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An Engineering Approach to Reductionism

Various aspects of reductionism are considered. It is shown that the uses of reductionism lie in the separation of variables, which allows the construction of models required to answer specific questions. It is shown that a particular object or process can be modelled in many ways, so that no model is coextensive with that object or process. In spite of this limitation the use of reductionist models is wonderfully useful.

Key words: reductionism, modelling, knowledge.

An understanding of reductionism continues to be important in present-day discussions about the relationship between science and faith. These discussions generally focus on science as represented by theoretical physics and cosmology or by biology with special reference to evolution. As a result of this selective approach to science the discussion of the nature and validity of reductionism tends to be dominated by the special features of physics and biology and this obscures the function of reductionism as a tool in pursuit of knowledge in all scientific studies.

The immediate impulse for writing this short article came from reading Dr R. D. Holder's book—'Nothing but atoms and molecules?'[1]. Dr Holder writes from a background of mathematics and astrophysics and the title of his book reflects his view that reductionism consists in explaining complicated phenomena in terms of supposedly simple constituents. If this is indeed the entire reductionist method then I agree heartily with Holder's conclusion that the method is fallacious. However, in my view there is more to reductionism than appears from the writings of some popularizers of the method who use it to attack the Christian position. For this reason I think it would be useful to look at reductionism from the engineering point of view with which I am familiar. Engineering makes use of many sciences and so avoids undue specialization. It is my contention that reductionism in engineering is legitimate and necessary. Of course I may be mistaken in this view, but even if with Dr Holder and many other Christian apologists one agrees that reductionism is inadmissible, it must be desirable to understand its positive as well as its negative influence on Christian apologetics.

1 R. D. Holder: 'Nothing but Atoms and Molecules?' (Monarch Tunbridge Wells 1993)

Two Examples of Scientific Reductionism

In order to highlight the differences between the engineering approach to reductionism and the approach of the pure sciences I want to discuss briefly the two well-known examples mentioned by Holder, namely the biological reductionism of Richard Dawkins and the physical reductionism of Stephen Hawking. The choice of these scientists is purely for the purpose of illustration and I shall confine myself to some comments on Dawkins' book 'The Blind Watchmaker'[2] and Hawking's book 'A Brief History of Time'[3].

Dawkins faces the problem of the complexity of organic processes which has led Christians to the, in his view, erroneous conclusion that these processes are evidences of design. He discusses as an example the sonar direction finding of a bat and seeks a simple explanation for its complexity. This he finds in the evolutionary principle of natural selection operating on small random mutations of the genetic structure of the ancestors of present-day bats. The mutations are completely random but their outcome is guided by natural selection and this gives the appearance of design. Moreover the minuteness of the mutations makes evolutionary development continuous and so avoids the need for additional explanations which might be required to account for discontinuities. All that is needed is sufficient time to allow the effects of small mutations to accumulate.

Holder distinguishes between methodological, epistemological and ontological reductionism. Dawkins describes himself as a hierarchical reductionist. He explicitly does not follow Crick's assertion that the ultimate aim in modern biology is to seek an explanation in terms of chemistry and physics. Dawkins allows that below the biological level there may be explanations in terms of physical particles. In that respect he might be described as a methodological reductionist. However, in his view physics deals with essentially simple objects, although these objects are described in abstruse mathematics. Thus in terms of explanatory power physics has little to add to biology. Also he does not attach much value to higher levels of explanation above the biological level. Human consciousness and self-reflection are a by-product of biological complexity. Dawkins conjectures that perhaps complex computers will one day develop self-consciousness and begin to speculate about their own origins. In all this there are strong pointers to epistemological and ontological reductionism. It is at first sight surprising that Dawkins does not equate evolution with progress and the 'arrow of time'. He does not regard the increase of complexity produced by the mutations as an advance. His radical view is that there is no purposefulness in nature. Temporal effects are akin to fluctuations without directionality. Time has no other significance than to provide a background for chance mutations.

2 R. Dawkins: 'The Blind Watchmaker' (Penguin, London 1988)
3 S. W. Hawking: 'A Brief History of Time' (Transworld, 1988)

These views can of course be criticised from many angles. For example Thomas Nagel in his masterly book ‘The View from Nowhere’[4] dismisses the possibility of an evolutionary epistemology by pointing out that natural selection may explain the survival value of such a capacity as vision, but it cannot explain how vision is possible. Evolution does not deal with the possibilities but with a selection among them. Nagel also doubts the survival value of some human intellectual capacities. He adds for good measure that an evolutionary explanation of human rationality would throw doubt on the use of that rationality in understanding the world. The evolutionary theory is therefore self-defeating as far as epistemology is concerned.

It is not, however, my aim to seek to refute Dawkins’ theory, which clearly has great attractions for many people in view of its elegant simplicity and generality. I am trying to understand the strengths and weaknesses of Dawkins’ reductionism and my thesis is that such understanding can be reached by means of an engineering approach. However, before proceeding to offer such an explanation I want to make some comments on Hawking’s work. My subsequent argument needs at least two examples of this type of reductionism.

Stephen Hawking’s concerns are different from those of Dawkins but there are similarities in his method. He deals with the structure of the universe in terms of fundamental particles, energy, space and time. The particular problem which Hawking faces is how to reconcile the theory of relativity, which deals with large-scale phenomena, with the quantum theory which deals with small-scale effects. This difficulty becomes most strongly marked in the consideration of singularities of space-time, which might be present inside black holes or more strongly at the big-bang when the universe occupied an infinitesimal region of space-time. If in some way quantum theory and relativity could be combined, this would lead to a complete theory, which could serve as the basis for finding an answer not only to the question of how the universe is arranged but also to the deeper question as to why we and the universe exist. Hawking writes ‘then we should know the mind of God’.

Like Dawkins, who claims for his representation that it describes the ‘one true tree of life’, Hawking seeks for completeness as well as consistency in his description of the world. This involves the removal of the singularities. The black holes do not present a great difficulty because they evaporate slowly, but the big-bang singularity is an obstacle. As would be expected of a theoretical physicist Hawking has a deep knowledge of the nature of time in its relationship to space and to energy. The big-bang is a singularity in time as well as in space, which suggests that the big-bang describes a true beginning—a boundary which cannot be crossed by physics. Hawking conjectures that this boundary can be removed by the use of complex numbers for space-time. The time-axis of the

4 T. Nagel: ‘The View from Nowhere’ (Oxford University Press 1986)

4-dimensional coordinate system would represent the imaginary component of the complex numbers. I have discussed the geometrical effect of this transformation elsewhere[5]. Basically it straightens the geometry and removes the directionality of time. There is then no beginning and no boundary. Hawking suggests that the removal of the boundary removes the need for a creator of the universe. No further explanation is required.

This unique description of all that exists is remarkably simple and general. Even without the claim that there is no beginning to time the cosmology presented by Hawking is a magnificent achievement although of course it can be criticised. Like Dawkins' biological world it omits human consciousness and there is no room for Stephen Hawking in Hawking's universe.

Reductionism in Engineering

Engineering is unashamedly and necessarily purposeful. In this respect it differs from pure science which heartily dislikes references to usefulness. Although there is such a subject as engineering science, it can never be independent of engineering practice. The objective of any engineering project is always usefulness, or more accurately 'added value'. The objective of the Laputians in extracting sunlight from cucumbers might have been useful, but it does not meet the criterion of added value.

This value is closely associated with the welfare of human beings. For example the supply of water suitable for drinking is achieved by interfering with the environment in the destruction of micro-organisms. Engineering seeks to improve the human condition, although some of the side-effects may turn out to be harmful.

The close association of practice with theory forces engineers to an early acknowledgement that the world is exceedingly complicated. Engineering science proceeds by the method of the separation of variables and operates through the construction of models, which may be experimental or computational. The design of these models involves the selection of a small number of variables relevant to the engineering project. The number of the variables has to be restricted in order to understand their behaviour and the selection requires skill and experience. The selection of some variables involves the omission of others and it is generally necessary to use a variety of models for a particular engineering process. Moreover the separation of variables cannot be achieved completely, and there will be interaction between the models. No single model, nor indeed any combination of models, can give an exhaustive description. Ultimately it is necessary to test a complete installation, but even such tests cannot predict with complete accuracy the behaviour during the designed life-expectancy.

5 D. Baldomir & P. Hammond: 'Geometry of Electromagnetic Systems' (Oxford University Press 1996)

An example may be helpful to illustrate the method. Suppose it is desired to construct a large modern office block. One of the aspects which needs to be studied is the temperature control of the offices. A suitable model would be in terms of a thermal network, which would include internal heating, solar heat-gain and various losses due to conduction and convection. The heat-flow is subject to various physical laws. The thermal network would be divided into a sufficient number of nodes and branches to give the desired information. Other models would be needed to study such matters as stress distribution and deflections, electrical supplies, illumination levels, fire hazard, internal and external movement of people and goods. There would also be a variety of architectural models and of course there would be economic models.

It is clear that in this modelling procedure there is no confusion of the object with the models chosen to represent it for the purposes of understanding its behaviour. The modelling is a reductionist process, but it does not easily fit into Holder's classification. Each separate model is methodological, together the models are epistemological and in Polkinghorne's suggestive phrase their epistemology models ontology.

Although these descriptions of types of reductionism can be applied to engineering, the method is very different from that used by Dawkins and Hawking. No single model nor combination of models describes 'the one true tree of life' nor do the models lay any claim to completeness as does Hawking's cosmological model. I chose the two models of Dawkins and Hawking to make the point that the mere existence of two different descriptions of the totality of things suggests that neither can be complete in the sense desired by their authors. They are models and models by definition cannot be identical with the object being modelled.

On the other hand the usefulness of models does not require completeness. Reductionism is both useful and necessary in engineering and from an engineer's point of view it needs to be endorsed rather than regarded as harmful.

Hierarchical Reductionism

Although Dawkins describes himself as a hierarchical reductionist, he does not explain the meaning of this term in detail. Such an explanation is, however, given by Peacocke in his book 'Creation and the World of Science'[6]. Peacocke starts with the observation that there are hierarchical systems in nature and cites as an example the sequence: atom–molecule–macromolecule–subcellular organelle–cell–multicellular organ–whole living organism–populations of organisms–ecosystems. This sequence is in his view characterised by an increasing level of complexity. He relates these levels to the scientific subjects studied in universities and argues that it is impossible to reduce the higher levels of scientific description to those at lower level. Biology cannot be reduced to chemistry and chemistry

6 A. R. Peacocke: 'Creation and the World of Science' (Oxford University Press 1979)

cannot be reduced to physics. This avoids the explicit reductionism of Hawking in his quest for a universal theory and it avoids the implicit reductionism of Dawkins in his claim to possess a complete explanation of complexity.

In Peacocke's discussion there is considerable autonomy among the different levels, which he describes as 'theory autonomy'. Nevertheless the notion of hierarchical levels connects the theories of the different subjects. He pays great attention to the idea of emergence of the higher level systems and this is linked to the evolutionary mechanism of natural selection. The hierarchical structure of theories is therefore subject to Nagel's criticism which has been mentioned earlier. Its reductionism is similar to Dawkins' claim of having discovered the 'one true tree of life'.

Since reductionism is an essential part of engineering, as was explained in the previous section, it is interesting to look at the hierarchical model from an engineering viewpoint. The first difficulty arises from the idea of the desirability of complexity. As mentioned previously engineering is always utilitarian. That means that complexity is to be avoided as far as possible. Progress is often achieved by a reduction in complexity. For example aircraft jet engines are less complex than the reciprocating engines which they replaced. Similarly, fibre-optic cables are less complex than copper telephone cables. Such examples can be multiplied. A second difficulty also arises from the engineer's pre-occupation with usefulness. At every step of Peacocke's sequence from atom to ecosystem an engineer would wish to know the purpose for which these descriptive models are to be used. An atom considered as a part of a molecule is useful inasmuch as it helps in the understanding of molecules. It is a part of a larger whole. On the other hand an atom in isolation is a system which needs for its explanation an understanding of electrons and nuclei. The search for fundamental particles is from an engineering point of view never-ending, because once found and isolated such particles would have to be treated as wholes and not only as parts. The irreducibility of the levels is due to the fact that the terms used have different meanings at each level. A part of a system is defined by the system. There is no such thing as a part on its own.

The third difficulty arises from the consideration of engineering models. Sequences similar to that used by Peacocke do arise in manufacturing processes, but the models used in such sequences are not unique. Every process and every object involved in such a process can be modelled in an indefinite number of ways. There are connections between the models, but they are extremely intricate. Instead of a one-dimensional linear sequence of levels the engineer is confronted by a multi-dimensional network.

Focal and Tacit Knowledge

In view of the difficulties encountered with the hierarchical scheme it appears that in spite of all its attractive simplicity its explanatory power is limited. A more flexible model is provided by Michael Polanyi in his book 'Personal Knowledge'[7]. Polanyi's chief concern is to show that human knowledge is a personal achievement. He stresses the importance of the skilful selection of a research project and this idea fits well with the method of the separation of variables in the construction of engineering models. The choice of a model is arbitrary in the sense that it is the choice of an individual person, but the knowledge is not arbitrary because it reflects the reality of the external world. Since Polanyi is particularly interested in pure science, although he has a medical background, he writes about the accreditation of personal knowledge through groups of scientists in their professional associations. In engineering this accreditation is found chiefly in engineering practice, which of course also includes human cooperation.

Polanyi makes great use of visual metaphors. A particular scientific explanation provides focal clarity of vision, as indeed does any skilful activity. Every focal field is necessarily surrounded by a field which is out of focus. There is a difference between a photograph or hologram of a landscape and a view of the landscape of which one is a part. The photograph has edges, the real landscape does not. It is therefore, impossible to achieve overall focal clarity and knowledge cannot be completely objective. Polanyi gives the name 'tacit knowledge' to the unfocused part of the field. This also fits engineering reductionism, where any particular model is surrounded by an indefinite number of other models.

The idea of tacit knowledge is further enlarged by Polanyi. In his visual metaphor any particular unfocused part of the visual field can be converted into a focused region by shifting the eyes. This however is not always possible in terms of knowledge. There are tacit aspects which defy the possibility of being made explicit. Polanyi instances the simple procedure of riding a bicycle and concludes that 'we know more than we can say'. This implies that no finite number of models can exhaust our knowledge. The use of reductionism has limits.

This radical conclusion is consistent with engineering method, which always relies on experience and skill as well as on numerical calculations related to various models. The method of the separation of variables is a reductionist method which deals with approximations and 'confidence limits' rather than unique solutions of equations. Nor is the lack of completeness and consistency confined to engineering. Gödel's remarkable theorem, which Holder mentions, shows that no axiomatic mathematical system can be complete and consistent. The limits of algorithmic models are also illustrated by the example of Turing's incomputible numbers.

Models act like metaphors. They illuminate a particular aspect of reality, but they are not statements of identity. Our entire language is

7 M. Polanyi: 'Personal Knowledge' (Routledge and Kegan Paul, London 1958)

governed by metaphor. We 'throw light' on a problem and our understanding grows through 'linkages'. A telling metaphor and a good model of a physical process are both human achievements which should be celebrated. Reductionism is a wonderful tool and is made all the more useful if its limitations are understood. In St Paul's memorable words: 'We know in part and prophesy in part'.

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