware of the current limitations of interdisciplinarity, such as the cognitive shortcomings of participating scientists. I started with two basic questions: "Why do we need interdisciplinary research?" and "What are the problems and possible solutions?" In order to address both points, I first identified methodological and epistemological issues at the core of interdisciplinarity. The former emphasises the fact that interdisciplinarity means open inquiry in order to avoid the usual blinkers of disciplinary research. Unfortunately, the human mind is susceptible to "it ain't broken so don't fix it" canalisations so that we quickly get caught in ignorance and denial of other approaches that might turn out much more fruitful. The latter issue refers to setting up scientific worldviews, i.e. the problem of fusing experiences from a variety of sources. I then turned to typical problems of existing interdisciplinary practice. They encompass mutual information deficits (i.e. ignorance of the details of other disciplines involved), divergence of terminology (i.e. even if you wanted to overcome the information deficit you would encounter the problem of understanding the others' jargon) and various differences among scientific disciplines. These divergent aspects include a number of contrasts, including emphasis on prediction (hard sciences) vs. explanation (humanities), basic vs. applied sciences, and single vs. group efforts. An interesting aspect of interdisciplinarity arises from the phenomenon of black-boxing, i.e. when entire fact compounds or procedures are turned into unquestioned single facts. I predicted that this would ultimately lead to various stages of interdisciplinarity. Such stages can be identified in the literature. The spectrum goes from loosely coupled multidisciplinarity to transdisciplinarity, where borders between disciplines fade away. As an intermediary conclusion, I claimed that interdisciplinarity can be regarded as the attempt to avoid the sub-ordination of disciplines to a prevalent discipline, which otherwise would result in scientific reductionism. Subsequently, I offered a reflection on these initial questions and the ensuing conceptual reviews from the radical constructivist perspective.

This perspective can be characterised as the insight that the starting point of our scientific endeavour is not reality but our experiences. It is from these that we construct our world, which leads to the epistemological issue of worldview generation. A central aspect of RC, assembling various experiences into a coherent whole, secures the distinct position of science in society, but at the same time does not warrant an exclusive authority claim: "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"[45]. RC is aware of the fact that it must remain self-applicable. In other words, from an RC perspective, formulating (biological, mathematical, ... constructivist) hypotheses has the same purpose as Wittgenstein specified: to recognise relationships and to find coherent connecting pieces.

The alternative radical constructivist perspective results in five suggestions and implications for interdisciplinary practice. (1) The verbal coordination among participants of an interdisciplinary project has to be viable rather than absolute. This follows from the radical constructivist perspective of knowledge, according to which knowledge is a system-relative and system-related cognitive process rather than a representation or mapping of an objective world onto subjective cognitive structures[46]. Language, therefore, is a process that triggers orienting actions in scientific peers rather than denoting absolute entities and events. (2) Lopsided application of single methodologies should be avoided such that a plurality of approaches becomes possible. (3) Consistence and coherence should be maximised rather than anchoring theories in "reality." They fill up gaps in the scientist's constructive cognitive patchwork. (4) The concept of cognitive canalisation has implications for science education. It may be disadvantageous to create curricula that focus on a narrow domain at an early stage, as this may prevent the student from building up "interdisciplinary habits." This is not at odds with the demand that interdisciplinary researchers "must at first develop outstanding excellence in their own field"[22]. Rather, in order to overcome the weakness of common sense reasoning it is necessary to develop profound knowledge in an auxiliary (formal) discipline such as mathematics or computer science. This warrants the independent status of scientific thinking by introducing a layer of abstraction/detachment between scientific and common sense reasoning. The layer will create the flexibility necessary to escape the canalisations of a single (sub-) discipline. (5) We should proceed with the realisation of the contingency and contextual dependence of our own views and a readiness to revise them and improve on them. Or as Konrad Lorenz once put it "it is a good morning exercise for a research scientist to discard a pet hypothesis every morning before breakfast."[47]

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