The unity of science

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Abstract *The paper addresses the question of how the unity of science can adequately be characterized. A mere classification of scientific fields and disciplines does not express the unity of science unless it is supplemented with a perspective that establishes a systematic coherence among the different branches of science. Four ideas of this kind are discussed. Namely, the unity of scientific language, of scientific laws, of scientific method and of science as a practical-operational enterprise. Whereas reference to the unity of scientific language and of scientific laws does not provide a viable basis for the unity of science, the methodological and practical unity might. The unity of science can be characterized by the way in which methodological criteria enter into the assessment or evaluation of theories, and, moreover, by a transdisciplinary approach to problems. Accordingly, the unity of science is not expressed by theoretical uniformity but by the unity of scientific practice.*

1. Classification versus systematics

The dream of the unity of science or of a system of science is as old as science itself and as old as philosophy in its European form. Even before philosophy of science was invented, Greek thought developed the notion that even science and philosophy constituted a philosophical unity. This notion has long since lost its influence. In those areas where it was once dominant we now more and more find ill-defined empirical and systematic relations. We no longer speak of the unity of science (with or without philosophy) but rather of disciplinarity, multidisciplinarity, interdisciplinarity.[1] Retrospectively, we seek an order of knowledge no longer recognizable in the knowledge itself.

The background to this is not a philosophical dream but rather a disturbing scientific reality, which makes itself felt in a progressive particularization, or even atomization of the fields of study, in the course of which even reflection in terms of (broader) disciplinarity is gradually lost.[2] A catalogue of fields of study at German universities at present lists more than 4000 fields; there is clearly no longer any disciplinary order among these fields. Add to this various signs of institutional dissolution conspicuous in the German university system. The almost arbitrary grouping of fields of study into departments and faculties makes no recognizable theoretical sense; the same applies to the invention of one-field faculties. One-field faculties are the McDonalds of this strange university landscape; fields like hymnology and Brasilian language studies resist a systematic ordering. The disorderly state of scientific knowledge and its disciplinary structure has been extended to its organizational and institutional forms.

Thus, it is not surprising that *interdisciplinarity* has now become such an important keyword. The estranged disciplines are to be joined together again at least temporarily in concrete research and teaching programs. As a rule, however, this remains a half-hearted project. We have realized that the boundaries between fields of study are becoming not merely limitations on perception but also on knowledge itself, but we hesitate to dissolve them permanently. The boundaries of fields and disciplines are becoming boundaries to the world of scientists. The latter become ever narrower, as the former become ever vaguer.

The traditional means of nonetheless introducing a kind of unity into this diversification of fields of study and disciplines consists in combining them to form larger groups of sciences. The systematics of science is accordingly to be documented in a *classification* of individual sciences. The idea of such a classification is in turn as old as science itself. It is already expressed in the educational canon of seven 'liberal arts' of antiquity, which largely determined European education and scientific development up to modern times. In the encyclopedic literature such classifications took on a textbook form.[3] Whereas Isidor of Seville introduced extensions of the liberal arts simply by compilation, Hugo of St Victor (*Didascalicon de studio legendi*) under Aristotelian influence—which reached the encyclopedic tradition by way of Porphyry, Boethius, and Cassiodorus—distinguished among theoretical, practical and poietic (or 'mechanical') philosophy as well as logic. To theoretical philosophy belong theology, physics, and mathematics; ethics and politics belong to practical philosophy; and already in Martianus Capella, the mechanical arts bestowed in return upon Mercury were assigned to poietic philosophy (*De nuptiis Mercurii et Philologiae*; the seven 'free' arts are the wedding presents of Mercury). Logic was comprised essentially of the disciplines of the *trivium* (grammar, rhetoric, dialectic). The largest encyclopedia of the Middle Ages, the *Speculum Majus* of Vincent de Beauvais, collated from around 2000 sources, listed more than 20 disciplines.

The great French encyclopedia published by Diderot and d'Alembert (*Encyclopédie ou Dictionnaire raisonné des sciences, des arts et des métiers*, 1751–1780) also proceeded along classificatory lines. In d'Alembert's 'Discours préliminaire' (1751) all contemporary disciplines were assigned to one of the three faculties memory, reason, and imagination. Under the heading 'Philosophy' in the section on reason, Fig. 1 is given.

The unity of science is understood here as the unity of philosophy in the form of classification. At the same time the beginnings of the autonomization of the exact sciences in the paradigm of the natural sciences can already be seen. The classificatory brackets over metaphysics, theology, humanities (*sciences de l'homme*) and natural science still display the old systematics without providing any firmer foundation. The order of knowledge exhibits more and more contingent elements.

The same also applies to more recent attempts. Take for example the four-part classification[4] that distinguishes among 'formal-operational' sciences, natural sciences, anthropological sciences, and cultural sciences or the three-part classification[5] that separates the empirical-analytical sciences, the historical-hermeneutic sciences, and the systematic sciences of action. The first classifies according to the subject matter, the second according to cognitive interests. The choice of a point of view for classification also alters the 'systematics' of the sciences.

Thus, strictly speaking, a suggested classification does not automatically count as a contribution to the production or preservation of the unity of science. On the contrary this kind of classification scheme can (as in the case of Habermas) be linked to the explicit assertion of the fundamental distinctness of the so classified areas of science. As early as the French *Encyclopedia* the unity of science was expressed not only in the notion of order but also in the

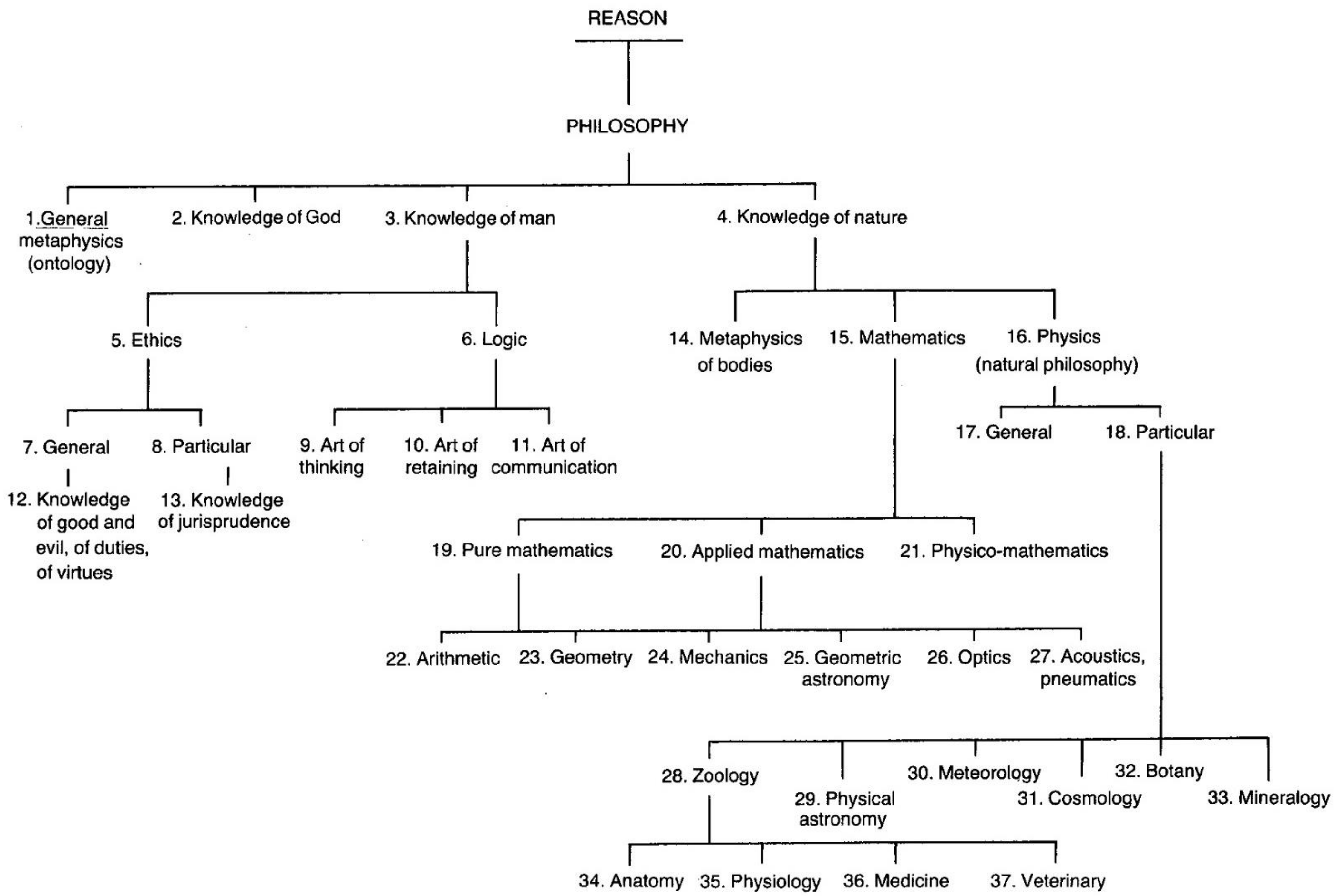

Figure 1. *The system of human knowledge. (Taken from d'Alembert, 1751,* The Encyclopedia. Selections, *pp. 42–43.)*

notion of the interconnections of human knowledge. The *Encyclopedia*, said d'Alembert in his introduction, "doit exposer [...] l'ordre & l'enchaînement des connoissances humaines".[6] The classification thus may not simply juxtapose disparate elements but must evidence a unifying point of view. In other words, if a classification is to be the expression of the unity of science, then it must represent a *system*. On this point Kant remarked:[7]

> In accordance with reason's legislative prescriptions, our diverse modes of knowledge must not be permitted to be a mere rhapsody, but must form a system. Only so can they further the essential ends of reason. By a system I understand the unity of the manifold modes of knowledge under one idea.

Consequently, the unity of science is not itself the result of a classification; rather, it lies in the systematic coherence of knowledge ordered by an idea.

But what makes science cohere? It is difficult to find a character general enough to be ascribed to every science and yet specific enough to have some content. If we see the unity of science as characterized by the fact that all scientific disciplines strive for the acquisition of knowledge, this is correct but too indeterminate. For, consciousness raising groups and educational travel both serve this purpose, too. Much the same applies to the characterization of science as an open enterprise, as a never ending quest. This is also true, but it applies just as well to the striving for personal perfection or for the establishment of the ideal state. Thus, the task arises of characterizing the unity of science in a manner both general and precise.

In the following we shall discuss two basic approaches to the solution of this task. These are the unity of science with respect to *theory and structure* and with respect to *practice and operation*. The theoretical-structural unity of science can in turn be divided into three particular aspects: (1) the unity of the *language of sciences*; (2) the unity of scientific *laws*, and (3) the unity of scientific *method*. These four options will be examined more closely. We shall come to the conclusion that the theoretical-structural unity of science can only properly be said to exist in the third variant, the unity of method, and that the practical-operational unity of science to a certain extent already holds and to a certain extent represents an important desideratum.

2. The unity of the language of science

The idea of a unity of the *language of science* finds its first convincing expression in Leibniz. Leibniz considered a fundamental reorganization of knowledge, which was his program, to be dependent on a reorganization of the language of science, the heart of which was the construction of an artificial language, the *characteristica universalis*. This was supposed, on the basis of a theory of signs (*ars characteristica*) for the representation of states of affairs and their relations to one another, to include both logical inference and decision procedures (*ars iudicandi*) and also substantial conceptual determinations on the basis of a theory of definition (*ars inveniendi, ars combinatoria*) thus giving inferences based on content the formal certainty of calculation. What Leibniz had in mind is not a doctrine of classification (in the sense of Lullus), but also not a more general philosophical doctrine of method (as Descartes conceived it). It is rather a *formalism* for generating and representing knowledge, according to which the construction of the scientific language sought after is guided by the idea of organizing the relation of the words (concepts) of this language to their basic concepts in the same manner as the natural numbers relate to the prime numbers. The definite derivability of all concepts of this language from certain basic concepts was to be modelled on the definite divisibility of all numbers into prime numbers.

Leibniz was only partially able to realize his ideas, namely, within the framework of the infinitesimal calculus and a number of logical calculi. His calculus program is in a sense the first successful language-of-science program, but it covers only one aspect of that program. More recently, the idea of the unity of scientific language constituted the core of the program of the unity of science propagated in the 1930s within Logical Empiricism. This program now concerned itself primarily with the uniformity of the principles of concept formation in science. It is characterized by the thesis that all scientific statements can be formulated in one language, namely, in the *physicalist* language. The physicalist language was considered to be the universal language of science and thus to constitute the unified foundation of all particular scientific theories. A language is considered physicalist when it ascribes to particular space-time points particular, intersubjective and intersensual qualitative traits or quantitative values.[8]

The justification of this thesis rests decisively on the so-called *verificationist theory* of meaning. According to the verificationist theory the meaning of a statement coincides with the results of the procedures that allow its validity to be tested. A proposition is only meaningful if it can be assigned at least one test procedure. Its meaning is unequivocally fixed by the possible results of this test procedure. In particular, its reference is identical to the assigned test indicators. When this semantic theory is applied, for instance, to psychology, we get the following interpretation: All propositions relating to the mental events of other persons (thus e.g. 'Henry is happy') can only be tested with reference to observable behavior (such as Henry's utterances and expressive actions). This implies that such psychological propositions mean precisely the same as propositions about the corresponding behavior. Statements about psychological phenomena are thus always translatable in statements about behavior, that is, about physical circumstances. It cannot sensibly be said that the physical expressive action is the effect of a psychological state; rather, the two are identical.[9]

This example illustrates the basis of the general assertion that all states of affairs can be expressed in physicalist language or that their descriptions can be translated into it. The fragmentation of science disappears with this uniform language and its unity becomes clear. This unity applies, however, only to the uniform *description* of the states of affairs not to their uniform *explanation*. That all states of affairs can also be explained by physical laws is not a semantic but an empirical thesis.[10]

In the concrete form expressed in Logical Empiricism, the thesis of the unity of the language of science evidently rests on verificationist semantics. However, this has in the mean time been abandoned and replaced by the *double language model* or by the *theoretical context account of meaning*. In both conceptions *theoretical concepts* are permitted, that is, concepts which refer to entities not directly or not at all observable and which can also not be defined explicitly in terms of observational concepts. On the contrary, theoretical concepts are introduced by the postulates of a theory and their function and role is explicated accordingly by the appropriate theoretical context. While theoretical concepts are generally coordinated with observational indicators by correspondence rules, nonetheless, these concepts cannot be translated into such empirical indicators. The reason for their introduction is that they help successfully to order and unify experimental laws. Concepts such as electromagnetic field or the quantum-mechanical wave function, to which empirical characteristics can be assigned only indirectly, partially, and in a manner mediated by theory, are considered legitimate, because with their help the explanatory power of the theories can be increased. Theoretical concepts are thus legitimate explantory constructs.

The essential aspect in this connection lies in the fact that not only the natural sciences but also the social sciences employ theoretical concepts. This can be illustrated on an example taken from psychology. The concept of motive in cognitive psychology is such a concept. Motives are not directly observable; rather, they are introduced as hypothetical constructs that serve to systematize and predict observable behavior. The practical success of such a theoretical description can be seen, for instance, in the theory of cognitive dissonance developed by Festinger. This theory tries to clarify the influence of a particular motivational process on behavior. The theory assumes that cognitive dissonance is a motivational state that always occurs when a psychological conflict arises, e.g. between two incompatible convictions or between beliefs and behavior. This motivational state generates behavior calculated to alleviate the dissonance. In the case of a conflict between attitude and behavior, either the attitude or the behavior is changed in such a manner that the two are again brought into harmony.

The extent of the cognitive dissonance is dependent not only on the degree of opposition between conviction and action but is also determined by the availability of justifying grounds. If one can adduce good external reasons for a behavior that goes against one's convictions, the tendency to adapt convictions to behavior is reduced. This central prognosis of dissonance theory has been experimentally confirmed.[11] Brehm & Cohen (1962) asked students to write essays defending a thesis that contradicted their own real opinions, which had been ascertained in advance, and rewarded them for their efforts with different amounts of money. Subsequently, the experimental subjects filled out a purportedly anonymous questionnaire which once again ascertained their real opinions.

According to dissonance theory there is a conflict here between belief and behavior, behavior being fixed by the experimental conditions. In this case a reduction of dissonance could only be effected by a change in attitude. The theory then predicts that the less convincing the justifying grounds for the conflict laden behavior are, the more the opinions expressed in the questionnaire (i.e. those influenced by the experiment) will deviate from the original opinion. The justifying grounds consist here in the sums of money paid. This leads to the prediction: the less the sum paid, the greater the experimentally induced change in opinion. This prediction was confirmed.[12]

This example illustrates how in psychology a theoretical law can specify an interaction between hypothetical magnitudes (namely mental events) and in this manner allows us to arrive at an explanation and prediction of behavioral regularities.[13] This suggests the conclusion that the principles of scientific concept formation in different disciplines do in fact correspond to one another. On this point the Logical Empiricist assertion of the semantic unity of science is thus legitimate, even though these principles are quite different in content from those that Logical Empiricism (at least in its early forms) envisioned.

This conclusion, however, only provides a convincing justification of the unity of science as long as no other, non-scientific enterprises can be characterized by the same semantic principles. Otherwise, the recourse to semantics would be too imprecise to characterize the unity of scientific procedure (and thus would share the fate of the other attempts mentioned above). This is in fact the case. Let us illustrate this on the example of the theological theory, that is given allegorical sculptural expression in the Venician church Santa Maria della Salute. There we see Venicia on her knees praying, entreating the Virgin Mary to rescue her from the plague. Mary hears her prayer and sends an angel to drive away the plague. The angel carries out his commission and expels the outraged and fleeing plague.

It is not difficult to recognize the semantic structures designated above as the characteristics of scientific concept formation. First we have the empirical data base: the praying citizens of Venice. This observable state of affairs is connected by correspondence rules with a particular theoretical state, namely, the state of mind of Mary. The theory assumes the influence of an observed magnitude on the theoretical magnitude 'Mary's mood'. Furthermore, Mary's act of rescue is carried out essentially according to a theoretical law. We have the effect of a theoretical state (the favor of Mary) on another theoretical state (the activity of the angel). This activity is in turn connected by a correspondence rule with observable occurrences (the recession of the plague). The observable events are thus connected to one another by a hidden causality on the level of not directly observable, theoretically determined states and thus explained by theoretical laws.

This example makes it clear that theological and scientific theories can display the same semantic characteristics. In both cases we find a connection of observable events with theoretical entities (that is, correspondence rules), and furthermore, theoretical laws that establish relations between these theoretical entities. These relations then provide correlations between the observable events so that the theoretical laws can explain the empirical correlations. To sum up: the unity of scientific language, in the sense of a uniformity of the principles of scientific concept formation, does in fact exist, but the significance of this fact is much too limited to serve as the foundation of the unity of science.

3. The unity of scientific laws

The notion that the unity of science is documented by the unity of scientific *laws* was also articulated within the framework of Logical Empiricism. It represents a radicalization of the semantic thesis: All states of affairs can not only be described in a uniform manner, they can also be explained in a uniform manner. The unity of science accordingly takes on the form of *unitary science*. The assertion is that in the last analysis all science can be traced back to a single discipline, namely, physics. This assertion is conceived of as a plausible hypothesis whose viability will be decided by the progress of science.

For Schlick, for instance, scientific knowledge is characterized by the fact that it orders different events and shows them to be instances of a single universal law. A system of sciences arises in which particular propositions are traced back to general laws and these in turn are traced back to more comprehensive theories, which finally coalesce to a universal comprehensive approach.[14] Although thus far three basic disciplines coexist disparately— the science of the inorganic world, i.e. physics, the science of the living, i.e. biology, and the science of mental and emotional processes, i.e. psychology—, we may nonetheless expect this separation gradually to be overcome.[15]

> The sciences band together of their own accord through the progress of knowledge; [. . .] Human knowledge becomes a unified closed whole that itself bears the marks of a system. This seemingly contradicts the complaint that the specialization of the sciences at present is continually increasing [. . .] If we have in mind with the word 'science' the different procedures that we must apply to acquire knowledge, [. . .] then it is indeed correct to speak of fragmentation. [. . .] However, if we mean by 'science' [. . .] the system of statements, of truths, of knowledge, then we find [that it] is becoming ever more unified to a coherent whole.[16]

Thus, the unity of science is documented not by the uniformity of scientific methods but by the uniformity of scientific laws.

Feigl (1953) articulates the program of unitary science in the same vein. Like Schlick before him, Feigl believes this program to be supported by studies of the history of science. Once separate disciplines such as mechanics, acoustics, astronomy, or thermodynamics can today be derived to the largest extent from a unified basic approach. Consequently, it is to be expected that in the future further progress along this path to synthesis will be achieved.[17] On the other hand, Feigl attempts to dispose of logical-conceptual impediments which might block further nomological unification. One such impediment is the appearance of *emergent* regularities. In emergent laws the concepts of one theory can be coordinated with the concepts of another theory which potentially applies to the phenomena under consideration, but no deduction of these laws succeeds within the framework of the theory. If for instance the biological mechanisms in a cell could be described with physical concepts but could not be explained by physical laws, then cell biology would be emergent relative to physics.

If emergence is to present an effective argument against the unification of science, it must be made plausible that the non-deducibility is not merely factual but rather a non-deducibility in principle. To this Feigl points out that emergence could be the consequence of the particular arrangement of the components of the system[18] so that the impossibility of deducing the behavior of the whole from the behavior of the parts is based on ignorance of the precise interactions of the parts and thus is merely contingent. Feigl further seeks to defuse the problem of emergence by pointing out the existence of emergent phenomena in inorganic nature.[19]

Oppenheim & Putnam (1958), too, consider the program of unitary science to be credible. This program is to be carried out by *reducing* the theories in various sub-areas and disciplines to physics. It can plausibly be assumed that by way of a step-wise reduction, e.g. the laws of psychology could in the end be reduced to atomic physics.[20] Besides the historical justification, that reductions have again and again been successful in the history of science, Oppenheim & Putnam introduce among others a heuristic viewpoint: The assumption of reducibility has encouraged scientific research in manifold ways, whereas this does not hold for the assumption of non-reducibility.[21]

The thesis of unitary science has thus been supported above all by three strategies of argument:

(1) The *historical inductive argument*. The history of science is characterized by a multiplicity of successful reductions. Therefore it is to be expected that presently separate disciplines, too, will in the future be joined together.

(2) The *argument as to possibility in principle*. There are no logical-conceptual impediments to the unification of all disciplines.

(3) The *heuristic argument*. The assumption that all disciplines are to be unified is scientifically fruitful in as much as it encourages the search for more comprehensive theories. The assumption of non-reducibility lacks this fruitfulness.

These strategies of argumentation remain unconvincing. First of all, the historical inductive is factually wrong. The history of science by no means presents a triumphant unbroken chain of successful reductions. A more complete study reveals, on the contrary, that the number of failed reduction programs surpasses the number of successful programs. Remember the Descartes-Boyle program of reducing all interactions to pressure and impact of particles, or the attempt by the corpuscular theory of light to trace all optical laws back to mechanics. Similar misfortune befell the attempted reduction of electrodynamics to mechanics ('mechanistic world picture') or vice versa of mechanics to electrodynamics ('electrodynamic world picture'). The same goes for Planck's attempt to reduce the early quantum theory to Boltzmann's statistical mechanics. This suggests that the historical inductive argument rests on a one-sided choice of examples.

The historical inductive argument is, however, the only one of the three arguments that would in principle be suited (if it were correct) to give some factual support to the thesis of unitary science. Without such factual support, the argument of the possibility in principle (although it is correct) also does not carry much weight, since this merely affirms the lack of self-contradiction or the coherent intelligibility of the thesis of unitary science. Such a property can also be ascribed to the fairy tale of Rumpelstilzchen.

Finally, the heuristic argument fails to ground the notion of a unitary science. First of all, fruitfulness does not imply objective validity (as Duhem already saw).[22] Furthermore, the heuristic fruitfulness of the claims of reduction is doubtful. For instance, the development of electrodynamics in the nineteenth century can be characterized by an increasing independence of the concept of field and a corresponding rejection of mechanistic reductive claims. In this case the insistence on fulfilling the claims of reduction would not have helped the development of science but rather impeded it. Even as a working hypothesis the program of unitary science is not convincing.

All considerations taken together thus lead to the conclusion that the unity of science cannot be grounded on the notion of a unitary science, that is, on a unification of the content of science. A comprehensive claim for reduction cannot credibly be maintained. On the contrary, modern chaos theory makes it clear that in some areas of science demands for reducibility can no longer sensibly be applied. Due to the inability of theory to track the development of certain systems over time, the regularities of this development cannot be expressed by theoretical laws. The notorious unpredictibility of the weather bears eloquent testimony to this. Although the laws of thermodynamics in principle are, or should be, able to describe meterological events completely, nonetheless, a definite theoretical explanation and especially prediction of the weather remains unsuccessful.[23]

Furthermore, there are scarcely any empirical indications that the comprehensive claims of reduction can be met. Thus for instance there is no path whatsoever in sight by which the theory of cognitive dissonance sketched above could be derived from the laws of neurophysiology. Generally speaking, a reduction of psychology to neurophysiology is not even visible on the horizon. That means that the program of unitary science is not convincingly supported, and that accordingly the unity of science cannot be founded on nomological unity.

4. The unity of scientific method

Alongside the unity in terms of semantics and uniformity in terms of content there is a third option in the notion that the unity of science can be grounded in the unity of scientific *method*. We consider this option to be justified. However, it must be carefully specified what 'scientific method' means in this context and what it does not mean.

In the first place the expression 'scientific method' does not refer to the mathematical or physical tools, that is, to the methods of measurement and evaluation. Romance language studies makes little use of the method of statistical significance testing, and sociology rather seldom consults an ammeter. The employment of quantitative results is also not characteristic of scientific method. It is evident that Linné's system for comprehensively classifying biological species is science and that Darwin's theory of evolution has scientific status. Nonetheless, there are scarcely any quantitative concepts in either theory. Now, we could weaken this condition so that we merely say that science strives for the most precise expression possible. But let us hope that this endeavor is not exclusive to science.

Instead, we shall understand scientific method as the ways and means by which *claims to validity* in science are *justified*. The central point here is that the simple reference to facts does not suffice for a justification. Theories are *underdetermined* by facts. In science such an underdetermination occurs in at least three respects, namely (1) ambiguity, (2) factual empirical equivalence, and (3) as complete empirical equivalence.

First of all, in some situations, the facts do not allow a definite decision between theoretical alternatives, because one theory is empirically more successful in one domain of phenomena while its competitor is more successful in another. One example is optics in the 19th century. For the wave theory of light the paradigmatic cases of application were the phenomena of interference and polarization, whereas it ran into considerable difficulties in the explanation of rectilinear propagation and dispersion. The corpuscular theory, on the other hand, had no difficulty with the latter phenomena but could only insufficiently account for the former. In such cases as these the facts do not speak unambiguously.

Secondly, the electron theory of Lorentz and the special relativity theory of Einstein were at first empirically equivalent with regard to all actually feasible experiments and observations. Both theories led to the same predictions for the domain of experience accessible at the time. In spite of the fundamental difference of the theoretical mechanisms employed, an empirical decision between the two was not possible in their common domain of application.

Thirdly, the Newtonian theory of gravitation can be expressed in a manner that is conceptually fundamentally different from the usual formulation. Instead of assuming, as in the usual formulation, a gravitational force acting in a flat space-time structure, we can interpret gravity as an expression of the space-time structure. In this approach a curved space-time is introduced and gravitation as the effect of force in the narrow sense is dispensed with. Both theoretical options are indiscernible not only with regard to actually conducted but with regard to all possible observations. They are empirically completely equivalent.

The systematic expression of the underdetermination of theory by fact illustrated by these three examples is the *Duhem-Quine thesis*. Duhem pointed out that in the application of a hypothesis to experience, that is, in its experimental testing, the hypothesis in question is never employed in isolation. Rather, a number of other assumptions must also be introduced (e.g. theories of observation, background knowledge, and auxiliary hypothesis). An experimental failure accordingly shows only that somewhere in this network of assumptions there lies an error; it does not specify which of the assumptions employed is false. Hypotheses, consequently, cannot be judged unequivocally by experience.[24] This insight has been radicalized by Quine as the thesis that any arbitrary theoretical hypothesis could be maintained in the face of any arbitrary empirical data as long as one is prepared to make changes (perhaps even drastic changes) in other parts of the theoretical system to which the hypothesis belongs.[25] However tenable this (controversial) radicalization of Duhem's assertion is, it is in any case clear that facts do not stipulate their theoretical descriptions. Science has considerable freedom *vis-à-vis* nature.

The essential trait of scientific method should be seen precisely in the way science deals with this freedom. The form of scientific theories is determined by *methodological criteria*. One such methodological criterion is the demand raised by Whewell in the mid-nineteenth century that theories ought to explain not only those phenomena they were invented to explain but also to allow the explanation of other phenomena which until then had been considered different in kind ('consilience of inductions'). Thus Newton's theory of gravitation showed that the fall of a body on the earth and the motion of the planets could be described by the same laws; the general theory of relativity was invented to remove the privileged character of inertial frames and thereby, as it were by surprise, solved the problem of the anomaly in the motion of Mercury's perihelion.

A similar criterion can be seen in the demand (already mentioned by Leibniz) that a theory predict novel and unexpected phenomena. Thus the credibility of Fresnel's transverse wave theory of light was considerably raised by the correct prediction of a bright spot

(Poisson's spot) in the shadow of a round object illuminated by a point light source. In other words, both criteria distinguish certain historical developmental patterns of science. If a theory in the course of its development unifies different areas of experience and anticipates new experiences, then it is better confirmed than a theory that seeks to cope with the same phenomena in a disconnected manner and adduces *post hoc* explanations.

It is not our intention to solicit support for the particular methodological criteria presented here. The point is merely, that not only in the natural sciences but also in the social sciences and the hermeneutic disciplines methodological criteria are employed. Thus, for instance, in the cognitive dissonance experiment described above an effect was predicted that was incompatible with the previously accepted reinforcement theory of Skinner. The characteristic prediction is that the behavioral changes induced by the experiment increase as the reinforcement decreases. Skinner's theory of reinforcement led to just the opposite expectation. The example shows that prediction according to laws is also found in psychology and that psychological theories can in principle be judged according to the same methodological standards as can theories in natural science.[26]

The hermeneutical disciplines, too, that is, those disciplines dedicated to the explication of expressions in language, to the reconstruction of text and context, employ principles that can be judged as analogous to methodological criteria. The basic problem consists in the fact that from someone's linguistic behavior (e.g the utterance by A: Constance lies on Lake Constance) we can only infer a particular conviction (that A actually believes that Constance lies on Lake Constance) if we know the meaning that A gives to his concepts (that with the word 'Lake Constance' he is referring to Lake Constance). Of course, in this geographic example the problem is rather trivial; difficulties generally arise when the systems of belief of author and reader differ to a considerable extent. Thus, for instance, Kant mentions that the chemical elements earth, water, air and fire are to be conceived as ideas,[27] a remark that must seem rather peculiar to the modern reader. The confusion only increases when one takes into consideration that for Kant 'ideas' are fictitious ordering viewpoints, i.e. principles for systematizing experience to which nothing in nature corresponds. If we take Kant's remark in this sense, then it seems to express the conviction that all chemical elements are mere fictions.

The solution to this problem of understanding is that Kant attributes to the concept of chemical element a meaning that differs from our current understanding. He is referring to the chemistry of principles which sought to explain the properties of chemical materials by introducing a few elementary principles considered to be the source of such general properties as hardness or combustibility. The principles are not conceived to be common substances but to be the causes of the properties of chemical substances. Principles can in principle not be isolated chemically but are used only to systematize the observable characters of chemical substances. We can see that on the background of this (historical) conception, Kant's view of the elements as useful fictions gains some plausibility.[28]

The example just given illustrates a typical hermeneutic problem and the way it is solved. Such a problem is characterized by the fact that an author uses concepts in a way unfamiliar to us, so that we may not ascribe to him those beliefs that a contemporary speaker would express with these words. In such cases the meanings of the concepts can only be more precisely determined through the reconstruction of the system of beliefs of the author studied. In our example the consideration of the background beliefs of the time leads to a hypothesis about Kant's system of beliefs, which provides a basis for determining the appropriate meanings of the concepts. This means that the meanings of the relevant concepts are derived from a knowledge of the beliefs, and on the other hand, the beliefs can only be inferred if one already knows the meanings of the concepts. The system of beliefs is thus *underdetermined* by the linguistic expressions.

The extent of this underdetermination can be reduced by the application of further criteria which guide the interpretation. Two such criteria are the *principle of charity*, according to which the ascriptions of meaning should be done in such a fashion that as great as possible a number of the utterances (as judged by one's own standards) are true, and the *principle of coherence*, according to which the meanings are to be specified in such a manner that the system of beliefs that arises is consistent and as deductively systematized as possible.

Once again here, the point is not the actual adequacy of the principles. It is only important that these principles function analogously to methodological criteria in the empirical sciences. It is only through them that it is possible to select one particular interpretation from among many alternatives; only they allow a choice among interpretations of a text that appear equally plausible in light of the data available. The principles thus serve the same purposes as do the methodological criteria; they are the hermeneutic counterparts of these criteria.[29]

Thus, it is the existence and role of methodological criteria that is common to all scientific theory formation and all scientific activity. *Such criteria characterize the methodological unity of science.* We may also express this by asserting that the unity of science consists in the unity of scientific rationality or of the criteria of scientific rationality, that is, in the unity of the idea of scientific progress.

5. The unity of the subject matter of science

Having examined in the last three sections three attempts to ground the unity of science with regard to theory and structure, we now turn to the practical-operational unity of science. This point of view refers to the *disciplinary organization* of science. Just as little as theories simply track the facts of nature, does the disciplinary structure of science track them. There is no simple rationality of the facts that the organization of disciplines could follow. Disciplines are historical entities and their boundaries are historical boundaries.[30] The historical identity of disciplines is constituted by particular research objects, methods, theories, research purposes which often do not complement one another to form a disciplinary definition but rather instigate interdisciplinary interference.[31]

This also becomes clear through the fact that the problems whose solutions the sciences seek often do not fit a clear disciplinary framework. This is by no means a peculiarity of the modern world or of modern science. If we examine, for instance, the history of the problem of the theoretical description of heat, we see that the disciplinary jurisdictions were quite doubtful there. On the basis of early theories, heat was often conceived to be internal motion of matter and thus to be the subject matter of physics. In the caloric theory of heat, formulated by Boerhaave at the beginning of the eighteenth century and later articulated by Lavoisier, heat was conceived as a substance and consequently became the subject matter of chemistry. Finally with the kinetic theory of heat, heat once again changed disciplines and again became the object of physics.

The history of science, too, thus shows that there are problems whose disciplinary membership is unclear. This can in turn be generalized as the insight that certain problems cannot be tackled by a single discipline. This circumstance has gained additional importance in the present in as many of those problems that resist the approach of a single discipline are precisely the ones that are particularly urgent. Examples are: environment, energy and the consequences of technology. There is an asymmetry between the development of problems and the development of disciplines, and this asymmetry increases to the extent that disciplinary development is increasingly determined by specialization. There are problems "whose discipline we haven't found yet"[32] and—on the background of increasing particularization and atomization of fields of study and disciplines—perhaps never will find. Therefore, the opposite path, the return to larger disciplinary and interdisciplinary units is also the more promising alternative, for instance, in the case of environmental problems. Ecological problems are complex problems, they can only be solved by the cooperation of many fields and disciplines.

Here, genuine interdisciplinarity is needed, however, not just a mere concatenation of disciplines. In light of the problem situation of the modern world and the development of science there are no simple additive (scientific) solutions along the lines: "if every science, every scientific discipline, every scientific field of study does its job, the whole project will succeed". When taken really seriously, interdisciplinarity is in truth *transdisciplinarity*. It does not simply shuttle back and forth between disciplines and fields; it does not leave things in these areas simply as they are, but rather changes them, removes the historical boundaries, and last but not least gives science the ability to make problems and problem developments recognizable before they begin to breath down our necks. This is, for instance, the business of science and technology assessment, which at present is to the largest extent an art without accomplished practitioners. In other words, interdisciplinarity as transdisciplinarity must begin in our own heads; it cannot be organized as an executive meeting of disciplines and fields of study which themselves do not change but persist in their historical and institutional boundaries.

One could view transdisciplinarity in this connection also as an expression of the *unity of the subject matter of science*. However, in this case the nature of this subject matter must be specified quite precisely. Otherwise, one unintentionally asserts the unity of limnology and water sports, both of which deal with much the same object: lakes and rivers. What we mean, again, is that science is confronted with problems whose solutions are possible only through the cooperative exertions of the sub-areas of science which themselves are changed by this exertion.

This would also mean that in regard to transdisciplinarity science is moving in a direction in which disciplinary and departmental structures fade away. This applies in particular to science as a *research activity*. We still conceive of science primarily as propositional knowledge, that is, as knowledge in the form of theories or textbooks. We thereby overlook the fact that the actual reality of science is its *research form*. Research, however, is essentially action, carried out, it is true, under conditions of theory and method, but not itself as theory or method. This is true of research only when it describes itself in its results and its pathways. If science had essentially only the form of theory and method, research would itself be trans-scientific, it would grow out of science.

Thus, a conception of science that considers only its theoretical and methodological aspects is insufficient. The objects studied, the theories, methods and research purposes which constitute the historical and systematic essence of disciplines and fields of study provide only an imperfect definition of what science is; they grasp research only in its 'theoretical' structures not in its practice. This means in turn that the future of science lies not so much in what it knows in theoretical and methodical form, but in what it does in concrete research situations, e.g. laboratory situations. Transdisciplinarity is first of all a *research principle*, not a theory principle.

Let us return once again to the unity of science. If we recall what has been said about the unity of scientific rationality or the unity of scientific criteria of rationality, the unity of science is expressed as the methodical and practical-operational unity of science. In diametrical opposition to the notions of Logical Empiricism, as represented by Schlick, we formulate and argue for the thesis that the unity of science is not displayed in the unity of a doctrinal structure but in its unity as a *practical research form*. In this sense the unity of science is the unity of scientific practice.

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Notes

1. On this and what follows cf. Mittelstrass, 1989, pp. 101ff. Throughout this article 'science' is taken in a comprehensive sense (i.e. in the sense of the German 'Wissenschaft'). It refers not only to the natural sciences but also to the social sciences and the humanities.
2. On the distinction between fields and disciplinarities cf. Heckhausen, 1987, pp. 129–131.
3. Cf. Mittelstrass, 1980.
4. Stachowiak, 1969, pp. 127–131.
5. Habermas, 1968, pp. 155ff.
6. D'Alembert, 1751, I.
7. Kant, 1787, B860.
8. Cf. Carnap, 1931, pp. 441–445; Neurath, 1935, p. 17. Intersensual means that the description contains no reference to particular sensations. The acoustic experience of the tone Middle A should be described as air vibrations of 440 hertz. Cf. Carnap, 1931, pp. 444–445.
9. Cf. Carnap, 1928, pp. 38–41, 64–68.
10. Cf. Carnap, 1931, pp. 448–449, 462–463.
11. Brehm und Cohen, 1962.
12. On this description of dissonance theory cf. Carrier & Mittelstrass, 1989, p. 144.
13. For further discussion cf. Carrier & Mittelstrass, 1989, pp. 152–157.
14. Cf. Schlick, 1933/34, pp. 54–55.
15. Cf. Schlick, 1933/34, pp. 57–58.
16. Cf. Schlick, 1933/34, pp. 58–59.
17. Cf. Feigl, 1953, p. 383; Schlick, 1933/34, p. 55.
18. Cf. Feigl, 1953, p. 384.
19. Cf. Feigl, 1958, pp. 414–415. For further arguments of Feigl's, especially on the reduction of psychology to physics, cf. Feigl, 1963, pp. 242–263.
20. Cf. Oppenheim & Putnam, 1958, pp. 7–8.
21. Oppenheim & Putnam, 1958, p. 16.
22. Cf. Duhem, 1906, pp. 41–43.
23. For an expanded form of this argument, cf. Carrier & Mittelstrass, 1989, pp. 363–378.
24. Cf. Duhem, 1906, pp. 280–285.
25. Cf. Quine, 1951, pp. 42–46.
26. For argumentative support of this thesis cf. Carrier & Mittelstrass, 1989, pp. 140–148.
27. Cf. Kant, 1787, B673–674.
28. On this example cf. Carrier, 1990 (section III.4).
29 For further explication of this theory of hermeneutics cf. Carrier & Mittelstrass, 1989, pp. 112–120.
30. On this and what follows cf. Mittelstrass, 1987, pp. 153ff., and Mittelstrass, 1989, pp. 104ff.
31. Cf. Krüger, 1987.
32. Krüger, 1987.

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