Reductionism Revisited

On the Role of Reduction in Psychology

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ABSTRACT. Reductionism in psychology is often linked with the mind–body problem. This paper reviews the reductionism debate and concludes that many of its controversies can indeed be traced to the relation between reduction and the metaphysical mind–body problem. It is proposed that reductionism, by bridging different theories, rather should be considered as a scientific stance which favours interdisciplinary co-operation. This perspective on reductionism throws a new light on the classical model of reduction, which may capture important aspects of intertheoretic reductions if it is recognized that the bridges between theories do not need to comply completely with the classical conditions. These ideas are illustrated by analysing an example of reductionistic research concerning the psychology and neuropsychology of attention-deficit/hyperactivity disorder.

KEY WORDS: attention-deficit/hyperactivity disorder, mind–body problem, models of reduction, reductionism, theories

Ever since Paul Oppenheim and Hilary Putnam (1958) developed their notion of theory reductionism as a working hypothesis, reductionism has attracted much attention and generated considerable controversy. In psychology, reductionism often takes the form of a thesis about the relation between the mind and the body. It is expected that the reduction of theories provides grounds for an articulation of the metaphysical mind–body problem in rigorous scientific terms. John Bickle (1998, 2003) labelled this the *Intertheoretic Reduction (IR) reformulation of the mind–body problem*. The idea is as follows. First, conceptions and intuitions about mental phenomena are seen as a psychological *theory* (Churchland, 1981). Consequently, questions concerning the relation between mental and physical phenomena can be construed as questions about the relation between this psychological theory and its physical counterpart. Traditionally, reduction is the kind of relation thought to obtain between theories, allowing ontological conclusions. For example, the reduction of thermodynamics to statistical mechanics yields the

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conclusion that temperature is ‘nothing but’ mean molecular energy. Along similar lines, the mind–body problem can be reformulated as the problem of the reduction of psychological to physical theories. A reduction relation obtaining between psychological and physical theories would answer the mind–body problem in a relatively transparent manner: the mental phenomena are ‘nothing but’ the phenomena described by the physical theory. For example, if psychological theories about pain were to be reduced to neurological theories concerning C-fibres, it could be concluded that the mental phenomenon of pain is nothing but the physical phenomenon of C-fibre firing. In short, reductionism in psychology is not only a thesis about the relation between psychological and physical theories but also a *reformulated ontological claim* about the nature of the mind in relation to the physical body.

This paper examines the issue of reductionism in psychology. One of its central theses is that the connection between theory reduction and the mind–body problem should be denied. First, the history of the reductionism debate will be briefly reviewed, focusing on classical reductionism and two recent readings of reductionism. This review will show that a metaphysical interpretation of reduction has led to problematic and highly controversial notions of reductionism and has unnecessarily complicated and obscured the real reductive issues. Second, we will present our own alternative view of reductionism. It will be argued that reductionism is not a theory about the mind–body relation, but that it is a methodological stance in science which aims at bridges between different theories. These bridges are needed for an interdisciplinary approach to scientific problems. Next, we will argue that this new perspective on reductionism may also shed a new light on the classical model of reduction. Finally, we will provide an illustration of the claims made in this paper by means of a concrete example of reductionism involving theories of attention-deficit/hyperactivity disorder.

The Debate about Reductionism: A Review

Classical Reductionism

Classical reductionism finds its earliest roots in Carnap (1938), who developed the concept of the unity of laws. The unity of laws is the construction of a homogeneous system of laws for the whole of science in which the laws of one scientific discipline are derivable from those of another. Twenty years later, Oppenheim and Putnam (1958) elaborated on this idea and formulated a precise concept of the ‘unity of science as a working hypothesis’ in terms of the micro-reduction of theories. Micro-reduction is the reduction of *higher*-level theories (such as psychological theories) to *lower*-level theories (such as theories in neuroscience). Oppenheim and Putnam employ a concept of reduction according to which a higher-level theory (the theory to be reduced [T_R]) is reduced if a lower-level theory (the more basic theory [T_B]) explains the same or more phenomena and is at least as systematized. A disadvantage of this concept of reduction is that it describes only the relation between T_B and the empirical claims of T_R. A more interesting notion of theory reduction, however, would obtain a direct relation between T_B and T_R (Schaffner, 1967).

Ernest Nagel's now classical model does involve a direct reduction of T_R to T_B (Nagel, 1961, Ch. 11). According to Nagel, T_R is reduced to T_B if the laws of T_R can be logically derived from the laws of T_B: the *condition of derivability*. T_B is often more general than T_R, in which case derivability is only possible by means of additional boundary conditions. When the higher-level theory contains terms that do not occur in the lower-level theory (so-called 'heterogeneous reductions'), derivation of T_R from T_B requires *bi-conditional bridge laws* between the expressions of both theories (e.g. organisms experience pain if and only if their C-fibres fire).

In the light of the IR reformulation, the ontological question about the relationships between mind and body can now be rephrased precisely in terms of intertheoretic reduction. Thus classical reductionism in psychology not only concerns the relations between psychological and physical (i.e. neuroscientific or biological) theories, but is also presented as an answer to the ontological mind–body problem. In this sense, classical reductionism amounts to the claim that psychological theories will (ultimately) be reduced to physical theories in a way that satisfies the conditions as outlined by Nagel's model. (For definitions of reductionism along these lines, see, e.g., Fodor, 1981, p. 127, or Sober, 1999, p. 542.) Especially these ontological claims, based on the classical model of reduction, have made reductionism a notorious view. Generally, the claims made by classical reductionism have been challenged on two different fronts. The first challenge questioned the premises of the reductionist argument: reductionism would be false because the classical reductions of psychological theories are not and will not be available. The second challenge argued that even if such reductions were available, this would not deliver any interesting conclusions about the mind–body relation. Both challenges will be discussed in turn.

Challenging the Premises of Classical Reductionism: Towards New-Wave Reductionism

Initial criticisms of classical reductionism accepted the validity of the argument that if psychological theories classically reduce to lower-level theories, this reduction offers the sought-after ontological reduction. Nevertheless, it has been argued that reductionism is *false* because such reductions have never taken place and will never do so. Almost every historical and paradigmatic example of theory reduction, like the reduction of thermodynamics to statistical mechanics, appeared *not* to conform to the conditions of the classical model (Hooker, 1981). Often, reduction involved the replacement of the ontology of the old theories, like the replacement of phlogiston by oxygen (Churchland & Churchland, 1994; Kuhn, 1970). Feyerabend (1962/1981) argued that theories involved in a reduction are almost always logically incompatible, which undermines the possibility of a classical derivation. Another and related reason why Nagel-style reductions never actually happen is that the model requires that both T_R and T_B are *true* theories. Most scientific theories, however, are strictly speaking not true.

Kenneth Schaffner developed the General Reduction Replacement (GRR) model to meet these objections. According to his model, a reduction involves a Nagelian reduction between T_R* and T_B*, which are the corrected versions of T_R and T_B (Schaffner, 1977, 1993, Ch. 9). Schaffner's model has been applied in particular in biology, where it was claimed that it captured the reduction of classical Mendelian genetics by molecular genetics (Ruse, 1984; Schaffner, 1984). Hull, however, observed a many–many relationship between Mendelian and molecular genetics (e.g. in the case of the concept of dominance), which undermines the possibility of bi-conditional bridge laws even between the corrected theories (Hull, 1974, 1984; see also Kitcher, 1984/1994).

Hull's objection concerned the biological version of one of the most influential arguments against psychological reductionism: the *multiple-realization argument* (Fodor, 1981, Ch. 5; 1998, Ch. 2; Putnam, 1980). The thesis of multiple realization asserts that higher-level properties may have a multitude of different lower-level realizations, making the mapping between higher- and lower-level theories one-to-many. It is not the purpose of this paper to discuss the multiple-realization debate in detail (for critical discussions, see Batterman, 2000; Bechtel & Mundale, 1999; Keeley, 2000; Nasrin, 2000; Shagrir, 1998; Sober, 1999). For present purposes, it is sufficient to note how multiple realization applies to reductionism. A weak version involves multiple realization *across structure types*: for example, hunger in humans is different from hunger in octopuses. Weak multiple realization is relatively easily overcome by admitting that reductions are domain-specific and local (Lewis, 1980): for example, human hunger reduces to a human brain state and hunger in octopuses to another brain state in octopuses. But mental properties may also be multiply realized within humans or even within individuals at different times. For instance, hunger in a human individual at time *t* is different from hunger in that individual at a later point in time. An appeal to local reductions cannot capture this radical multiple realization, because such reductions would be too local and lose all generality. Only *token* instantiations of mental properties can be reduced (token physicalism), but reductionism of psychological *kinds* would be impossible.

The problems indicated above (the requirement of true theories, theory replacement and multiple realization) motivated John Bickle (1998) to develop the new-wave model of reductionism), which is built on earlier work by Hooker (1981), Churchland (1985; Churchland & Chuchland, 1994) and Schaffner (1967). New-wave reduction involves the construction of a T_R* that is designed to be an *image* of the original T_R. The distinguishing feature of the new-wave model is that T_R* is constructed *out of the reducing theory TB using TB's conceptual resources* (Bickle, 1998, Ch. 2; Churchland, 1985). Only in this way, it is claimed, can reductions like that of the phlogiston to the oxygen theory be captured, because the phlogiston theory was so defective that no correction could be formulated in its own vocabulary. Another proclaimed advantage is that problems concerning bridge laws do not arise, because T_R* only contains terms that are already present in T_B. So the condition of connectability is not an issue between T_R* and T_B. Bickle also claimed his new-wave reduction can handle multiple realization by developing token reduction, the reduction relation between the reduced and reducing theories being a relation between specific *instances* of psychological and physical terms.

Reductions are smooth when the isomorphism between T_R* and T_R is perfect. The weaker the isomorphism between T_R and T_R*, the less smooth the reduction between T_R and T_B. The new-wave model thus yields a *spectrum* of reductions, ranging from smooth to 'bumpy' reductions when the T_R* derived from T_B is only very weakly isomorphic with T_R. In the middle of the spectrum, cases are found where T_R is somewhat corrected or revised (Bickle, 1998; Churchland & Churchland, 1994). In order to determine precisely how smooth or bumpy a specific reduction is, Bickle uses model-theoretic formalisms (e.g. Balzer & Moulines, 1996; Westmeyer, 1992). One tool is particularly relevant: ontological reductive links (ORLs). ORLs are links between the elements of the models of different theories. *Homogeneous ORLs* involve *identities* between elements of models of T_R and T_B and point towards a retentive reduction. *Heterogeneous ORLs* link these elements without implying identities and point towards a bumpy reduction. And, finally, *mixed ORLs* are both homogeneous and heterogeneous, indicating a reduction somewhere in the middle of the spectrum (Bickle, 2002).

New-wave reductionism is the prediction that from completed physical theories (T_B), images (T_R*) of mature psychological theories (T_R) can be constructed (Bickle, 2003, p. 28). It should be noted, however, that this is in fact a very weak kind of reductionism. It leaves open the question whether the reduction will be smooth or bumpy. New-wave reductionism offers many traditional solutions to the mind–body problem by taking these answers as ontological conclusions of different types of reductions. For example, reductive materialism amounts to the prediction that the reductions will be smooth, while eliminative materialism is the prediction that those reductions will be bumpy. Accordingly, the IR reformulation of the mind–body problem finds its most formidable expression in new-wave reductionism, which brings many opposing views into a single framework.

New-wave reductionism has not gone unchallenged. What has been most controversial is the mapping of intertheoretic reductions with the ontological reductions supposed to be deductible from these. Richardson (1999) and McCauley (1996; McCauley & Bechtel, 2001; see also Nickles, 1973; Wimsatt, 1976) argued that we should distinguish between *intralevel* cases of theory succession and *interlevel* cases of microreduction. In the case of the former, bumpy reductions are accompanied by ontological elimination, while such an elimination does not take place in the case of interlevel reduction. McCauley and Bechtel (2001) list a number of considerations that make it improbable that a higher-level theory at the bumpy endpoint of the spectrum will be displaced: the amount of empirical support for the theory, the status of the theory within its scientific field and the institutional health and longevity of that field. Moreover, the motivation for interlevel reduction in science is explanatory rather than ontological simplification. Thus, the practice of scientists does not sustain the assumption that poor mappings between psychological and physical theories are followed by ontological elimination (Richardson, 1999).

Also, Endicott (1998) observed that at the bumpy half of the spectrum new-wave reduction ignores co-evolutionary development between the reduced and reducing theories, involving a bottom-up *and* a top-down flow of information). This bi-directional co-evolution cannot be reconciled with the new-wave constraint that T_R* is constructed solely out of T_B (Schouten & Looren de Jong, 1999). According to Endicott, problems also emerge at the smooth endpoint of the spectrum, where homogeneous ORLs imply identities. Because identities constitute bi-conditional bridge laws, the retentive endpoint of new-wave reduction ‘collapses’ into classical reduction, including the problems that motivated the development of new-wave reduction in the first place (Endicott, 1998).

Both Endicott (2001) and Bontly (2000) worry that, contrary to the new-wave aspirations, ontological issues are not completely secondary to reduction. Bontly (2000) finds it troubling that reduction needs ORLs, which seem to necessitate that at least some ontological issues are settled before it can be determined whether psychology reduces to physics. Endicott (2001) is concerned about the status of Bickle’s rendition of token reduction as a response to multiple realization. He argues that the reduction of multiply realized properties cannot be located at the retentive endpoint of the spectrum because this requires smoothness of intertheoretic mappings. Hence, token reduction must be located at the bumpy endpoint. Yet, bumpy reductions would involve the replacement of T_R’s ontology and, consequently, there are no tokens of T_R’s ontology. So, new-wave token reduction is '"token reduction" in name only' (Endicott, 2001, pp. 389–390). In fact, it is eliminative materialism in disguise (Wright, 2000).

In sum, although some have welcomed the new-wave model for stressing that theory reductions often come in degrees (e.g. McCauley & Bechtel, 2001), its pretension that ontological conclusions can be derived from its model of intertheoretic reduction seems to be problematic (Beckermann, 2001): these ontological conclusions do not follow from scientific practice, and ontological issues seem to have slipped in prior to theory reduction.

Challenging the Validity of Classical Reductionism: Towards Kim's Functional Model

A second challenge to classical reductionism concerns its validity. Jaegwon Kim (1998) claimed that the classical model does not result in proper ontological reductions. First of all, Nagel's model does not bring the desired *explanation* of psychological properties. The bi-conditional bridge laws only describe the correlation of psychological and physical properties; they do not explain why these psychological properties are always occurring together with the physical properties. Second, classical reduction does not provide ontological simplification. It does reduce the number of laws (the higher-level law is shown to be a special case of the lower-level law), but this reduction is achieved at the cost of introducing unexplained bridge laws.

In order to save reductionism, Kim (1998, 1999) developed the functional model. According to Kim, reduction starts with (1) a specification of the causal role of the (mental) properties to be reduced, making these properties relational. This step is known as the functionalization of mental properties. Reduction then proceeds by (2) finding the physical realizers of these functionalized properties, that is, the physical property that fits the causal specification, and (3) formulating a theory that explains how the physical realizers perform the causal role of the reduced properties (cf. Beckermann, 1997). The first step of functionalization is crucial: it is necessary and sufficient for reduction (sufficient in a conceptual sense; the second and third steps are the result of scientific research). Moreover, functionalization allows for the identification of the mental property with the physical.[1] By virtue of this identification, the correlation between the mental and physical properties is explained and ontological reduction is achieved.

This functional model of reduction is coupled with Kim's principle of the *causal closure of the physical*: any instance of a physical property must have a physical cause. Consider a mental property M causing another mental property M* while M* is supervenient on the physical property P* (it is assumed that mind–body supervenience as well as, more generally, physicalism holds). The answer to the question of how it is possible that M causes M* is that M causes the instantiation of P* that realizes M*. Now, let M supervene on the physical property P. Given the causal closure of the physical, it follows that P does all the causal work and there is no causal work left for M. Mental properties cannot have causal powers over and above physical causal powers if causal overdetermination is to be avoided (Kim, 1998, 2002). This argument also has implications for multiple realization: if mental properties are realizable by different physical structures, it follows that mental properties inherit different causal powers. Hence, multiply realized mental properties are causally heterogeneous. If scientific kinds are to be individuated by their causal powers, as Kim believes, then these multiply realized mental properties are not acceptable as scientific kinds. Thus, instead of grounding the autonomy of psychology, multiple realizability seems to threaten psychology's scientific status.

This way, Kim's reductionism consists in the assertion that all mental properties can be functionalized, and if they can be functionalized, they can be reduced (Kim, 1998). This reductionism saves the causal efficacy of the mental as it demonstrates how mental properties have causal powers by virtue of being identical with physical properties with causal powers. Anti-reductionism faces serious problems, according to Kim. It consists in the expectation that mental properties resist functionalization because they cannot be specified by their causal role. So, if mental properties are irreducible, then, because of the causal closure of the physical world, these properties are causally impotent. There only seem to be two options: either one accepts reductionism, which provides an account of mental causation *as* physical causation, or one accepts the irreducibility of mental properties *and* the causal impotence of the mental.

Against Kim's reductionism, Block claims that if higher-level causal powers drain into physics, then any causal power will 'drain away' if there is no bottom level in physics—and Block (2003) provides some reasons to believe that the 'bottomless-ness' of physics is indeed an open hypothesis. The alternative that Block presents is the scientific view of explanation which recognizes causal efficacy at different levels without regarding them as competing. Looren de Jong (2003) also argued that Kim confuses metaphysics with scientific explanation. Causal explanation in science calls for a pluralistic and pragmatist view: what is considered a cause depends, according to Looren de Jong, on explanatory interests, background assumptions and experimental practice. Thus, ontological reduction does not lead to explanatory reduction. Interestingly, Antony (1999) countered Kim's reductionism by arguing precisely the other way around. According to Antony, a higher-level property is real if it figures in regularities that cannot be found at lower levels. As long as mental properties figure in scientific generalizations which are indifferent to lower-level generalizations, there is empirical evidence that the property is ontologically irreducible. So, in Antony's view, the functionalization of the property and its being explained by its realizer, that is, explanatory reduction, does not entail ontological reduction. According to Jacob (2002), however, such defensive manoeuvres fail to appreciate the metaphysical problem of mental causation posed by Kim, which will not be solved by a shift to explanation.

To summarize, this review indicates that the controversy concerning reductionism may at least partly be due to the connection of ontological and metaphysical issues, on the one hand, and explanatory issues and scientific practices, on the other. Classical reductionism was mainly criticized for its ontological claims because classical reductions either are not available, or do not justify mind–body reductionism. Along similar lines, other reductionist claims have been challenged on their mapping of theory reduction and metaphysics: new-wave reductionism for the assumed tight relation between intertheoretic reduction and ontological conclusions and Kim's functional model concerning mental causation for its implications for scientific explanations. But what if reductionism does not involve such ontological claims? In the next section we will develop another understanding of reductionism which is not thus obscured by metaphysics.

Reductionism as a Stance

A central claim of this paper is that, as a consequence of hooking up intertheoretic reduction with ontological questions associated with the mind–body problem, the discussions about reductionism in psychology have gone astray in several respects. We think that reductionism should be interpreted not as a theory about the mind–body relation, but rather as a stance in science with pragmatic motivations.

In his most recent book Bas van Fraassen (2002) makes a strong case that major philosophical positions, like materialism, realism and empiricism, are not to be identified with statements about what the world is like. We will skip the topic of reductionism for the moment and follow van Fraassen in his discussion of another philosophical position: materialism. According to van Fraassen, materialism should not be interpreted as the metaphysical claim that matter is all there is. The problem is that it is not clear how 'matter' should be identified (cf. Radder, 2001). A Cartesian interpretation of matter as *res extensa* would not do because it is wrong: *inter alia*, Hertz's massive-point particles would not count as material. If matter is understood as 'composed of elementary particles', the thesis would have been falsified by Newton, who introduced forces, which are not composed of particles. According to van Fraassen (2002), the problem is a general one:

> Whenever philosophers take some general feature of physics and use it to identify what is material, what happens? Physics soon goes on to describe things that lack that feature and are altogether different. When that happens, does materialism bite the dust? Surely not! But if materialism were really, purely and simply, some such thesis as 'everything is composed of elementary particles,' I could not so readily say 'Surely not'! (p. 53)

If materialism were really a metaphysical belief, how could we make sense of the fact that, as science changes, materialists very readily change the content of their belief? Van Fraassen answers this problem by interpreting the indicated philosophical positions not as beliefs about what the world is like, but as stances, as commitments or approaches. Materialism, then, should not be regarded as a theory, and therefore the question whether materialism is true or false is beside the point. Materialism should be regarded as a cluster of attitudes. The relevant issue, according to van Fraassen, is to identify the 'spirit of materialism': the invariant attitudes, goals, commitments and convictions characteristic of the materialistic stance.

Back to reductionism. If reductionism is interpreted as a theory about the mind–body relation, similar problems arise: the content of the theory continuously changes. The classic reductionist theory holds that the laws of psychology can be derived from the laws of physics. If the classical bridge laws are restricted to identity claims between mental and neuronal terms, classical reductionism would amount to the mind–brain identity theory, fashionable in the late 1950s (Place, 1956/1970). But problems like multiple realizability persuaded many that this theory is false. Alternative reductionistic theories were developed, including the new-wave theory that physical theories can provide corrected images of psychological theories and Kim's theory that functionalization leads to psycho-physical identities. From this point of view, reductionism is not one single theory, but comprises many different, sometimes mutually exclusive, theories about the relation between the mental and the physical. The problem is, we think, that this interpretation of reductionism attests, to use van Fraassen's words, to a 'false consciousness' by reductionists of what reductionism involves. The true reductionistic spirit is something other than a thesis about what the world is like. Reductionism is a stance and consists in attitudes, goals, and the like. As a stance, reductionism is neither true nor false—that is simply not an issue. It is a way of thinking, a view of how to do scientific research.

Recently, Bickle (2003, Ch. 1) has started to follow a similar route. In response to his critics, he says he is no longer prepared to alter his model of reduction in order to make it more applicable to scientific cases. He now considers the IR reformulation, which formed such a central part of his new-wave reductionism, as still 'too metaphysical' (p. 32). Instead, he propagates a neo-Carnapian point of view, especially by distinguishing between fruitful 'internal' and fruitless 'external' questions and by numbering the mind–body question among the latter. We believe that Bickle is right in separating the reductionistic wheat from the metaphysical chaff. Our views diverge, however, on where to go from there. Bickle pursues a 'new-wave metascience' which exclusively builds on scientific practice, bypassing all philosophical issues. We, however, believe that a lot of philosophical work still needs to be done to flesh out and identify the true reductionistic spirit.

So, then, what exactly is the spirit of reductionism? Reductionism originated in the Unity of Science movement as a conception of theoretical unity. This is an important starting point. To Otto Neurath (1938), Unity of Science meant the co-operation between scientific disciplines. He provided the example of the prediction that the forest fire will soon be extinguished, which draws from biology (about trees), chemistry (about fire), sociology (about fire service), and so on (Neurath, 1983, Ch. 11). Also according to John Dewey (1938), Unity of Science 'is essentially a co-operative movement' (pp. 33–34). To him there are important *pragmatic* aspects to it: different sciences are 'brought together in common attack upon practical and social problems' (p. 34). The first task, he acknowledges, 'is to build bridges from one science to another' (p. 33) that enable scientists who work in different fields to co-operate.

Reduction may be considered a way to build these bridges. It links the terms and laws of different branches of science. It is important to note that neither reduction nor Unity of Science should be imposed a priori on scientists. The question of whether or how much science could or may be unified is an empirical one. Following Carnap (1938), reduction presents itself as a *tool* for unified science, not as a constraint. For Neurath and Carnap, Unity of Science is not the imperial dominance of one science over another but the equal co-operation of all the sciences (Creath, 1996). Keeping these considerations in mind, reductionism appears to be the scientific attitude that aims at bridging theories from different fields. Reduction is a tool for scientists pursuing unified science as a co-operative movement. It is not a theory about the nature of psychological entities, and not even a theory about the relations between the laws of the various sciences. It is to be understood as a heuristic *methodology* serving scientists who favour an interdisciplinary approach to scientific problems.

The Classical Model of Reduction Reconsidered

The recognition that reductionism is a methodology for interlevel co-operation without ontological concerns, and that reduction is a tool for bridging theories at different levels, throws a new light on the classical model, which may still capture important aspects of these intertheoretic bridges.

How can the classical model be a successful description of reduction if there are no actual applications in science satisfying the classical conditions? The answer is that the classical model describes an *ideal* case of reduction and actual cases *do not need to* conform all the way to this ideal. Here, a parallel with Railton's notion of an ideal explanatory text is apparent (Railton, 1981; Salmon, 1989). Many explanations that are commonly accepted are, strictly speaking, rejected by the Deductive-Nomological

(D-N) model (Hempel & Oppenheim, 1948). But Railton (1981) shows that the D-N model of explanation may account for such less than ideal but allegedly legitimate explanations, in particular by introducing a distinction between *explanatory information* and an *ideal explanatory text*. An ideal explanatory text is an explanation that perfectly meets the formal requirements of the D-N model. The fact that most proffered explanations do not conform completely to this ideal explanatory text is not problematic for the model because these explanations still provide *explanatory information*: information that highlights or fills in (parts of) the ideal text.

We propose that the classical reduction model be treated analogously. The role played by the classical model is to describe an ideal case of reduction that can be called an *ideal reductive text*. This is a text that perfectly satisfies all the formal requirements, including derivability and connecting bridge laws. Actual cases of intertheoretic reductive relations, however, will all deviate from such an ideal reductive text due to problems discussed above, like the absence of bridge laws and true theories. However, such cases can be interpreted as *reductive information*, that is, information that highlights or fills in parts of an ideal reductive text. For example, the reduction of thermodynamics to statistical mechanics involves the bridging principle 'temperature is mean molecular energy'. Strictly speaking, this principle is false: it only holds true when the particles of the gas are in perfect random motion, which, as a matter of fact, they never are (see Bickle, 1998, p. 26). Although the reduction of thermodynamics to statistical mechanics is not an ideal reductive text, it does provide substantial information about that ideal. It fills in almost every part of the ideal text, except for the fact that the suggested bridge law can only be approximately realized. The reduction of thermodynamics to statistical mechanics thus can be interpreted as providing a lot of reductive information.

The notion of an ideal reductive text should not be interpreted as something to be strived for (such as expressed in the sentence 'The ideal body weight for an adult man of average height is around 75 kg'). The sense of 'ideal' in 'ideal reductive text' rather is comparable to the sense of 'ideal' in 'ideal gas' (as in the ideal gas law): an ideal gas is a gas in which all molecular collisions are perfectly elastic without any intermolecular attractive forces. This meaning of 'ideal' is not normative (there are no connotations that gases *ought* to behave like that). Instead, an ideal reductive text refers to the maximum of attainable reductive information. It shares some important characteristics with Weber's sociological notion of '*ideal* type' (Weber, 1968, pp. 42ff.). An ideal type (e.g. of modern capitalism) does not refer to moral ideals but is a general conceptual pattern that, although it never corresponds to concrete reality, serves as a measure for similarities or deviations in concrete cases and offers a theoretical framework for clarifying the important elements of empirical reality (Coser, 1977, pp. 223–224). Both an ideal type and an ideal reductive text do not exist in reality and neither should be interpreted as a normative conception.

Another characteristic shared by an ideal type and an ideal reductive text is that both may function to clarify important aspects of reality. In this light, many specific kinds of intertheoretic relations suggested by philosophers of science might be interpreted as providing reductive information. For instance, the *heuristic identity theory* states that interlevel identity claims are used by scientists as *hypotheses*, not to make reductionistic claims but as a *means* for theoretical expansion (McCauley, 1981; McCauley & Bechtel, 2001; Wimsatt, 1984). Explanatory properties of entities at one end of an identity statement must be explanatory properties at the other end as well. Employing this ‘reversed’ use of Leibniz’s Law, theories can exploit each other’s explanatory resources, which might stimulate discovery at both levels. Darden and Maull (1977) described *interfield theories*, which are theories connecting entities or processes of different fields by their mutual relations (e.g. part–whole or causal relations). An example of an interfield theory is the theory that (classical) genes are in or on the chromosomes, which bridges the fields of cytology and genetics (Darden & Maull, 1977). Philip Kitcher (1984/1994, 1989) has developed the idea of *explanatory extension*, which has been introduced in psychology by Hardcastle (1992). A theory provides an explanatory extension of another theory if it can be used to derive some of the (often problematic) *premises* of that other theory (Kitcher, 1984/1994). Thus, a lower-level theory extending a higher-level theory takes some of the premises (and not complete laws) of the higher-level theory as the conclusions from the lower-level theory. These kinds of interlevel reductive links may fit well into the general scheme of reduction presented here, that is, they may be understood as providing reductive information. Heuristic identities do not constitute genuine bridge laws, but they do put forward intertheoretic identity claims that hypothetically fill in parts of an ideal reductive text. Interfield theories describe relations between entities and processes that partly clarify or illuminate ideal bridge laws. So, these two notions may be understood as providing reductive information about the connectability condition posed by the classical model. An explanatory extension, on the other hand, may perhaps be interpreted as filling in those parts of an ideal reductive text that concern the derivation of an ideal reductive text: it suggests how parts of one theory can be derived from another.

If scientists were really interested in ontological reduction, they should probably aim at ideal reductive texts, as only these texts seem to be constrained enough to draw ontological conclusions (although, as discussed above, Kim questioned the validity of such an inference). From this point of view, reductionism would indeed be problematic because ideal reductive texts do not seem to be available in reality. However, we argued that the metaphysical thesis of mind–body reductionism and the methodological stance of theory reductionism should be separated. Understanding reductionism as a theory about the mind–body relation obscures the real issue of reductionism. Reductionism might better be interpreted as the scientific stance that aims at bridging different theories in order to make interdisciplinary co-operation possible. For this goal, an ideal reductive text is not necessary and hence its assumed unavailability is unproblematic. Reductionism should be interpreted as striving for intertheoretic relations that provide reductive information, that is, information that fills in parts of an ideal reductive text. The classical model captures some important elements of this reductionistic stance as it provides a description of this ideal reductive text. This interpretation is much less problematic because, in contrast with ideal reductive texts, these kinds of relations do obtain in real science.

An Application: Attention-Deficit/Hyperactivity Disorder

A description of a concrete example of reductionism in research on attention-deficit/hyperactivity disorder (ADHD) will illustrate the main points made above. ADHD is a common childhood psychiatric disorder, characterized by inattention, hyperactivity and impulsivity (American Psychiatric Association, 2000). A great deal of research has been devoted to this disorder, ranging from psychosocial (Root & Resnick, 2003), neuroscientific (Castellanos & Tannock, 2002), biological/genetic (Bradley & Golden, 2001) to pharmacological (Biederman & Spencer, 1999) investigations. One of the most influential *theories* of ADHD is Barkley's theory (1997a, 1997b, 1999), which was developed in two steps. The first step involved the application of Bronowski's model of human language to ADHD. In the second step, Barkley incorporated Fuster's theory of the working of the prefrontal cortex in order to construct the 'hybrid model' for ADHD.

According to Bronowski (1967/1977), the distinctive feature of human language with respect to animal communication is the use of language for *reflection*. He argued that the capacity to inhibit immediate responses to external stimuli is necessary for reflection, and also that four unique properties of human language are dependent on this capacity. The first property, which he called *separation of affect*, refers to the capacity of humans to separate the emotional charge of a message from its content. The second is *prolongation*, which he described as the ability to recall the past and refer to future events. The third unique feature of human language is *internalization*, which is the 'producing of an inner discussion of alternatives before an outgoing message is formed' (p. 117). Finally, *reconstitution* comprises two procedures: the analysis of messages into their constitutive parts and the synthesis by which the parts are rearranged into another message.

Barkley's initial theory of ADHD was based on Bronowski's model and designed to explain the numerous cognitive and social problems seen in ADHD (Barkley, 1994). It was already widely recognized that an inability for delayed responding is one of the problems in ADHD, but Barkley hypothesized that this inability is the *central* problem. Extrapolating from Bronowski's model, he predicted that an impaired delay should lead to an impairment in the four functions depending on response inhibition. Thus, an impaired capacity for separation of affect explains the emotional reactivity of patients with ADHD. A problem with prolongation accounts for difficulties of arithmetical computations of ADHD children. The findings that children with ADHD have less mature self-directed or private speech and are delayed in moral reasoning could be explained by an impaired internalization. Finally, problems of reconstitution would result in less well developed creativity and less adequate problem solving, which can both be seen in ADHD.

Three years later, Barkley (1997a, 1997b) reduced many parts of the Bronowski model to Fuster's neuropsychological theory of *the prefrontal cortex*. Fuster (1989) drew from anatomical and biochemical evidence as well as lesion and ablation studies of the human and animal prefrontal cortex, and advanced 'a theory of what the prefrontal cortex does and how it does it' (p. 157). He concluded that the overall function of the prefrontal cortex is the *temporal structuring of goal-directed behaviour*, including a *synthetic role* to bridge temporal discontinuities between the different behavioural elements. In Fuster's view, this supraordinate synthetic function of the prefrontal cortex consists of three component processes. One of these processes was called *provisional memory*, defined as the retention of information in a temporal sequence towards a goal. Another hypothesized component function was the *anticipatory set*, involving both foresight and preparatory action. Fuster argued that these two functions, thought to be needed in the organization of goal-directed behaviour in order to keep the action in line with the goal, are mediated by the *dorsolateral* prefrontal cortex. In contrast, the *orbital and medial* cortex was thought to subserve an opposite function, namely *control of interference* involving the inhibition of responses to unrelated distorting influences. Furthermore, based on anatomical evidence that the prefrontal cortex has relevant (though indirect) connections with the primary motor cortex, Fuster suggested that the prefrontal cortex plays a role in *motor control* as well

Barkley (1997a, 1997b) linked the various concepts of Bronowski's and Fuster's theories based on their similarities. First, Bronowski's concept of delay between stimulus and response was connected to Fuster's inhibitory function attributed to the orbital and medial prefrontal cortex. Second, the concept of prolongation was linked to provisional memory and the anticipatory set located in the dorsolateral prefrontal areas. Bronowski's concept of reconstitution was considered to be related with the overall function of the prefrontal cortex of synthesizing behaviour into a goal-directed complex, although Barkley recognized that the latter concept stressed the synthetic and neglected the analytic aspect of reconstitution.

These links enabled Barkley to construct what he labelled the *hybrid model* to account for ADHD. This model was basically his initial application of Bronowski's ideas to ADHD, but with the following modifications. First, based on the conceptual links described above, the components of the model were renamed and given more precise definitions. For many identified functions, this more precise definition included a neurobiological description. For example, the functions of prolongation and delay were now attributed to specific brain areas. The impairments and problems in ADHD could now be assessed not only in higher-level terms (like emotional reactivity or impaired moral reasoning), but also by psychophysiological methods such as measures of cerebral blood flow, magnetic resonance imaging (MRI) or positron emission tomography (PET). Second, motor control as suggested by Fuster's theory was added to the model. Not only did Barkley's theory include effects of behavioural inhibition for the four depending functions, but those functions themselves were thought to have an effect on motor control. This addition accounted for many motor problems that can be seen in ADHD, like impaired fine-motor co-ordination.

There are three key implications that follow from this sketch of ADHD theorizing. First, the connections between Bronowski's and Fuster's theories in the hybrid model were not motivated or inspired by metaphysical issues about the nature of the mind in relation to the brain. Neither do the intertheoretic connections warrant ontological conclusions as envisioned by the IR reformulation. Instead, concepts of both theories were connected in quite a fuzzy manner. The interlevel connections were suggested by Barkley merely on the basis of—sometimes rather weak—conceptual similarity.

Second, the reductionism involved in Barkley's work served to bridge the gap between Bronowski's and Fuster's theories. This gap was bridged by means of the reductive connections between Bronowski's unique features of human language and Fuster's neuropsychological functions. The purpose of these reductive connections was the construction of the hybrid model, which was made possible because these reductive links brought the theories within a single realm. The hybrid model, consequently, provided the basis for, and made available, an interdisciplinary co-operation between psychological and biological approaches by conjoining both perspectives. Owing to the model, results of neurobiological studies (e.g. on the basis of brain lesions, MRI or PET) could be interpreted in terms of their psychological importance. This also allowed comparisons of the use of animal studies of ADHD with studies among humans. Furthermore, the model had implications for the co-operation between cognitive and pharmacological *treatments* of ADHD. The hybrid model provided a framework for understanding how different treatments may be combined and how they may interact (Barkley, 1997b, pp. 337–347). In short, thanks to the reductive connections between Bronowski's and Fuster's theories, Barkley could construct the hybrid model of ADHD on the basis of which psychologists and neurobiologists could truly co-operate in their attack on ADHD as a scientific and social problem.

Finally, the reduction involved is clearly not an ideal classical reduction. Some parts of Bronowski's theory were not reduced at all, like the concept of internalization, for which Barkley did not find a neural counterpart. Moreover, those links between the concepts of both theories that have been described were not truly bi-conditional bridge laws. As already noted, concepts were linked based merely on similarities. For instance, Bronowski's concept of delay is not co-extensive with Fuster's idea of inhibition: Bronowski's concept referred to the inhibition of primitive immediate responding, while Fuster's concept referred to the inhibition of reacting to distorting influences. Although the concepts did substantially overlap, the link between them did not constitute a law in any strict sense of the term. Nonetheless, the reductions involved are captured by the classical model, not as an ideal reductive text but as reductive information. Although the link between delay and inhibition may not be a law, the mutual overlap provided enough points of co-extension to suggest what the ideal bi-conditional bridge law would look like and thus provided reductive information. The overlap between the concepts provided sufficient justification for Barkley to put these concepts together into a single component in the hybrid model. Similar lessons can be drawn from the other intertheoretic connections. Although these connections do not completely satisfy the conditions of the classical model, the links do provide reductive information about an ideal reductive text represented by the classical model. The generation of the links providing reductive information was sufficient to bridge the intertheoretic gaps and subsequently to formulate a theory advancing a more interdisciplinary approach to ADHD.

Conclusion

It has been argued that reductionism in psychology should be considered distinct from the metaphysical mind–body problem. The relation between intertheoretic reduction and its presumed ontological implications—that is, the IR reformulation of the mind–body problem—should be rejected. Many of the current controversies concerning reductionism can be at least partly traced back to this confusion of theory reduction with metaphysical reductionism. Instead, reductionism is to be understood as a methodology for bridging theories at different levels. The resulting bridges between the theories enable scientists to co-operate and to tackle their research problems from an interdisciplinary approach. This conclusion throws a new light on the classical model of reduction. The classical model still provides an adequate representation of reduction as long as it is recognized that actual reductions, which all deviate from the ideal, are sufficient for bridging different theories.

Note

1. The identification is guaranteed on the basis that the reduced mental property is defined as the property of having a specific causal specification and that the reducing physical property satisfies that specification. So, the mental property is the property of having the physical property. Because, Kim claims, the property of having a property Q = property Q, this amounts to the identification of the reduced mental and the physical properties.

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