CONCEPTUAL AND COGNITIVE PROBLEMS IN CYBERNETICS

Thesis submitted for the degree of Doctor of Philosophy

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0.1 Abstract

Controversies have existed for some time about cybernetics as a subject and difficulties have existed for students in obtaining an overview despite the fact that at some level several cybernetics concepts can be grasped by twelve year olds. An attempt is made to unpack the notion of a subject entity and to indicate how far elements in cybernetics conform to such a concept within a generally acceptable philosophy of science. Ambiguities and controversies among key themes of cybernetics are examined and resolutions offered. How far the nature of cybernetics is likely to create problems of understanding is discussed, along with approaches towards the empirical examination of how cybernetic ideas are understood. An approach to better understanding is formulated and used in an investigation of how and how effectively the concept of feedback is grasped by various groups. Suggestions are offered from the foregoing analysis as to the balance of problems within cybernetics and effective strategies for the future.

Chapter 1

The nature of the problem

The original orientation of this thesis was purely towards how cybernetic concepts could be taught more effectively. It soon became apparent however that problems necessitated looking at the subject as well as the students. The stimuli for this investigation then are firstly the signs of dissatisfaction, among cyberneticians and their critics, with the success of the cybernetic enterprise and secondly the writer´s familiarity with the facility with which school children can absorb systems and cybernetic ideas.[1] This thesis aims to analyse the reasons for dissatisfaction and to develop the experiences gained from school pupils and investigations with adults to suggest appropriate courses of action.

The following illustrations may help to clarify the climate of dissatisfaction alluded to. The writer first encountered this mood at the Forward Planning Committee of this university in 1972 [2] when the question of the long

term funding of the Institute of Cybernetics was raised. One Head of School opined that cybernetics had failed to deliver the fruits promised at its inauguration while another asserted that the vast majority of work undertaken was being adequately covered in other departments. The next evidence of unease was met with among students of the Chelsea College cybernetics MSc. course which the writer attended in 1974/5 and 1976/7. For both year groups the question, "What is cybernetics?" was problematic long after the beginning of the course. In subsequent years the question was sporadically raised at meetings of the Cybernetics Society, one resolution being the concept of, "second order cybernetics." [3]

However cybernetics was attacked as an enterprise almost from its birth when Taylor [4] [5] questioned the philosophical basis of the "birth certificate of cybernetics" by Wiener, Rosenblueth and Bigelow.[6] In 1962 Pierce [7] was attacking its status. In 1976 Berlinski in, "On Systems Analysis," attacked aspects of the cybernetic enterprise.[8] The eighties began with the Norbert Wiener essay prize title of, "Whither Cybernetics, past achievements and future prospects"; the "prospects" sections of the four winning essays published [9] do not read like histories of the last ten years. In 1984 Sowa

writing "Conceptual Structures: Information processing in mind and machine" while acknowledging the common origin of A.I. and cybernetics was at pains to distance his activities from cybernetics which he implied was a failed research program.[10] A critical review by Flood and Jackson "Cybernetics and organisation theory" in 1988 cites criticisms by various other authors and comes to conclusions that are at best guarded and open ended.[11]

When the writer attended the Brunel cybernetics MSc. course the degree of anxiety about the nature of the subject appeared lower than at Chelsea, -whether due to course content, the smaller number of students or other factors is uncertain. However uncertainty did exist and culminated in one student´s questioning the validity of cybernetics as a subject entity.[12] The academic recognition of a problem may be reflected by the appearance of the question "Distinguish between cybernetics and systems theory," on the exam papers of both the Brunel and Chelsea MSc. courses during the 1970s.

Examination of the syllabuses and research interests of the six Commonwealth universities or colleges listing cybernetics as part of their work shows diversity. Some courses seem more similar to courses with "systems" in their title, others to those including the label "control,"

rather than to all of those labelled cybernetics. An equivalent diversity appears in mainland Europe. The variety of content between introductory cybernetic texts is not what would be expected of an established subject.

Thus we must face the question, is cybernetics some kind of a mistake and if so how did it arise?

However it may be that the dissatisfaction which has arisen is due rather/also to our own difficulties in handling the ideas which cybernetics attempts to deal with. At the individual level it may be that despite their ubiquity in the real world, concepts involving dynamism, flow and abstract associations are peculiarly difficult for our mental machinery. Certainly some cognitive science computer models of how memory and understanding work propose a relatively reference-book-like, hierarchical model of information storage which would pose problems for the conceptual modeling of cybernetic concepts. At the pedagogic level there is some evidence that existing syllabuses, concepts of knowledge and teaching styles are inimical to pupils´ and students´ understanding of systems and cybernetic concepts and that caught early enough they may be acquired with considerable aptitude.[13] [14] At the higher level of the conventional administration and conceptualisation of fields of academic knowledge it is

worth asking whether there are any particular aspects of cybernetics which actively militate against its placement alongside existing knowledge divisions. If so what degree of importance should be attached to this? Claims for a useful abstract overview of any field despite a lesser knowledge and experience base are hardly going to be met with indifference from experts within that field.

Lastly to obtain perspective one must consider the self questionings of other subjects. Self doubt and external criticism are not unique to cybernetics. Social scientists are particularly prone to attacks on the validity of their subject entities but even such models as physics are not immune [15] [16] and areas of uncertainty potentially destabilising most previous assumptions have been as vigorously debated there as anywhere.

While there is always a danger that too abstract a level of analysis may become a substitute for useful activity at more basic levels, the previous considerations lead us firstly, in the next two chapters, to some examination of the insights that the philosophy of science can offer us and how we can recognise a properly formed scientific subject. Chapter four examines cybernetics in the light of these criteria and after considering how the whole hangs together examines potential weaknesses in some

of the parts. In view of the fact that part of the malaise in cybernetics might be due to sheer intellectual difficulty a review is conducted of research which might enable an examination of that possibility and suggest ways in which cybernetic concepts could be grasped more effectively. From this analysis the main investigation of chapter six chooses the concept of feedback to explore how effective individuals´ facility with a cybernetic concept can be. These results and the previous work provides arguments for a particular perspective of cybernetics outlined in the last chapter.

Chapter 2

What is a Field of Knowledge?

Before determining what is uniquely cybernetic it will help to clarify what are the general characteristics of any field of knowledge. Surprisingly very little recent philosophical work has been done on this; intriguingly most of what has been done has been done by writers with a systems orientation. [17] One of the problems clearly has been the proliferation of subject categories during this century. Reschler [18] blames the trend in philosophy to matters of microscopic detail and the aversion to syntheses for the failure of this century´s writers to follow the attempts of Comte, Mill, Pierce, Hegel or Kant.

A search among educational theorists likewise reveals a failure to attack this question. Conceivably this is because curriculum theorists have come to define the role of education as serving society or the individual rather than conveying an abstract body of knowledge.[19] [20]

In this century it is among librarians that the most impressive responses to the challenge of deciding what is a field of knowledge have been made. Foremost has been Ranganathan [21] whose general theory was a response to the limitations in the serial nature of the Dewey, Library of Congress and early Universal Decimal Classification systems.

However before we consider Ranganathan´s response it is as well to identify the limitations of an answer to be expected from any particular professional viewpoint and indeed whether an answer can exist separable from such a viewpoint. The obvious constraints of a librarian are that his or her system must generally be reducible to a linear organisation (until all documents are stored electronically) and that once catalogued the information must be retrievable in a way which is intuitively appropriate to the user. Most particularly the user expects when browsing to find related subjects together - Ranganathan´s APUPA pattern (Alien -Penumbral -Umbral -Penumbral -Alien).[22]

It could perhaps be argued that there are no such things as fundamental subjects or any intrinsic divisions of knowledge. Such a viewpoint might claim that popularly accepted categorisations are simply the remnants of

outmoded academic curricula which for historical reasons remain convenient. Put more generally one might propose that what we see as separate subjects loosely connected in some dimensional space are merely social conveniences reflecting the lifestyles arising from our particular organisation of work and leisure in the last few centuries. An even stronger stance might state that all knowledge was inextricably related (or unrelated, the conclusions are the same), and that therefore any divisions could only be arbitrary and subjective.

To refute this would involve a kind of multivariate analysis for the whole universe of present knowledge; a drawing of relationships between nodes to identify the prominent clumps. Even ignoring such epistemological questions as whether the initial process of crystalisation out of the basic "facts" would not predetermine the results, it is clear that such a task is untenable; librarians have devoted lifetimes to less ambitious projects. Thus we must tolerate tenets which arise from intuition and are not refuted by analysis or experience.

Pask´s "entailment structures" provide a suggestive approach to identifying the cohesion of knowledge areas.[23] However they are dependent initially on the opinions of a subject expert and an infinite number of

entailment structures may be produced for any one topic. Until many entailment structures were publicly available for at least the conventional range of educational topics the project of trying to cluster knowledge by this method would be overwhelming if built up from details, and as subjective as any other starting at a grosser level of analysis.

While Popper´s, "World Three," concept of objective knowledge [24] would provide a "high level" basis to begin an enquiry into the coherence of subjects or fields of knowledge it is safer to begin by examining the utility of such conceptions from the viewpoint of the mind of the user. Memory, it has been observed for a long time, works to some extent by association.[25] [26] [27] Association itself is not a homogenous network but tends to work in a series of levels i.e. associations are grouped together and so on. Thus "chunking up" to subjects might be regarded as the top level of such groupings. These considerations do not it should be noted pre-empt holographic or other distributive models of memory [28] [29] although arguably such models or models with a distributive component enable a greater variety and flexibility of coordinative "superstructures" - which would help to explain the existence of controversy in the first

place.

Without a tendency to make associations the brain would almost certainly face an insurmountable retrieval problem (among others). Hence what appears at first sight as a superficial limitation in the librarian´s task of categorising subjects emerges as at least an identical restriction on human beings, if not a fundamental determinant. On what basis are such associations made and which criteria of similarity can be accepted as legitimate for the formation of subject classification? Clearly associations based on mnemonics, [30] despite their power, would not do. The reason, apart from any aesthetic revulsion, would appear to be their inability to tie together large bodies of knowledge and their tendency to become unique to the individual, which restricts useful communication. The Associationists particularised their own criteria of association (eg. contiguity succession similarity contrast) [31] which are a slightly condensed subset of those formulated by librarians, particularly Ranganathan [32] (eg. his PMEST criteria, Personality Matter Energy Space Time, or cf. Richardson, [33] Logical Geometrical Chronological Genetic Historical Evolutionary Dynamic). It does not seem illogical to suggest that criteria that have utility for the human mind may be

reasonably homologous with objective reality, both because of the exigencies of evolutionary development [34] and because brain and mind must be a part of that reality. Hence the answers of librarians appear to give the best available response to the question posed in the title of this section.

Despite its age we must return to the work of Ranganathan as the most fundamental exposition of what librarians have to tell us on this subject. It is true that by 1961 the Universal Decimal Classification had taken on Ranganathan´s, "colon" feature [35] and since then it has utilised and modified other of his principles.[36] However Ranganathan provides the fullest articulation of principles. As a reasonably contemporary confirmation we may quote Foskett [37]. "In the vast majority of cases they (the citation orders found in Ranganathan´s Colon Classification) are both clear and helpful, and this is the only scheme in which we find this situation." Other writers show a growing acceptance of facet analysis constructed from Ranganathan´s PMEST formula as the best basis for an index language.[38]

Ranganathan´s basic inspiration was the Meccano set [39]. In the same way as a variety of different toys could be built with a few simple components he sought to "combine

bits of ideas in several ways to represent a variety of subjects." Ideas, facts, books and documents were seen as having a number of facets, which could in turn be categorised under the PMEST isolate divisions outlined above.

These facets were capable of being embodied in the document´s coding, creating a classificational system which was potentially multidimensional. Ranganathan posited various canons (such as decreasing concreteness) to determine priorities in ordering such facets (and thus make reduction to a linear systematisation possible). Post facto the formulation of facets and thus necessarily of basic subjects could be presented as a purely recursive operation. In fact the process was inevitably primed by using some traditionally accepted subject categories; its validity was supported by the fact that facets built up into entities which grouped (by Ranganathan´s canons) into intuitively acceptable subject categories and permitted the development of new ones. (The system is dynamic.)

Although his efforts to produce the most helpful sequence of facets and isolates led him to postulate an "absolute syntax of ideas" [40] the task of articulating it was never undertaken --it would require, "cooperative research .. in psychology, statistics, linguistics,

anthropology, and reference service." What is of use to us is his criteria of main or basic subjects (for our purposes the same thing) which were cumulatively formulated over the three main revisions of his colon classification.

It is simplest to quote the relevant sections from Gopinath´s summary [41], firstly to classify main subjects.

"1 Traditional main subjects - these are main subjects that have been traditionally taken for granted as the first order divisions of the universe of subjects. Mathematics, physics, chemistry, engineering, medicine, literature, linguistics, religion, and history are examples of traditional main subjects.

2 Distilled main subjects - a pure discipline is evolved out of the experiences in its appearance-in-action in diverse compound subjects going with different basic subjects. .. Management science and system analysis are examples of this kind.

3 Fused main subject - the trend of inter-disciplinary approach among specialists has created a number of fused main subjects. Biochemistry, chemical engineering, and geopolitics are examples of this kind; they stem from the fusion of two or more traditional

disciplines.

4 Other kinds of main subjects - literary warrant on a few subjects satisfy certain criteria stipulated for deeming a subject as a main subject. .. Journalism, public health, applied psychology, industrial economics, and social work are examples."

Criteria for identifying a new subject include [42]:-

"1 A subject which calls for schedules of special isolates forming facets of a set of compound subjects going with one and the same host subject;

2 A subject which has to be taken as the central subject and in which one cannot distinctively recognise isolate facets. In other words, a subject which can not be expressed as the compound subject; and

3 A subject which has some specialisation in academic circles - such as degree courses, periodicals, etc."

Thus a subject may be regarded as coalescing (or for a non-subject not coalescing) in the multi-dimensional space of the facets but by prioritising the facets a linear position may also be found.

It is worth noting that the classification of cybernetics in the Colon system has occupied four separate positions to date (with similar shifts in the U.D.C.) and merited a paper by Gopinath on the issue.[43] It entered as related to biology and maths, then became a division of maths, followed by the status of a distilled main subject dealing with integrated wholes. Its latest classification was primarily influenced by an article on cybernetics by Caianiello [44] corroborated by Klir and Valach [45] and Cybernetic Abstracts and it now resides as a main subject with a position between maths and physics.

We may bear the previous discussion in mind as we examine the status of cybernetics, but before we examine cybernetics per se we must determine what should be the criteria of validity of a subject; phrenology might once have attained subject status but its knowledge claims are discredited.

Chapter 3

What is Justified Knowledge?

To continue to secure our grounds and guide future analysis we need to decide upon what the status of any subject, particularly a science, rests. There is little point in trying to assess cybernetics according to criteria under which all subjects would fail. On the other hand to swallow the case of some of the most radical philosophers of science [46] which put all belief systems on a par would make this inquiry meaningless or at best restrict it to sociology.

Various necessary or sufficient conditions have been proposed as ensuring the validity of a set of conjectures:- statements should be; logical [47], empirical [48], coherent [49], operationalisable [50], falsifiable [51], or able to create novel predictions [52].

While all of these are useful tools, we accept the analysis of Newton-Smith [53] that there is no known static set of objective criteria that will identify justified

knowledge; the judgement of the scientist can not be excluded. This does not mean however that the whole question becomes merely a part of the sociology of knowledge; such a programme would invalidate the sociology of knowledge itself. Science certainly makes progress in the range of phenomena it can accurately predict, and while any particular theory outside mathematics will probably be invalidated within two hundred years the concept of science continually increasing its verisimilitude, its closeness to the truth, is plausible enough for us to work with, even though Newton-Smith´s defence of the concept of verisimilitude is not rigorous [54]. "The ultimate test (of superiority of a scientific theory) in terms of long-range predictive success controls the evolution of the other factors through a feedback mechanism."[55]

Thus the various criteria of justified knowledge offered by philosophers of science will be treated as useful tools in assessing cybernetics but we will not reject the possiblity that in some respects its progress has been affected by sociological pressures. While noting Etemad´s conclusion at the end of his cybernetics dissertation [56], "There is as yet no consensus on the form of a scientific theory," without recapitulating the protagonist´s arguments, our judgement is that the most

respectable banner to proceed under is that of Newton-Smith´s, "Temporate Rationalism."

Chapter 4

The (dis)unity of the field of cybernetics

Before attempting some kind of cybernetic taxonomy it helps to be clear about the nature of the subject one aims to taxonomise. A variety of viewpoints are available with respect to cybernetics:

a) cybernetics as a field of basic phenomena to be studied; analogous with, say biology or physics,

b) cybernetics as a toolkit of concepts for handling situations or phenomena which may arise unpredictably in a variety of areas; analogous with mathematics or logic,

c) cybernetics as a school of philosophy; for example the view that sentience is simply the result of a concatenation of feedback loops [57] or second order cybernetics.

d) cybernetics as an epistemology i.e. the notion that reality is best understood in the analysis of

relationships and processes rather than by division into absolutes or fundamentals along the lines of Plato[58] or 1960s particle physicists.

e) cybernetics as a series of questions, problems, a research programme to which we seek, adapt and reject provisional answers; thus the question might be, "How is purposive behaviour possible?" or "How do the values which emerge in ´justified interventions´ in sub-systems develop from the simple systems out of which they are ultimately created?" [59]

f) cybernetics as systems theory with philosophical sophistication,

g) cybernetics as that subset of systems theory which excludes non-gubernatorial phenomena, [60]

h) cybernetics as a synonym for systems theory,[61]

i) cybernetics as a set of axioms from which a set of deductions about higher level interactive phenomena can be derived, [62]

j) cybernetics as a subset of maths dealing with abstract systems characteristics.[63] [64]

k) cybernetics as (one of a series of -cf.Goethe

[65] [66], Bogdanov´s Tektology [67], the later Logical Positivists [68], F Capra´s manifesto [69]) socio-historical epiphenomenon arising out of a general orientation to interdisciplinary studies.

1) cybernetics as an abstraction of science, being the study and classification of interactions.[70]

Clearly these viewpoints can be subdivided and/or recombined.

4.1 Higher level classification problems

A review of syllabuses, book sales and research publications could only be made to yield a consensus viewpoint by simplistic initial assumptions and sophisticated statistics. It could then still be argued that truth is not a matter of head counting and that a general consensus simply reflects general misapprehension. Thus our task is either to choose one of the available models of cybernetics or to indicate something better.

The task is one which has been attempted more by self avowed systems theorists than cyberneticians, although

contents pages of general texts provide some form of model. Troncale has produced a relatively simple model of eleven focal packets of fifty seven "principle systems concepts."[71] He provides a graphic display using nine of his focal packets. (Seven of these are detailed in the next section giving some key concepts with applications taken from a putative "cognitive map." The items chosen were arrived at independently.) A possible limitation might be the lack of integration of the concept of information in the display and the impression that some concepts are chosen for mutual support rather than their predominance in publications.

Another systems theorist wrote to all the contributors of, "Trends in General Systems Theory" (ed. G Klir 1972) asking them who were the major influencers of their views on general systems. The writers cited with most frequency were; Ashby (17), von Bertalanffy (9), Rapoport (7), Wiener (7), Klir (6), Zadeh (5), Boulding (4), von Foerster (4), Bateson (3), Shannon (3) and von Neumann(3). Another 46 authors were mentioned once.

Systems theory at least then shows a degree of both coherence and diffusion. However simply describing states of affairs is not a sufficient scientific activity. One looks for some justifiable unifying rationale. Kant put it

quite well. "For it will often be found, that the originator of a science, and even his latest successors, remain attached to an erroneous idea, which they can not render clear to themselves, and thus they fail in determining the true content, the articulation or systematic unity, and the limits of their science.

"It is unfortunate that, only after having occupied ourselves for a long time in the collection of materials, under the guidance of an idea which lied underdeveloped in the mind, but not according to any definite plan of arrangement - nay, only after we have spent much time and labour in the technical disposition of our materials does it become possible to view the idea of a science in a clear light, and to project, according to architectonical principles, a plan of the whole, in accordance with the aims of reason. Systems seem, like certain worms, to be formed by a kind of generatio aequivoca - by a mere confluence of conceptions, and to gain completeness only with the progress of time. But the schema or germ of all lies in reason; and thus is not only every system organised according to its own idea, but all are united in one grand system of human knowledge, of which they form members."[72]

While rejecting a pure coherence theory of truth, operating broadly on a correspondence model, coherence may be regarded as the essential criterion for the denomination of a subject entity, as also emerged from Ranganathan. Coherence is also a useful tool in truth testing, being necessary but not sufficient. For some the notion may have an old fashioned ring in view of the notions of complementarity and scientific pluralism [73] [74] , but its driving force in the development of science remains undeniable. For clarity of exposition a possible coherence model of cybernetics is introduced first and justifications and objections considered later as they emerge in its development.

Let us assert that those aspects of the world with which science is at present having most difficulty lie in the understanding of large complex systems, such as ecosystems, economies, societies, brains, ´brain-like´ artifacts (computers or intelligent programs) and the expression of animal development through DNAs. Prima facie evidence for this lies in the failures of human society in predicting the behaviour of such naturally occuring systems, and the volume of research effort invested in developing artificial systems with similar potential. A part of this difficulty lies in the impossibility of applying the traditional scientific principle of "ceteris paribus" in such situations; thus comes the demand for new tools of analysis.

If we accept such notions we may assert that cybernetics is unified by the search for and application of common explanatory concepts for the common phenomena unique to large complex systems. Life becomes more contentious when we try to assert what such common concepts are or place them in a hierarchy. Obviously the set is open, some concepts may be yet to be arrived at, others may prove to be misconceived. The justification for cybernetics would only collapse if it were proven that there were no common unique properties to such systems, although it would retain

a place in the history of thought along with say animism to explain why such properties were imagined to exist in the first place. Given common phenomena the set of explanations would be corrigible and capable of refinement. However if the set were limited and easily articulated the research impetus could soon decline.

Trivially almost anything may be viewed as a system. If the quark and its friends prove to be products of mutual interaction and reflection [75] then at a certain level most forms of matter may be regarded as systems or agglomerations of such. Hence there is a danger of trying to include an unwieldy number of properties as system properties. We may prune this set by refusing to regard as cybernetic anything that can be explained by static analysis, without a time arrow, and continue to refine it by excluding say dynamic systems which can be characterised by single value functions and so on up to a prescribed level of mathematical complexity; or we may define the adjectives ´large complex´ recursively and characterise them as pertaining to those systems whose properties interest us as being common to the highest level systems and inexplicable by particulate analysis (i.e. analysis of their most atomistic units). That the latter definition is recursive may be deemed unsatisfactory but recursive

definitions are ubiquitous in science and may be tolerated pending a fuller understanding of the field being investigated. Moreover the two pruning systems may be regarded as mutually supporting in so far as they prove coterminous.

Before venturing to propose common unique properties of large complex systems it is helpful to note the development of key concepts in other areas. It is part of the success of science that its concepts are corrigible and not static. Thus Dalton´s concept of the atom is so different from say Pauli´s as to hardly merit the same name, likewise the Newtonian and string theory views of space.[76] Nevertheless earlier concepts may retain their usefulness for pedogogical reasons or within a limited universe of discourse. For example electrical (as opposed to electronic) theory does not require anything more sophisticated than the Rutherford model of the atom and it is hard to see how anyone could understand De Broglie´s model without first grasping Bohr´s. Paul Lorenzen´s comments about physics, though possibly reflecting frustration more than belief, warn us that we should not expect our task to be easy. "When we simply speak about physics we use it only as a collective noun for a multitude of past and present scientific activities. The word

´physics´ describes one aspect of human activity which for the moment at least, is given only in historic terms."[77]

To focus first on Wiener´s earliest notions; "The group of scientists about Dr. Rosenblueth and myself had already become aware of the essential unity of the set of problems centering about communication, control, and statistical mechanics, whether in the machine or living tissue."[78]. Since the concept of control can largely subsume the notions of communication and statistical mechanics and because of its link to the etymology of the word cybernetics we shall begin by examining the role of the notion of control as a unifying characteristic among the properties of large complex systems. Such systems we may propose either control some aspect of their own behaviour or part of some process which may be viewed with the control system as part of a larger system.

Less interesting is open-loop control, with a linear chain of causation in which there is no way of adjusting according to the effectiveness of the control process; as for example when the depression of a key leads to a symbol appearing on the screen of a word processor. More interesting is closed loop control with a circular chain of causation where there is automatic adjustment according to the effectiveness of the basic control

process; frequently circular causal processes are labelled "feedback".

While the notion of control is ubiqitous, problems have emerged. From a conventional scientific viewpoint it highlights the problem of dualism. There is the controller and that which is controlled; from the former emerges the notion of purpose-like behaviour which so intrigued the early cyberneticians [79]. Clearly at some level some behaviours of both animals and automatic control machines bear formal similarities [80] and both embody feedback mechanisms but the attempt to attribute the property of purposiveness to all systems with feedback mechanisms [81] has been discredited by Taylor and Searle.[82] [83] [84]

Pursuing the spectre of dualism in cybernetics (which cyberneticians usually claim to transcend), as the notion of control implies control for a purpose, so purpose leads to the notion of reasons or rationale for that purpose; in other words, ultimately, values. (The choice of "ethics" as part of the theme for the 1990 annual conference of the Cybernetics Society possibly reflects awareness of this problem.) Such an emergence may be seen as inevitable once cyberneticians had formulated the notion of automatic, closed loop control: with the simple thermostat there is an outsider to select the setting of

the thermostat, with more sophisticated machines which can function according to various criteria the choice is internalised into a higher level loop, hence the inevitability of a top level values loop (so far only in human "systems"), and the tension in the program to derive common phenomena from the properties of animate and inanimate large complex systems.

Obviously the introduction of the notion of values into science may be seen as a challenge to its traditional purview.

Many cyberneticians and systems analysts clearly believed that from the notion of control and thereby information they could elicit a rational, optimal analysis of a system or situation which obviated the explicit need for the importation of (presumably subjective) values [85]. As Sharp´s article in "Computing" showed this belief was also discredited.

The tendency of cybernetics to divide the world into two universes of discourse; the physical and the informational (at which level resided control) also had challenges from within,

> "Norbert Wiener, ... is partly responsible for that secret mongering in connection with the concept of information and the theories about it. The haze with which Wiener surrounded this concept in order to place it

alongside, as equally important and equally fundamental as the concepts of mass and energy can probably be traced back to a mix up of statistical, communication theoretical information with semantic information. This was recognised if somewhat late, but a confusion did result and even nowadays, twenty years later, people still fall for it."[86]

Waddington more reservedly commented that, "Wiener shouted ´Eureka´ at least as loud as the traffic could take."[87] The notion that physical information measures provided the entree to cracking the problems of mind found first widespread enthusiasm and then widespread disillusionment. Science had previously accepted such uncomfortable notions as action at a distance and probability but as possible implications of reifying the matter and energy vs. information distinction dawned, and progress appeared to falter, credibility was strained. One strategy has been to delimit the notion of information and find an available conceptual field for the remaining areas of difficulty. This leads us to Stewart´s "Ternary" theory which gives concepts a position in a physical domain, an informational domain and/or an evaluative domain.[88] [89] [90] [91]

The danger of the waters into which cybernetics was getting with either the denial of or the emergence of value (and other higher level concepts eg. consciousness [92]) might have been anticipated from the strictures of Hume (as Stewart pointed out).[93] "Hume´s Law" which is popularly

rendered as, "You can´t get ´is´ from ´ought´," is unarguable, but the reverse proposition which he argued for, that values or moral distinctions can not be derived from the facts [94] i.e. information, creates problems for cybernetics.

Just as Bar-Hillel´s comments indicate unease about the distinction between the physical and the informational level of description it appears that the informational domain itself may be insufficient to handle the notion of control, at least at all conceivable levels;[95] if so cybernetics would need to be divided into three parts and we would face the issue of whether the information/´values´ split was any more intellectually satisfactory than that of the physical/informational split. If we examine Hume´s reasons for his shibboleth, "Moral distinctions not deriv´d from reason," we find that however impressive his conclusion his justifications are less so.

Hume distinguishes between the "actions and affections" and "reason" which he identifies with the process of deriving conclusions from facts. He then proceeds, "Since morals, therefore have an influence on the actions and affections, it follows that they cannot be deriv´d from reason." [96] i.e.

p is not = q

r affects p therefore

q not affect r

which is simply a non sequitur, both because p not being q does not exclude any relationship of influence between them (eg. I am not my father but he may influence me) and because any such influence is still irrelevant to the possibility of q affecting r.

His failure to divorce data from values is illustrated in the next paragraph. "As long as it is allow´d, that reason has no influence on our passions and actions, ´tis in vain to pretend, that morality is discovered only by a deduction of reason." The first premise is surely false; eg. reports of the prospects of acquiring HIV virus have reduced the level of similarly transmitted diseases: the inclusion of the word "only" in Hume´s conclusion is an admission of possibility which severely damages his case.

The diversity of Hume´s arguments, which are mainly presented in the first twenty pages of Book III of "A Treatise.." suggest the inadequacy of any one of them. His solution of deriving values from a sense of values, "Moral

distinctions derived from a moral sense," [97] is unsatisfactorily tautological.

However as Hume continues he appears to end up at the opposite position to which he began; the impressions by which we determine moral good or its contrary are simply particular pleasures or pains. [98] The link with Utilitarianism has been made explicitly by Mary Warnock [99] and was acknowledged by Bentham himself.

At a practical level Kohlberg´s work on moral development explicitly attempts to show the inappropriateness of the "Naturalistic Fallacy" (you can´t get "ought" from "is") by demonstrating a series of stages which individuals (may) go through in arriving at a their own moral values and which stand up in cross cultural comparison.[100]

The upshot for our purposes is that a provisional distinction between values and information may be legitimate in cybernetics but we can not assume that this divorce is permanent; the effort to link the two might ultimately produce useful insights. The practise of accepting a principle eg. action at a distance, which can not be fully justified has been fruitful in other areas and may serve where we can not yet explain in cybernetics.

The discussion of a "tertiary domain" in cybernetics [101] is necessary because it might be here that some ultimate "higher level" unifying factors could be assumed to inhere. But it is worth noting Mill´s caveat, [102] (echoing Kant) "The truths which are ultimately accepted as the first principles of a science, are really the last results of metaphysical analysis, practised on the elementary notions with which the science is conversant." The problem of the tension elicited in the previous paragraphs is underlined by Mill´s potentially contradictory statement, "Questions of ultimate ends are not amenable to direct proof." [103]. Could a tertiary domain in cybernetics have a single unifying theme? For example must it consist of a collection of unrelated value dimensions or could such elements be subordinated to a hierarchy under a system such as some form of utilitarianism? With respect to this question respectable philosophers differ.[104]

However values are not the only possible contenders for a domain of cybernetics transcending information. Traditional Darwinism would offer us the simple notion of survival as the justification for higher level information control loops. More modern notions of co-evolution [105] offer emergent phenomena within which a justification space

for other cybernetic manifestations might be located. Another claim to transcend notions of information comes from Maturana [106] with the notion of autopoesis in which the organism is seen as creating its own meanings (values?) which can not be meaningfully interpreted within any overarching system. The formal similarity to Husserl´s idea of a ´ding an sich´ which held together phenomenology and out of which emerged existentialism is obvious. It is probably not co-incidence that Prigogine´s concern with self-transcendent systems leads him and Stengers to a concern with "becoming" reminiscent of the earlier school of philosophy.[107] However it might be argued that none of these alternatives are essentially more than the selection of a single value coherence notion from what is essentially a plurality. It may be noted that unless values are somehow linked to "what is" - Stewart´s primary and secondary domains, the task of demonstrating the unity of cybernetics can never be completed. Having established that an examination of the notion of control can be used to demonstrate the feasibility of Stewart´s tripartite division of cybernetics (or at least the examination of systems), despite some difficulties, we can continue to examine the connotations of the central idea of control.

While being a useful every-day concept the notion

of "control" incorporates some assumptions which we may be less happy about when examined close up. Firstly the notion is not wholy objective. It contains the subjective imputation beyond what can be observed that X only did Y because of Z. As such it carries all the philosophical objections that Hume raised to the notion of cause and effect and more. Secondly the notion is ambiguous because it is not necessarily clear whether a goal is implied in Z´s control of X and any status attributed to such a goal can easily be either tautological or yet more subjective. Another ambiguity in the word "control" is that it is unclear on the degree of determinacy between X and Y as a result of Z.

There is a pool of analogous words, each with their strengths and weaknesses, which might offer themselves as alternative core concepts in cybernetics; influence, communication, interaction, autonomy, dynamic pattern, cause; each carrying a greater or lesser weight of attribution by the observer. However even when we attempt to use the notion which most drastically aims to purge the presuppositions of the observer i.e. to simply describe pattern [108] the patterns we are able to see will be a function of our previous suppositions embodied in our theories and the "wiring" of our nervous system [109].

Neuro-holography theorists would attribute such perceptual rigidity to the "grain" of the filter. [110]

Hence if it is a requirement of a science that it does not incorporate presuppositions the validity of which can not be demonstrated then apparently cybernetics can not be a science, at least with its present "core" notions. An obvious rejoinder to this is that under such stringent requirements no subject can be regarded as scientific as yet. Nevertheless it may be conceded that in observing systems cybernetics appears to have to attribute more a priori to focus in on its interests than does, say physics or anatomy (although there may be a cultural influence in the confidence with which we regard phenomena as directly observable). [111] Various moves have been made to deal with this difficulty and to objectify notions that easily become subjective, for example von Bertalanffy´s concept of "equifinality" [112] or Sommerhof´s "directive correlation" [113]. Beer [114] appears to endorse Maturana and Varela´s attempt to cope with the spectre of subjectivity which involves the denial of the notions of even communication or information so far as the living organism is concerned. They appear to allow that an organism controls its own organisation but elsewhere the concept of control is proscribed. For them organisms create their own reality

independent of anything "out there" and to attribute virtually anything other to the organism than a homeostatic maintainance of its own internal relations is a kind of self-indulgent subjectivism on the part of the observer. Why their own position is not therefore equally so is not readily apparent. Certainly it could be accused of merely being an elegant tautology. Provisionly we might simply concede that large complex systems show "control-like" phenomena and examine what notions of interaction are useful in explaining them.

This brings us back to generally familiar cybernetic notions which could be characterised as belonging to the secondary (and usually also the primary) domain.

4.2 Elements of a Cybernetics Syllabus

It might be assumed that in order to fulfil the aim of this section to indicate the unity of cybernetics, and to show the area that this thesis generally refers to, it was necessary to produce a detailed interrelated taxonomy of cybernetic ideas. Although even then it would be necessary to show that the taxonomy produced was either not significantly different from all the rest or that it embodied superior organising features of coherence and correspondence.

Fortunately in order to demonstrate unity a detailed delineation is not necessary; we only have to show a reasonable degree of cohesion. Further, it is not necessary to claim priority for the cohesion model produced. To some extent the model below pre-empts certain alternative viewpoints. But it is necessary to offer some reasonably articulated structure at this stage in order to create a position from which to consider alternatives. However alternative models in the same area generally would reinforce the basic claim of unity rather than compete with it. Certainly if all "cybernetic" concepts could be

non-repetetively parcelled out to separate fields where they stuck together with other ideas more strongly than in cybernetics there would be no point in demonstrating cybernetic unity. However to demonstrate this would be a considerable task, its very size tending to weaken the "anti-cybernetic" claim. Moreover apart from the basic, "knowledge cohesion" demonstration later sections will reinforce the cohesion-of-cybernetics claim with cognitive efficiency arguments.

While not producing a comprehensive taxonomy the principles by which one would be developed are still of interest to us in showing cohesion. One approach would be to look for guidance to systems and cybernetic notions of growth and development. One could seek an elementary notion to begin with - hopefully from a more "basic" field and aim to show that its elaboration incorporated more cybernetic notions, and thence by following an expanding vortex demonstrate the "re-emergence" of cybernetic notions in more complex areas, from more primitive concepts. We might also anticipate that some higher level concepts or systems would attain a greater significance and ubiquity than the lower level systems phenomena on which their emergence originally depended.

Hence a possible schema or "cognitive map" is

presented below. Starting from the central, elementary and abstract notion of "interaction" it spirals round to interactive notions of increasing complexity. As far as possible in two dimensions related notions are placed closer together. Clearly since the brain can make connections in many more dimensional characteristics than can clearly be represented on paper, positions will become more arguable further from the "central core". This is reinforced by the fact that complexity frequently provides more facets from which linkages can be made. Thirdly complexity is frequently associated with specificity; thus items at the outer layers will tend increasingly to be attributed to the domain of other subjects.

The notion of "interaction" is chosen as at once more general and more elementary than anything else available. It does not for example carry the "one-way" connotations that traditionally restrict the concept of "control." To the extent that there emerge from conceptions of increasing complexity of interaction phenomena to which control-like or teleonomic features may be attributed we may educe a further level of coherence of traditional cybernetic concerns.

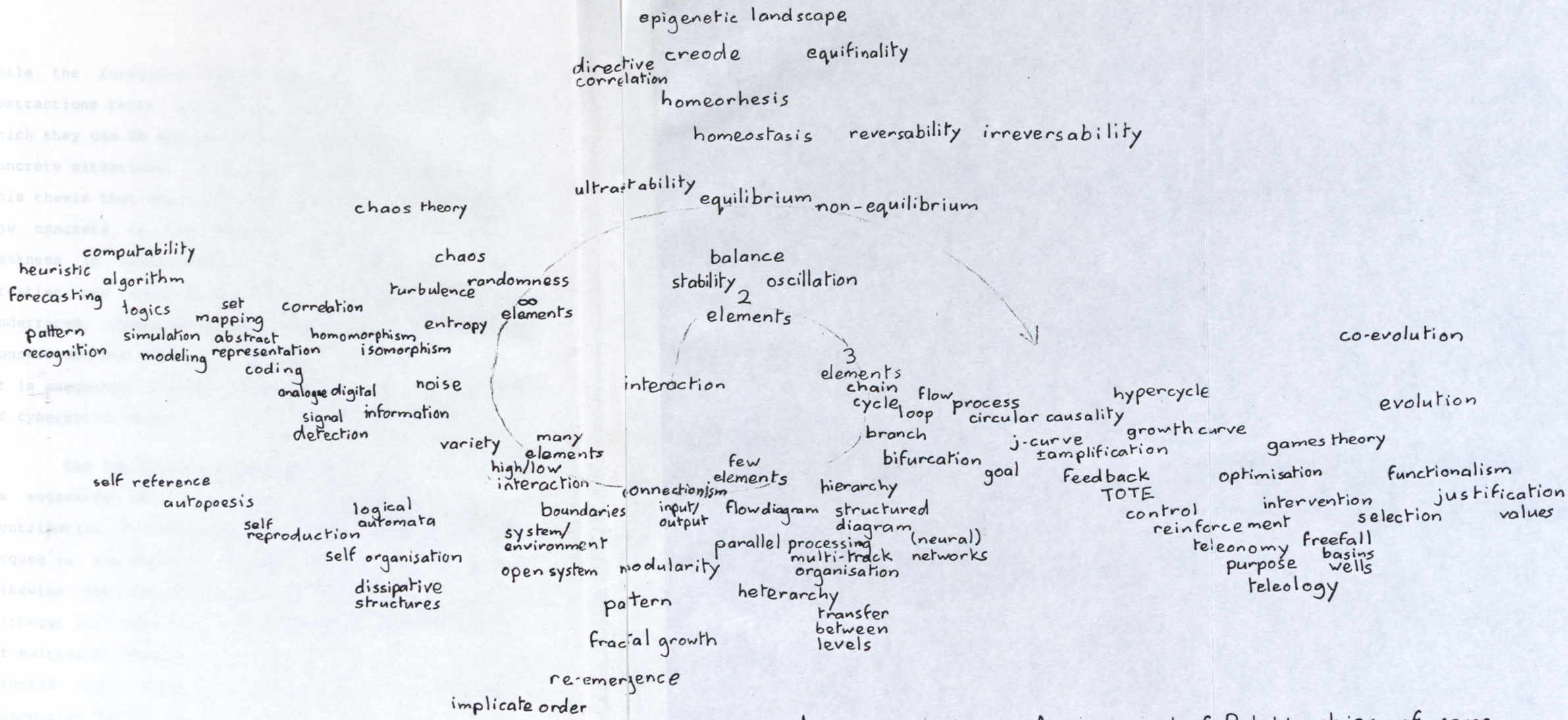
The arrangement below is not as "hard wired" as a Buzan "mind map" [115], in that there are no specific

branching pathways between one concept and the next; the provisional cognitive map is more a network than a taxonomic tree. To achieve a more elegant dimensional schemata would put cybernetics in a suspiciously isolated class. An examination of A-level syllabuses [116] for example suggests that the best any subject does is take a handful of broad categories and sub-divide each into a list of items.

Apart from criteria of coherence and correspondence to some "reality" a conceptual subject schema may also be evaluated as an effective memory device (as indicated) and ultimately for its utility in indicating possible research directions both by identifying gaps and by drawing attention to overlaps and correlations which may be worth elaborating. It is worth remembering that the usefulness of a classification scheme lies in the relationships which it omits as well as includes (part of the function of boundaries and modularity). Finally of course it is a fundamental of librarianship that subjects grow and require reclassification; thus the ultimate purpose of any conceptual scheme is as a provocation to reconceptualisation.

Thus follows an indication of what a two dimensional arrangement of relationships, generated on the

principles described above, can look like.



A Two Dimensional Arrangement of Relationships of some Cybernetics and Systems Concepts – starting from elementary concepts of interaction and spiraling out to concepts of greater complexity - with potential for mapping onto a sphere

While the foregoing scheme presents an arrangement of abstractions their usefulness depends on the extent to which they can be applied to and recognised in a variety of concrete situations. It will be a central contention of this thesis that while the human difficulty of moving from the concrete to the abstract is widely accepted the weakness in moving from the abstract to recognising or creating new applications in the concrete is vastly underrated. Cyberneticians´ failure to articulate such connections and the wider human difficulty in doing so is, it is suggested, a significant factor in the limited impact of cybernetic ideas.

The importance of such apparently mundane activity is suggested in the history of biology. Darwin´s contribution to evolutionary theory was not it may be argued in its formulation, which had been proposed before, likewise the driving principle of natural selection although more significant was developed under the influence of Malthus´s Principle of Population; however Darwin´s crucial contribution was in marshalling a plethora of supporting detail for over twenty years.

Thus to give some indications of the richness of the field of cybernetic notions we need to begin to itemise their occurence. Thus key concepts are taken from the

schema above and some applications listed. That some applications could be placed under more than one conceptual heading might either be evidence of muddle or of the unity of this set of ideas.

EQUILIBRIUM

balance, principle of moments, pulley system at rest, membrane diffusion, laws of diffusion, Le Chatelier´s principle, gas laws, 2nd law of thermodynamics, Newton´s third law, balance of forces- physical political, electron energy states, sea levels on rotating planet, fluid levels, floating in liquid or gas, cloud levels, balloon, body pressure/air pressure, maths = sentences, structure of solids liquids gases, engineering structures, any lawful process from some viewpoint, (In any enduringly identifiable entity some component may be identified as in equilibrium; something is conserved. It is worth being clear about what aspects of the system are or are not in equilibrium, what is being focused upon.) double entry book-keeping, long term balance of payments, eventual supply and demand, laws of market under perfect competition, most traditional economic models, tight rope walker, gyroscope, long term partnership, parts of games theory, minimax solutions, tit for tat, Nash equilibrium, tension on recording tape, muscle tensions round joints, depolarisation neurological firing, static dynamic unstable metastable neutral equilibria, stability, rule following, free fall, basins, chreods, epigenetic landscapes, stability through negative feedback, homeostasis, ultrastability, closed systems, possible view of some long term input output relationships.

NONEQUILIBRIUM

Prigogine´s dissipative systems, negative entropy, evolution of chemical complexity, ditto micro and macro material complexity, open systems, many positive feedbacks, growth economies, ecological spirals.

BOUNDARIES/INTERFACE

skin, guts, (cell) membrane, sense organs, effectors, keyboard musical computer, screen, surfaces atmosphere biosphere, bubble, national borders, hedgerows, enclosure, insulators, buffers, proscriptions eg. for programming style, social norms restricting forms of interaction, pencil paper, satelite dish, microphone, loudspeaker,telephone, leads carrying signals, channels, partitioning, brain/mind, science/society, technology, negotiating table, missionary sales advertising activity.

INTERVENTION

free fall, slippery slopes, uphill tasks, sinecures, physical informational justificatory, [117] barriers, wells, basins, search strategies, O.R. and decision theory strategies, relaxation & temperature in PDP systems, brief therapy [118], minimalism, feedback.

MODULARITY

car parts, computer components, stereo system, most electro- mechanical consumer durables, body organs, cells and cell sub- structures, flower parts, brain areas? construction kits, systems building, some college courses, subject divisions, universe of galaxies stars and atoms, conglomerate structure, some production systems, oil refinery, brewery, some retail structures, containerisation storage systems, bee hive, box & line diagrams, structured programs, Modula II, object oriented processing, Smalltalk, frame, chapters, paragraphs, any component of an iterated system.

HIERARCHY

some religious organisations, most armies, civil service, larger commercial organisations, large service organisations -N.H.S., pecking orders, computer languages, decision trees, some program structures, telephone connections, groupings of knowledge, taxonomies, material organisation sub-atomic to galaxies.

HETERARCHY

British or U.S. constitution, Winston's block worlds and some other A.I. programs, Minsky's brain models, brain per se, guerrilia army, SAS unit, some child leadership patterns, some working parties & project teams, interdisciplinery research teams, some sports teams, small co-operatives, possible view of some just-in-time manufacturing systems, possible grid network for water/electricity supply.

INPUT/OUTPUT

data processing eg. keyboard printer, much communication theory, production process -raw material product, stimulus response, reflex arc, conditioned reflex, "black box" testing, exploration of some novel objects, empirical science, food waste, mathematical function (or set of), educational system, imports exports, balance sheet, question answer, coin in the slot machine, orders action, "suck it and see", elaboration of cause & effect, a view of most flows of material energy information.

OSCILLATION

shuttle, tides, many flip flops or bistables, radio wave generator, Schmidt oscillator, metronome, pendulum, windscreen wipers, rocking horse or chair, see-saw, sine wave, simple harmonic motion, piston, candle on pin burning at both ends, bell, compression rarefaction resonance reverberation, brain waves, undamped negative feedback with external stability, coupled positive feedback systems, commuting, animal migration, heart beat, breathing, contractions, worn computer fan, oestrogen progesterone, manic depression, quartz crystal, pulsar, Piaget's assimilation & accommodation, hard/soft persuasion techniques, some institutional innovations eg. centralisation decentralisation rule enforcement, some classroom noise levels, some fashions, wake sleep, day night, periodicity.

CYCLES

water cycle, nitrogen cycle, Gaia, citric acid cycle for oxidation energy rich molecules (Krebs cycle), cAMP & slime mould aggregation, metamorphosis life cycles eg. liver fluke, protein RNA production, enzymatic behaviour, catalysis, autocatalysis, RNA phage (virus) infection of bacteria, viral mutation cycles co-ordinated with hosts´ lifespan, Eigen´s hypercycles (cycles of cycles) for (particularily) pre cellular evolution, epigenetic & epigenealogical development, dissipative self organisation eg, Belousov-Zhabotinsky reaction, Bethe-Weizacker cycle for the transformation of hydrogen to helium in stars, service sector of modern economy eg. tourism and roads, academic growth publications activity, [119] electrical circuit, blood circulation, hot water heating system, convection, sun spots, ice ages, Nemesis star (periodic world catastophe theory), electric motor, internal combustion engine, musical box, food chains, biomass cycle, seasonal cycles, menstrual cycle, the Circle line journey, the golden triangle trade, economic cycles, many board games, neon & traffic light sequences, Hebbian reverberating neural circuits, ascending reticular activating system, maintainance operations, Halprin´s RSVP cycle for creative action, the research process, "windows of order" within chaos functions, program loops, strange attractors, feedback.

FEEDBACK

Maxwell´s governor, homeostasis oxygen carbon dioxide salt sugar, animal´s balance, automatic tuning, back propagation in PDP systems, iterated prisoner´s dilemma, elections, TOTEs, many "chaos" equations, some of the cycles above, c. 300 examples from subjects in Chapter 6 section 4.

SELF ORGANISING SYSTEMS and AUTOPOESIS

Prigogine´s dissipative systems cited above, DNA accuracy self checking, genes, living biological systems, marriage, family, clan, breeding group, countries, religions, corporate structures, social (class) structures, some cognitive growth, educational process, scientific endeavour, growth of knowledge, mythopoesis.

EVOLUTION & ITS ANALOGUES

life forms, domestic products, music, ideas, science, art? game of life, Eigen´s evolution games, economic growth corporate variety complexity and efficiency, immune system operation, Edelman´s selectionist neural systems, variety generation & selection for eg. design, co-evolution.

POSSIBLE REQUISITE VARIETY STRATEGIES

traffic lights´ more potential states than available car behaviours, users´ reduction of language´s potential variety? teacher controling class by increasing own knowledge/range of behaviour, increasing detail of legislation & emphasis on self regulation, growth of computer records, emergence of norms constraining behaviour with stable personalities, Sadam Hussein´s 8 bunkers, genetic random mutation in evolution, immune system strategies, species & product diversification, some code breaking key word discovery and solution finding strategies, writing long theses, routinisation.

LOGICAL AUTOMATA

finite state machine, Moore machine, Turing machine, game of life simulated evolution [120], hodge podge machine [121], neural nets, perceptrons, PDP systems.

MULTI TRACK ORGANISATION

efficient housework & cookery, large scale production processes, critical path analysis, PERT, parallel processing (brain & hard/soft wear), household wiring, multiplexing, aircraft ground movements, overall physiological functioning.

4.3 Remarks on the development of cybernetics

The map above contains some elements that have not featured prominently in the cybernetic literature but which on the schema above are a logical development of it, specifically the concepts of chaos theory and non equilibrium and far from equilibrium situations. Their root influences are very much in the area which originally excited Wiener and his co-workers. Thus chaos is concerned with iterated cycles of development in which the outcome determines the next development as occurs with positive feedback mechanisms. (This relationship is discussed further in the examination of feedback in the next section.) It is noteworthy that Wiener warned against the use of existing mathematical models in the social sciences and was sceptical about the development of cybernetics there after contemplating Mandelbrot´s graphs of movements in the commodity markets where he showed that the market´s contemplation of its own irregularites created something more complex than could be handled by differential equations; in essence a fractal.[122] Statistical mechanics is one way of handling an infinite number of elements, chaos concepts are another.

Likewise Prigogine´s concern with the developments in negative entropy situations within the flux of entropy [123] [124] are essentially the implementations of Schrodinger´s theory about life [125] which as the prime example of an open system is a basic of cybernetics. However the working through of the details which Prigogine undertook has produced a richness of understanding and support which has been more impressive than simply reiterating the original broad concept.

Prigogine´s concerns also link with the increasing awareness in biology that the notion of control transcends itself and moves towards co-evolution. Jantsch in criticising Ashby´s claim that the notion of requisite variety models the interaction between species and niche quotes C U von Weizacker´s arguments that in life the issue is not control but dynamic connectedness,"Total adaptation and total non-adaptation are both lethal. In ecology, a niche fits the species sufficiently without defining it; the species, in turn, fits the niche sufficiently, without defining it. What else is fitting, but not defining each other, than an emancipated relation." [126]

If these developments had arisen from a self declared cybernetic or general systems school these fields might now be recognised as adequately fruitful. However

the historical fact remains that they emerged from engagement in detailed empirical work, (with chaos) in a variety of areas. The commonalities only gradually became apparent and then permitted the application of the same approach to some new areas.

A success of sorts is seen in the re-emergence of connectionism. When in 1983 Sowa (cited in Chapter 1) sought to distance his approach from the "bottom up" nets of the cyberneticians he expressed the widespread feeling that Minsky and Papert had demonstrated insuperable limitations in the connectionist approach. [127] In fact as Rumelhart and McClelland´s two volumes in 1986 showed [128] they only demonstrated the limitations of a particular type of model and the contents of such journals as "Cognition" show a recent outburst of connectionism. Whether their success will cause them to be regarded as a separate subject, no longer a part of cybernetics, remains to be seen.

The discussion above points to the probability that the status of cybernetics will partly depend on what it can continue to offer other subjects i.e. active research schools rather than past achievements.

The map above includes many areas which would be

regarded by systems theorists as at least shared territory and it is therefore necessary to address the major criticism of systems theory. While both fields have claims to universality systems theorists seem to attach themselves more exclusively to fields where humans enter the system, frequently ignoring Wiener´s warnings about the use of linear mathematics in such areas. This combined with the use of inappropriately generalised and simplistic models has been the main charge of Berlinsky and McLean. [129] [130] To the extent that cybernetics incorporates systems theory it must be tarred with the same brush. The message must be to avoid inappropriate mathematics but where there is an appropriate mathematics to further understanding of the situation to understand and use it properly. (cf. Power´s comments about some cybernetician´s grasp of control theory in the next section, under "Feedback".) Elsewhere it may be worth aspiring to Galbraith´s dictum, "There are few if any useful ideas that can not be expressed in clear English. Obscurity rarely if ever denotes complexity of subject matter; it never denotes superior scholarship. It usually signifies either inability to write clear English or - more commonly - muddled or incomplete thought."[131]

4.4 Controversies in various programmes of cybernetics

Having examined difficulties in the cohesion of a set of cybernetic concepts it is next necessary to examine specific elements to see how well they stand up to detailed examination, in our objective of identifying why the area appears beset with difficulties.

As has been suggested various proponents of particular aspects or interpretations of cybernetics have attracted criticism for their advocacy. This section considers positions in cybernetics which have been viewed with unease and possibly detracted from the objective consideration of other cybernetic notions.

4.4.1 The machine model of human beings

Understanding humans in terms of the behaviour, or potential behaviour, of machines and producing machines with human abilities has been seen by critics and expositors alike as a central theme of cybernetics. Negative responses to this have been that such a programme

is dehumanising and/or nonsensical.

To the dehumanising claim one might respond that the same anxieties raised by the theories of Galileo or Darwin did not make their theories untrue. Secondly to move to the induction that formal or fundamental similarities between people and machines legitimates treating people like simple machines is not logical. If fundamental similarites were found between what was regarded as a machine and a human being this would equally raise the issue of whether the "machine" should be treated with more consideration.

To critics of the sense in trying to understand humans in terms of actual or potential machines the argument depends on the depth of the homomorphism. To attempt to build better robots in terms of neuronal or parallel distributed processing models based on brain "guesstimates" seems to be eminently achievable.[132] [133] However attributing consciousness or sensation to fundamentally machine like processes [134] [135] [136]is to enter highly controversial philosophical territory.[137] Cyberneticians who continue to push the argument will face the odium of many philosophers unless machines are produced which demonstrate the range of characteristics by which individuals attribute consciousness and sensation to one

another.

However an attempt to produce machines which simulate some of the characteristics of consciousness may be justified by its by-products (eg. expert systems). Secondly the continued failure of such a program would itself be a useful piece of scientific and philosophical evidence. Pragmatically the machine metaphor or fact opens up lines of research into areas of human function which would once have been regarded as intractable and it has not legitimised any tendency for humans to treat other humans as inert tools. If debate were conducted at the level of inferred consequences of the machine model it is probable that protagonists would agree about what would be undesirable actions and what desirable but deny that the undesirable could be infered from their viewpoint.

4.4.2 Mechanising Purposiveness

A more specific controversy of the human,animal/machines parallel has been about the feasibility of creating purposive automata. The "birth certificate of cybernetics" - "Behaviour, Purpose and Teleology"[138] was attacked by Richard Taylor in 1951

[139] [140]. More recent contributors include Braithwaite [141], Charles Taylor [142], Sommerhoff [143], Woodfield [144], Bennett [145] and Searle [146]. However when examining the apparent positions taken or attacked it is necessary to be aware of the disputants´ tendency to qualify their assertions to a degree which if pursued would vitiate much of the debate.

Thus one aspect of the debate seems to be between the position that either purpose can be described by objective behaviour or that it is entirely a state of mind. For example Wiener et.al. define purposeful behaviour as what "may be interpreted as directed to the attainment of a goal" [147] (emphasis added), while Taylor is willing to accept that there is such a thing as purposive behaviour and lay down criteria for it which include, "the behaviour pattern in question" [148] and acknowledge that the "desires and beliefs" which he regards as crucial are observable "as inferences from what is directly observed" [149].

However the continuing debate may be broadly characterised by the polarities of describing purpose as external behaviour versus internal desire and/or calculation. We may grant the force of Taylor´s contention that, "purposive behaviour, as they describe it, is

indistinguishable from any other kind of active behaviour"[150] in that any movement towards a stable state in accordance with general physical laws has elements of finalism. But that observation may in itself help to enlarge our understanding of the notion of purposiveness.

If we acknowledge that there are some observable situations that we are more willing to regard as purpose-like than others then it is intriguing that we can identify a rough hierarchy of increasingly complex interaction with features which tend towards what is generally regarded as purposive [151]. Research towards the mathematical specification of goal directed behaviour can be applied in the design of artificial systems; eg. the work of Weir [152] and Chikrii [153]. The emphasis of R Taylor and Woodfield on the internal aspect of purposiveness while undeniable would have been sterile if it had been taken to imply that these internal states were not accessible to investigation or modelling. In fact results from artificial intelligence workers such as Winston have stimulated the growth of cognitive science supported by computer use and analogy. Minsky´s acknowledgements in "The Society of Mind"[154] provide historical evidence of the contributions of cybernetic paradigms to A.I. and current cognitive science.

Thus while the critics of Rosenblueth, Wiener and Bigelow had some reasonable points to make the licence which Wiener et.al. gave to scientists to investigate processes which smelt of teleology was enormously fruitful. For example in psychology it helped to foster the study of aspects which had been tabooed as mentalistic.

It should be noted that Wiener et. al. sought to change the meaning of the word "teleology" to exclude the idea of "final cause"[155] with its taint of a failed theory of the origin of species. However the connotation seems to have continued to create confusion. Papert sought to clarify things with the neologism "téléonomie" - "la téléonomie étant à la téléologie comme l´astronomie à astrologie."[156] However the distinction between appearance and attribution was not picked up in the English cybernetics literature. (The word "teleonomy" has been used by Medaware, a biologist [157] and Checkland, a systems theorist.[158])

An interesting postscript to this controversy is provided by Minsky´s concepts of "dumbell theories" and "bridge- definitions".[159] The initial "internal/external" debate provides another example of the cognitive tendency to polarise while "bridge-definitions" seem necessary for

cognitive A.I. systems to be able to handle words for human artifacts (eg. chairs, games). A bridge-definition has both a purposeful and a structural component. The purposeful component alone tends to include too many things not intended while the structural component tends to be too tight but including both in a word's semantic component (eg. the "frames" it can call) is a very useful component for a purposive/purpose-like system. This suggests the dual-aspect of the concept of purpose itself i.e. intention and action and highlights the limitations of exclusive attachment to only one end of the dumbell.

4.4.3 Fuzzy concepts of Feedback

The concept of feedback itself is ubiquitous but it is difficult to specify precise features for all situations regarded as embodying feedback. Thus Waldhauer [160] quotes Mason and Zimmermann[161]- "A feedback loop is a closed chain of dependency, a closed path of signal flow in a system diagram. Since the relationships among the signals in a given physical system may be represented as any one of the number of different systems diagrams, some containing feedback loops and some not, it can be argued that the presence or absence of "feedback" in the "system" is more a

matter of viewpoint than of physical reality. Nevertheless, many physical systems are, by the very philosophy of their design, strongly associated with diagrams containing loops, and in such cases, we find it comfortable to speak of the physical arrangement itself as a feedback system."

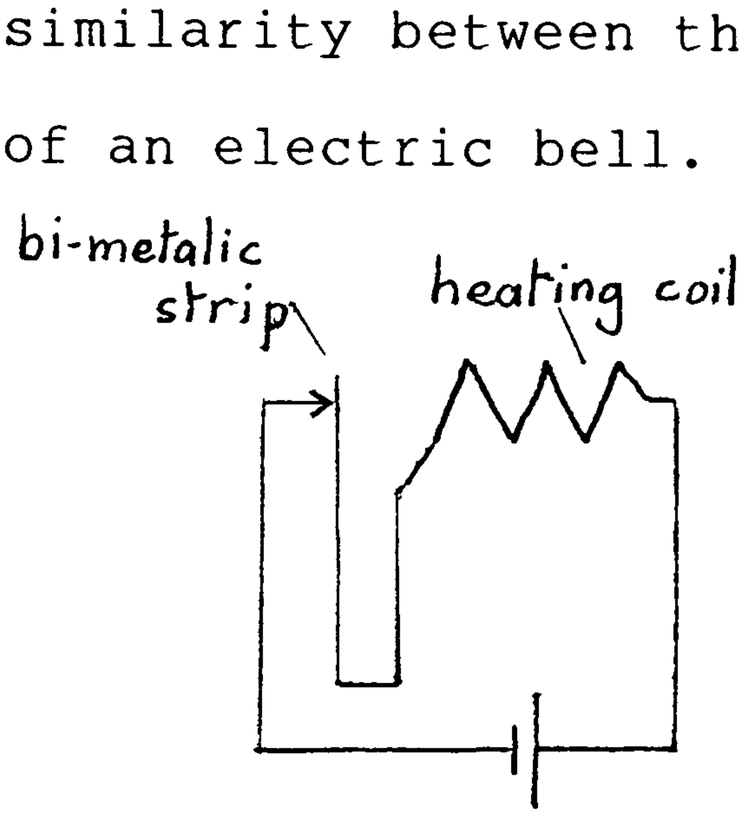
Beer [162] makes the point about the role of the observer more forcefully for all systems. If we accept the force of such arguments two responses are possible. One is to refer to Hume´s arguments about the general difficulty of attributing cause and effect [163] and claim that the problem of identifying feedback systems is little worse than many other scientific classification problems. The other is to follow Beer´s dictum that we simply have to agree on conventions [164], after which presumably we judge their worth by their convenience (ease of comprehension, guide to effective intervention, aid to design).

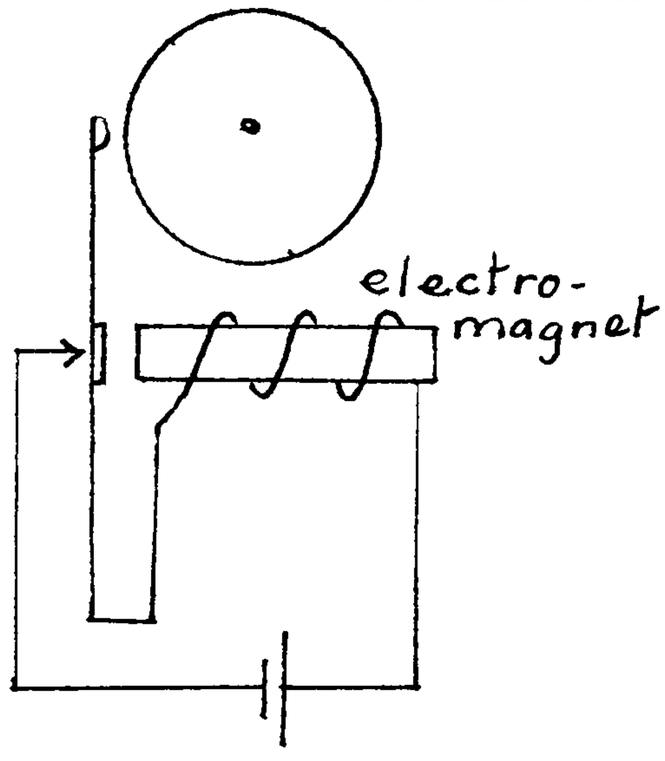
For example Waldhauer [165] introduces the dilemma of the observer in a simple feedback circuit where a transistor has a resistance connecting collector to base. Some analytic purposes find it convenient to regard this as the sole feedback path while others include the topologically similar internal capacitance of the collector junction.

Such items remind us that in any field to which we address ourselves the utility of a scientific training may lie very much in its ability to provide us with criteria as to what we can safely ignore in assessing significance and that significance will appear to depend in part on our theories and purposes.

Thus provisionally we shall view feedback as a "tool for thought" in Waddington´s [166] use of the phrase.

By way of illustration consider the formal similarity between the simplest thermostat circuit and that of an electric bell.





The two diagrams are virtually identical yet the bell is not normally regarded as an example of feedback. Clearly we can attempt to argue a distinction in terms of what is controlled - the vibrations of air molecules (heat) being seen as more external to the system than the electro-magnetic field created. However this simply emphasises Beer´s point that we draw the boundaries of

systems very much where we choose. Given that that we normally choose to regard the principle output of an electric bell as its noise rather than the maintainance of some level of electro-magnetic vibration the point is re-emphasised that the choice of cybernetic notion is muddied by human purposes.

This may be a problem for the physicist but it is an inevitable part of the task for the engineer and an unavoidable issue (albeit not only with humans) for many biologists. That a science that utilises our awareness of purpose can be rigorous is demonstrated at length in Simon´s "The Sciences of the Artificial" [167]. However this creates a challenge to clarification rather than an acceptable fuzzyness to live with.

Part of our problem in dealing with such notions as feedback lies in broader errors in misconceptions about philosophy and language. Thus we tend to try to impose a model of the universe appropriate to a world of "medium sized dry goods"[168] in Carnap´s phrase. He and Korzybski particularly have warned us of the error of regarding any word as necessarily having a concrete referent. The sentence "the word is not the thing named" is trivially obvious once stated, but it is nevertheless part of a compound of errors that we easily fall in to when

considering process notions. Korzybski in particular warned at length of the dangers of taking the Subject-Verb-Object linguistic structure too seriously when dealing with process notions [169]. His Non-Aristotelian General Semantics provides quite a good philosophical preparation for anyone preparing to investigate systems and cybernetic notions. The overall point however for our investigations is simply that some of our problems in clarifying feedback stem not from the validity of the notion itself but the structure and presuppositions of our language. When we use nouns to denote processes paradoxes will appear if we insist on using those nouns as if they were "medium sized dry goods" with the same incontrovertability of reference and lack of alternative viewpoint.

One of the first problems with feedback is determining the general range of the notion or deciding what part of that spectrum is worth considering. We may start with some such core notion as "any situation in which a portion of the output is fed back into the input" or note Wiener´s suitably general "the chain of transmission and return of information"[170]. However as we now realise "outputs" and "information" are very much in the eye of the beholder. Thus as R Taylor hinted any situation which

moves towards a finalistic state and would do so with minor modifications in its set up may have vectors chosen for its state description which make it isomorphic with some level of description of feedback. Thus if one wishes one might regard the speed and angle of distortion of a pendulum as signaling information about an appropriate compensation. Elstob [171] while recognising that one might regard the process of a stone rolling downhill as one of information exchange in computing the least energetic path, casts doubt on the utility of such a viewpoint.

In considering feedback we may recognise repeated dilemmas in science between simplicity, precision and generality. The notion of feedback can certainly be stretched but it will not always be telling us something new. Thus a "feedback" description of the motion of the stone in the last paragraph clearly flies in the face of Occam´s razor. It is hypothetically possible that developments in physical theory might make this seem less the case; thus Bohm´s belief that in micro-particle physics informational interactions are prior to energetic interactions [172] would reverse what seemed simpler, if accepted; but provisionally we may note interesting parallels but refuse to reify them.

Some cyberneticians seem happier with the notion of

"circular causality" rather than feedback. This certainly draws our attention to a large class of phenomena, virtually any "ongoing situation" with elements of iteration: it is of course subject to the criticism of being even more general than the notion of feedback. However since the circular nature of many interactions are frequently missed it is useful to have a phrase which draws attention to this. Such a denomination marks out an area into which a higher level of formalism eg. recursive mathematics or logic, may be introduced without pre-judging whether it is best seen as feedback.

A most interesting discussion of circular causality in this context is by Francis Halbwachs.[173] He gives a series of examples of reciprocal causality at various levels in physics and develops circular causality from a finer analysis of the steps in reciprocal situations, principally in the interaction of electrical and magnetic phenomena.

In passing he strikingly echoes and develops Mason and Zimmerman- "Elle nous montre clairement que nos variables conjugées sont en réalité des composantes d´une même grandeur vectorielle et que leur distinction en facteurs réciproques de la causalité circulaire est arbitraire et relative, est due à notre manière de choisir l´origine du temps, n´a pas de fondement dans la nature des choses.[174]

He thus suggests that circular causality is a stage

of conceptualisation in between the notion of linear causality and the highest level of theoretical abstraction and generalisation (explication homogène). This is an interesting notion, clearly derived from the Piagetian perspective. However that perspective pre-empts philosophical difficulties regarding appropriate high level perspectives in a way which is not universally accepted [175]. For example the priority of grand theory explanations over local empirical ones has been questioned [176].

Halbwachs cites Joan Bliss´s work on children´s understanding of an apparatus exemplifying feedback [177]. (Her investigations are partially replicated as part of the empirical investigations into individuals´ understanding in Chapter 6) It is interesting that he claims that full understanding is not attained until between 13 and 15 (in line with his and Piaget´s theories) although Bliss´s monograph appears to indicate that the fourth and final stage of understanding was reached at 11-12 years.

Inevitably the conclusions drawn from any one investigation are open to the criticism of contamination by the complexities of the specific apparatus and situation. Thus how far was children´s understanding of a very elementary feedback situation helped or hindered by Bliss´s

apparatus and specific saliencies which aspects of its parts held for them? Would the slightly more sophisticated form of negative feedback embodied in a lavatory´s ball cock mechanism prove subjectively simpler by virtue of its familiarity or, for many, more complex; because of the distracting problem of the siphoning mechanism? (A simplified apparatus is used to elicit understanding as part of Chapter 6) Children vary in their willingness to attend to or discuss the aspect of the situation the investigator is interested in when they find some other aspect which is problematic for themselves. Thus while most 11 year olds can grasp the operation of a simple thermostat comprehension will be muddied without adequate teaching and experience about the explanation of how a bi-metalic switch operates. (It is surprisingly difficult to rig up large scale apparatus which saliently and incontrovertably demonstrates a bi-metalic thermostat mechanism. The author has set up bi-metalic feedback systems as part of classroom teaching but a considerable preamble was necessary to convey the point. Hence a more visual heat response device was used where necessary in the investigation reported later.) Other examples of children´s failure to collaborate with teachers´ preconceptions as to what is significant in a concrete situation concerning communications concepts have been

listed by the writer elsewhere.[178]

Thus a key feature is the ability to identify the cybernetic feature or generalisation among the "noise" and this will depend on the student´s data-base of explanations for "irrelevant" aspects of the situation as much as on the purely abstract formal logical capacities which the Piagetians emphasised as the intellectual peak. In the classroom experience of this writer the capacity to produce more examples of feedback given a few specific cases is easier for most 11 to 12 year olds than grasping the initial examples whereas the reverse, a deficit in the ability to identify and apply a feedback viewpoint over a wider range seems to be a problem for many adults. This phenomena seems to be exaggerated in group as opposed to individual productivity situations, partly at least, presumably for extrinsic social reasons.

Our view of the complexity of evaluating understanding is enlarged by the work of Broadbent [179] [180] and Berry [181] on the disjunction between verbal and operational understanding in some systems of moderate complexity involving circular causality. Their finding that there could be a significant negative correlation between verbal and non-verbal understanding raises large question marks for the whole of the Piagetian data and

equally for our grasp of how people encounter problems in understanding systems and cybernetic notions. Broadbent and Berry´s data present us with an image of a somewhat modular view of mind in which each module may at some stage inhibit the operation of the other. Obviously this does not preclude the possibility of a higher level integration; the experimenters themselves would appear to have been capable of this and it might be argued that the unusualness of the relationship which effective performers often failed to verbalise was simply a function of current educational practise and has no fundamental implications as to the limits of human cognition.

Various ways of seeing feedback involve shifts in perspective the reasoning for which is at present usually justified in terms of its utility for the designer or analyst.

Thus Waldhauer [182] as a designer of feedback amplifiers promotes a view of feedback in which the input is seen as a function of the output. This "anti-causal analysis" involves simpler mathematics than the traditional feedback equation where output is seen as a function of input and is appropriate for a designer who knows what output is wanted and is concerned to modify the input. Waldhauer claims that his formulation is as intuitively

satisfying as the traditional one although acknowledging that it takes some getting used to [183] and providing over six hundred pages for the reader to acquire familiarity. The realisation that even when viewing a causal loop we prefer to start the loop at one place rather than another indicates the constraints of our previous conceptual experience and possibly our innate predispositions.

As a contradistinction to Halbwachs´ notions we may note that Waldhauer finds it convenient to distinguish feedback from loop gain and regard the former as the higher level more abstract concept [184]. Waldhauer suggests that many people find the teleological implications of circular causality uncomfortable and therefore he shows that all electrical "feedback" circuits can be reduced to signal flow graphs which under his "anti-causal" perspective have no element of circularity.

For the time being we may acknowledge that feedback can be pointed to in specific situations but that the protean nature of our conceptual systems may limit the accuracy of any canonical definition despite the notions´s usefulness.

However it is worth noticing that most problems seem to arise when we seek wider generalisations away from

the original context of the feedback notion. The concept has affinities with recursion and the "common sense" view of time itself. To see the world as sets of bounded systems or "transformation" devices which simply operate algorithmically on inputs to produce outputs is not very far from the world of Leibnitzian monads [185] in which a universe specified at time t = 0 can be specified for all ensuing instances t = n... Despite the theoretical plausibility of this in a universe of deterministic laws it conflicts with our experience as predictors that trajectories go awry, or that outcomes affect subsequent events i.e. that the best way to predict t = n is to know states at t = n - 1. Such a view is now bolstered by the acceptance of indeterminacy and chaos discoveries that tell us that even a deterministic universe can never be specified precisely enough to calculate all later states accurately from earlier states over a reasonable time interval.[186] Thus any situation where there is no perfect long term predictability and outcomes affect subsequents or outputs affect inputs is liable to be labelled feedback. It may be, vide Halbwachs, that this is simply a stage of conceptual development and should properly be followed by a restriction of feedback metaphors to situations where broader recursive notions provide a less adequate characterisation.

The link between feedback and more complex discoveries about recursive interacting systems is highlighted by the notion of variety reduction. Wiener hails this aspect of a simple feedback loop as its essential utility as a control function; likewise the discovery that a plethora of recursively characterisable variables operating apparently chaotically in n-dimensional phase space will reduce to interaction in low dimensional phase space [187] is simply the generalisation of Wiener´s original comments.

Above are some of the problems of conceptualising feedback per se. We must also be aware of difficulties appreciating the subtleties of its operation; consideration of message type, rates of decay, form of transformation and media limitations contribute to a variety of potentially counter-intuitive effects. Power´s program "Introduction to Cybernetic Control Theory" [188] which embodies his own behavioural theory of perception, is an absorbing attempt to overcome some of these counter-intuitive effects. In the process he criticises the grasp of some other writers on cybernetics. Apart from its apparent target group of individuals with at least college level education its only limitation as a tool which might investigate concept formation is that of any learning using a console, in that

it excludes three dimensional exploration of concrete artifacts.

Given the variety of considerations above we feel able provisionally to maintain the value of the feedback concept as a useful conceptual tool rather than some kind of category error. However it will be appreciated that empirical cognitive investigations will need to start with studies using simple paradigmatic embodiments of feedback.

4.4.4 The Limits of Information Theory

We have already alluded to Bar-Hillel´s criticism of the uses to which Shanon´s equations [189] were put but the basic theory itself was not without controversy. Mathematicians tended to regard its derivation as insufficiently rigorous and it took Kolmogorov´s championship of its broader ideas to widen its acceptability.[190] [191] Many other attempts to formulate acceptable measures of information have been made, notably Gabor [192], Wiener [193], McKay D M [194], Carnap and Bar-Hillel [195], Onicescu [196], hyperbolic methods, time and space computational methods [197]. However we may note that Padet [198] in her review of what we may characterise,

following Elstob [199], as p- (physical) information measures, concluded that Shannon´s formulation had the widest range of convenience.

In his argument for his formulation Shannon [200] appeals to our intuition and the usefulness of its implications as to what characteristics a measure of information should have and builds up the mathematics accordingly. The result, as Kolmogorov points out [201], is not a measure which calibrates the information content of individual items but a measure which approaches the sum of the average informational content of a string of items assuming that it is ergodic.

This is the case partly because of the use of probabilistic entities in Shannon´s formula (and Kolmogorov sought to overcome this objection by replacing the Pi´s by the length of a "program" calculation) but also because of the asymmetry of the curve generated when any function between 0 and 1 is multiplied by its logarithm (since this must vary between -infinity and 0). Thus the information measure of two items summing to p=1 is plausible enough, and Shannon himself presents an illustration of such a satisfactorily symmetrical distribution.[202] However when we consider that the information measure with p = .5 is the same (with log base 2) as that of p = .25 (viz. 0.5) and

that the maximum information level of an element comes at p = .37 (vis. 0.5307) we may acknowledge that the criteria of intuitive plausibility are not entirely fulfilled.

Incidentally the latter objection could be satisfied (at the cost of a further element of complexity) simply by calculating the informational complement of each probability [i.e. -(1-p log2 1-p)] and averaging it with -(p log2 p). This would obviously not invalidate the developments from Shannon´s basic formula nor of course would such a modification have any advantage with long ergodic time series.

However more controversy has arisen in cybernetics over the ambiguous claims as to the generality of Shannon´s measure, particularly the claims that it has something significant to tell us about human understanding [203] rather than just efficient ways of using cables. Obviously a random series of letters does not contain more information (in the everyday use of that word) than the same number of letters grouped into words; although on an information theoretic basis the opposite is the case. Nevertheless viewing the human being as a machine (using cables) we are obliged to ask why there is this discrepancy rather than to erect a veto on further investigation.

Attempts to measure human channel capacity in information theoretic terms have revealed a reasonable degree of consistency [204] at least in terms of simple sensory inputs. Yet we are faced with Shannon´s and Ashby´s [205] point that information or variety can only be lost or degraded during its successive transformation and re-encodement through a system. How then are human beings usually regarded as transforming data to extract more information? Why should physical and semantic notions of information appear to be counterpoised?

Clearly when we examine features of human neurological encoding we can view the successive processes of peripheral to central encoding as an organisational necessity of a system which needs to select from an environment with a virtually infinite set of differentiae (viewed either physically or informationally is irrelevant and anyway mathematically isomorphic) those features which require a response to permit its continued existence or maintainance of whatever state trajectory it may be interpreted as pursuing. (Information pathways embody a restriction as well as a potential extention of interaction.)

Thus the successive loss of redundant p-information leads to a higher quality of organismically useful

information, approaching the semantic everyday language notion of information. Such considerations draw our attention to the significance of the encoding or decoding process between levels of complex information processing systems as they transform "raw" information into progressively larger chunks. The hierarchy of language complexity that we are familiar with in computers has been used as the parallel for theories of mind by Hofstadter [206] and Minsky [207] and is corroborated in particular by our knowledge of visual information processing.

We can clarify this interpretation by focussing on Kolmogorov´s emphasis on conditional entropy [208] H (x | y) where y stands for an information processor analogous to or actually a decoder dependant on a data base, x is the physical information inflow and the whole equation represents its informational value to the system.

To dwell upon the semantic relationship this would mean that reconfiguring the decoder-data base so that input information was transformed to larger and fewer chunks would lead to a reduction in subjective complexity and in strict p-information theoretic terms to a reduction in information at that stage of the processing. Hence the apparent paradox that the better the system´s model of its environment the less the value (information content) of any

new item of data and the greater the information content of any element predicted by the decoder-data base as being improbable.

Cognitive development could be seen as the elaboration of the decoder-data base device(s) and the crucial feature of redundancy at each level of information processing may be recognised as an essential feature to permit classification of similarities and differences in the data flow so that less information is needed for decision making by the next stage as the previous filter becomes more complex and efficient.

Clearly we are far from being able to measure the complexity of the filters, decoders, data bases in the human brain (although it would be less difficult in the early steps of processing) and therefore the measure of subjective semantic information is elusive but the above analysis does suggest that the relationship between p and s information is non-trivial and remains a worthwhile area for development.

At a broader philosophical level such "discoveries" as those hailed by members of the Turing Institute [209], that the universe is a computer, can be seen as a combination of awkward intellectual moves. Certainly we

may view physical phenomena (i.e. whatever we can physically discriminate) in informational terms. Since the mathematical formula for entropy and information is the same and the matter/information entity has the same operational consequencies we may recognise that its classification is not intrinsic but a function of its impact on a receiving system. (Thus the same quantum of light may induce a sensation which is interpreted as information when falling on the retina but simply stimulates an increase in melanin or triggers a melanoma elsewhere on the body surface.) Also any universe which operates according to a set of laws which can be expressed mathematically may be regarded as indulging in finalistic behaviour which is homomorphic with the process of calculation. Naturally when the universe does not behave perfectly predictably (or one´s characterisation of the laws is still inadequate) one may characterise the computer (pace Deutsch) [210] as containing the best possible random number generator.

To be able to produce a fairly consistent view of the world does not mean to say that it is efficient; there are no logical inconsistencies in our viewpoint when we stand on our head. What such considerations may suggest is that all useful notions have a limited range of convenience

and that to stretch them too far may encourage others to challenge their usefulness even within their original territory.

4.4.5 The Status of Requisite Variety

The statement that, " ´only variety can absorb variety´: a regulating system must be able to generate as many states as can the system regulated"[211] challenges us to look for apparent counter-examples. These might include; the restriction of the behaviour of a large group by a person with a gun, the control of a relatively complex organism by a relatively simple virus, the modification of the output of a computer by the triggering of a sprinkler system or simply the flick of a binary switch. Beer´s algedonic controls [212] appear to override the variety dilemma in the control of large systems. Nevertheless Ashby claims that his law is of "very general applicability" and summarises albeit ´picturesquely´ "only variety can destroy variety" [213]. In contrast Checkland has criticised the concept as being trivial in organisational practise [214] and Jantsch´s objections were mentioned in section 3 of this chapter.

It is worth examining the assumptions that lead to Ashby´s conclusion. Ashby argues from a model of one system trying to control another where the possibilities are represented as a table in which the available "moves" of the controled system are listed along a vertical axis and those of the controling system are listed on a horizontal axis. A matrix of outcomes for all combinations of moves or states is given to represent "the hard external world."[215] However Ashby excludes for the sake of his argument matrices with certain properties, specifically those which make the controller´s game, "too easy to be of interest"[216] i.e. where a certain response from the controller will bring the same outcome with more than one (possibly all) of the controlled system´s states, which would mean, more significantly, that the controller needed a lower level of information about the controlled system´s previous state than Ashby goes on to consider. More briefly, Ashby excludes matrices where an outcome occurs more than once in a column (the controler´s responses occupying the horizontal axis, the controlee´s states the vertical).

Thus Ashby´s initial examples in no way deny the possibility that a simple system may control a more complex one. Sometimes the hard external world is like that and

arguably it might be most productive to seek to identify such situations. However having effectively excluded such situations Ashby is then able to deduce that when excluded they do not occur. Unfortunately various commentators seem to ignore the situations which Ashby excluded and proceed to argue as if all control situations belonged to Ashby´s selected set. Thus when Ashby argues that the control of Hitler over Germany was not total this may be true but to derive it from a statement that his control amounted to "just one man-power and no more"[217] is to court meaninglessness or self delusion in denying the efficacy of a very interesting control situation.

Another way of looking at the same facts is to state that Ashby´s notion of full control embodies the idea of the controler being able to make a differential response to every possible state of the control system. Frequently this is neither necessary or desired; consider the computer command IF X > 1 THEN ... Here the many possible states of the controlled system are collapsed into only two from the point of view of the controller. An analogous situation arises with many simple feedback loops. Thus Ashby´s conditions may seem to be fulfilled from the discriminating capacity of the controler but not that of the controllee. This issue is exemplified in controversies about central

government capacity to influence the output of universities.

Thus we need to ask how large is the class of actual or potential control or regulation relationships in which Ashby´s special conditions apply or are close enough to be useful. They can be accepted in the kind of communication channel relationships assumed in Shannon´s Tenth Theorem and have some plausibility in human relationships where there is no power differential and the influencer, say a teacher, wishes to be able to adjust to all the possible responses of the influenced. In management the variety explosion created by Ashbian assumptions about interaction draws our attention to the need for some non-Ashbian matrices of control relationships for the institution to survive. Ashby´s law does leave us with the useful empirical principle that it is frequently impossible (and pointless) to seek to control absolutely everything in a system but that does not absolve us in any specific situation from enquiring whether the matrix of outcomes of controller acting on controlled is really Ashbian or not.

Stewart has pointed out [218] that Ashby´s formulation is inferior to Shannon´s Tenth Theorem in that it does not take on board the question of with what degree

of probability any state by controller or controllee can be played.

From an even broader viewpoint it has been pointed out [219] that the identification of states in the controlled system and the controlling one can be rather subjective. This might enable one to maintain "empirically" that all controlled systems were Ashbian, possibly Ashby´s suggestion that the states of the controlled system may be ´vectors´ that are responded to does this, but it would not give one a priori criteria to make the law work nor would it remove the fundamental tautology.

The notion of variety reduction may be regarded as a useful expansion of the concept of stability but requisite variety is only a part of the set of strategies which may achieve it.

Chapter 5

Avenues to the Cognition of Cybernetic Concepts

Having examined problems of the relationship of cybernetic concepts and the validity of key concepts in themselves, and found some difficulties in the formulation of some of them, the next logical step is to consider how cybernetic concepts come to be understood and how such cognitive processes might be most appropriately investigated. Also we need a comparative base to identify what is and is not unique to cybernetics. All this requires an examination of fields to which the cognition of cybernetic problems might relate or from which investigational techniques might be extracted.

5.1 Overview

A variety of avenues of research suggest themselves as paradigms to investigate cognition of cybernetic concepts. Some fall into groups or have obvious links; others are more disparate. Of obvious relevance are the theories of Piaget and the post Piagetians who combine developmental interests with "clinical" methodology and a predisposition for large scale theories of cognitive "levels". The later links with Jaques´ theory of levels of abstraction [221] [222], while both authors are counterpoised by Dienes´ [223] emphasis on the limited ability to apply a capacity for abstraction in one domain to any others, despite his having done some similar investigations with children to Piaget. Vygotsky [224] and the neo-Vygotskians [225] share broad developmental theorising with Piaget but introduce a wider social and pedagogic emphasis.

The emphasis on the learner´s own conceptions and strategies on his or her own higher level learning effectiveness is illustrated by Pask [226] and Thomas [227] and a variety of more "micro-theoretical" writers.

The relatively recently developing field of discourse analysis [228] suggests not only ways of analysing cybernetics´ similarity with other subjects but also differences in the ways it is perceived by individuals obliged to talk or write about cybernetic concepts. The concept of macro-structures [229] which has arisen primarily from discourse analysis provides a possible conceptual model for the problem of identifying the structure of cybernetic topics.

At a slightly lower conceptual level generally but sharing some common structural ideas the A.I. theories which have contributed to the body of work denominated "cognitive science" and are characterised by "frames" and "scripts", for example Minsky [230], provide another language in which to conceptualise the processing of systems concepts. At what is generally regarded as a more micro-level still the contributions to cognitive science of the connectionists and parallel processers [231] have relevance to some of the issues in the development of cybernetic concepts; while the validity of both the list processing and parallel distributed processing approaches is supported by developments in neurophysiology.

To separate traditional cognitive psychology from cognitive science is largely a convenient taxonomic

fiction. However those elements of cognitive psychology and learning theory that do not utilise computer science, connectionism or linguistics might be expected to produce a relatively limited set of ideas for understanding how we grasp systems and cybernetic concepts, since their traditionally "bottom up" approach to how we understand things has meant a greater emphasis on more basic psychological processes and an unwillingness to deal with more complex processes until basic ones are clearer. However the development of that tradition (albeit influenced by cognitive science) by Broadbent and Berry (op.cit.) in their (already mentioned) work on the apparent paradoxes in people´s understanding of complex processes shows that mainstream psychological methodology has plenty to offer in enabling us to investigate how cybernetic concepts are understood.

Psychological studies of cognition at equivalent levels to cybernetics eg. maths and the sciences taught in schools provide a final area of relevance to our quest. Among these the work of Hacker [232] and Hart [233] are particularly enlightening.

5.2 Developmental Macrotheorists

This heading is merely a convenient characterisation of the group of authors referred to in the first paragraph of the previous section although some merely highlight or provide a critique of such theorists.

The largest body of work in cognition is still that published by Piaget and his collaborators (and critics). Some of the implications of his work for the understanding of cybernetic concepts were discussed in my MSc dissertation [234] out of which some of the problems addressed in this thesis arose. The broad message of Piaget is generally taken as being that cognitive development proceeds in at least three stages: sensory-motor, till about 18 months; concrete operational (sometimes split in two), till say 11 or 12 years, where thinking is still restricted to situations in which the child has performed similar physical acts on things, and lastly formal operational, which embodies the capacity for abstract logical thought exemplified in the intelligent adult.

Initially one might assume that systems concepts

required a fairly high degree of abstraction, depending on the ability to see a chain or network of similar dependencies within a variety of disparate structures and situations, frequently with the ordering of dependencies being not merely linear or reciprocal but recursive. Hence Piaget´s theory would suggest that a grasp of cybernetic concepts would be unlikely before the age of 12 but that once formal operational thinking had developed the field should be generally accessible.

However Piaget´s theory can deal with exceptions where the capacity for a particular level of thought in some area emerges earlier or later than predicted. It uses such concepts as task resistance and horizontal décalage (the French verb means to stagger, unwedge or displace). [235] But such flexibility weakens the strength of the theory. Thus without any predictions of when exceptions will occur the theory only indicates what may happen, with no significant change if the opposite occurs. The weak interpretation of the theory still leaves intact the notion that the key to higher level concepts may lie in attaining a succession of logical levels of abstraction.

A key concept for Piaget which might survive the rejection of the notion of stages, though less probably that of cognitive levels, is the concept of egocentrism

[236] or its converse decentering.[237] This refers to the child´s ability to see things firstly independently of its own immediate actions and perspective and see things from another´s viewpoint or any hypothetical viewpoint. Decentering involves the capacity to move away from only performing physical operations or mental operations on physical objects (to hand or in vision) towards the ability to perform mental operations on imagined objects or situations, classes of such and eventually on mental operations themselves.

Whatever the status of Piaget´s theorising in his recorded conversations with children, (what he described as a "clinical" method) there is a wealth of raw data. Such data it has been suggested gives more insight than the typical experimental paradigm where the permitted verbal response is highly restricted and statistical significance is gained at the expense of any other kind.[238]

However theories about levels of cognitive development are not exclusive to Piaget. Jacques and his co-workers [239] have produced a theory of (about five) levels of adult cognitive functioning related to capacity for useful organisational work. Stamp [240] cites Bennett in maths, Bloom in education and Kohlberg (inaccurately [241]) in moral development, as all having arrived at a

five level theory of human capacities. Jacques claims that his finding that five is the optimal number of layers for most large organisations reflects five fundamental human levels of capacity to make abstractions. One might note that Beer [242] arrived at five layers for his optimal viable system and that Peters [243] independently concludes that no organisation needs more than five levels. However such a consensus may be merely numerological or perhaps a reflection of limited human channel capacity in making distinctions [244] unless links can be made between individuals´ performance at specific levels across different fields.

Unfortunately the evidence so far is equivocal. Isaac and O´Connor [245] succeed in showing a multimodal distribution of performance scores in certain test situations. However the mode an individual falls into on one test is unrelated to the mode on another. The attempt to link score performance with subjective behavioural observations of strategy linked to each of the five levels [246] is interesting but would require more and clearer data to substantiate. Stamp suggests that at level three the capacity emerges to relate disparate elements together into a system and Isaac and O´Connor suggest that about half the school population have reached level three by

twelve, the majority still being there at sixteen.[247] Isaac, O´Connor and Gibson hypothesise a series of levels of abstraction and co-ordination of abstractions which typify each level. However until we can analyse the abstraction requirements of a task and then predict the performance of an individual at a certain level or mode at that task we need to treat such theorising as a possible guide but unproven.

In contrast to highly structured theories about general conceptual levels where it turns out to be impossible to predict what conceptual level an individual will be on in a particular instance is Dienes emphasis on the extreme difficulty and particularity of abstraction and generalisation.[248] [249] The significance of his approach is shown less in subsequent citations than in the ubiquity of his enabling equipment, "Dienes Blocks" in primary schools. Generally he states learning involves, "not personal, psychodynamic, superimposed concepts but is associative; children associate situations with certain processes and operate the processes in situations with which the processes have been associated."

His prescription is simple, abstractions will be made more effectively through a greater range of explorations with different concrete exemplars of the

abstract concept which is to be grasped. The greater the range of experience the less the probability of partial or overinclusive or inappropriate abstraction and the greater the probability of appropriate generalisation to other situations.[250] The structure of development is not greatly different he suggests with the creative mathematician developing new concepts [251], although appropriate practise in abstraction and class inclusion (generalisation) can in itself lead to a mental set for the process which speeds up the discovery of isomorphisms. [252]

Dienes touches on the phenomena of people apparently using abstractions and generalisations, either through formal symbols or language, for whom the original content is either severely etiolated or lost sight of [253] although this may not be immediately apparent to an interlocutor. The writer has been struck by the frequency of the false assumption, by conversationalists at all academic levels, that particular words have the same range of connotations for both.

Dienes emphasis on the utility of specific interventions in the teaching process to aid conceptual development contrasts with the view of many Piagetians who regard conceptual development as driven by a child´s own

autonomous activities making particular learning relatively straightforward at the right stage and earlier teaching futile. Vygotsky´s ideas have had an increasing influence recently due to their emphasis on the idea that what is learnable depends on the physical and conceptual tools of the society in and with which the child operates and the demands made by the teacher.[254] [255]

The point about the link between language and tools in human (mental) evolution is made repeatedly at present by palaeoethnologists [256]. Vygotsky instances such practices as counting on fingers and joints for understanding of number, learning of writing for a more reflective symbolic understanding of speech, [257] and aides memoires such as knot tying [258] and pictures [259] as ways in which culturally produced sign systems are internalised to aid thought processes. At a more diffuse cultural level he acknowledges Engels as the originator of the idea that the social context of tool use influences the ideas that individuals are likely to develop.[260]

The social and intellectual influence of adults is first highlighted by Vygotsky when he points out that the proportion of egocentric speech (which Piaget emphasises as typical of the first five years) declines according to the availability of the adult for interaction and increases

with the intellectual demands of the situation. [261] More generally his notion of the "zone of proximal development" denotes the existence of an area, "between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." [262] Thus Vygotsky regards it as appropriate for school learning and instruction to be somewhat in advance of children´s cognitive development.

5.3 Learner Self-Modeling of Learning Processes

The theorists in the last section all at some stage refer to the increasing capacity of learners to handle concepts as they become more aware of ways manipulating learning material as such and their relation to it. Conscious development of such abilities has been the theme of many study skills advocates, for example Mace [263], Rowntree [264] and Buzan [265]. However in a review of research on the effectiveness of such taught skills Biggs [266] points out that there is no straightforward

relationship between use or non-use of such skills and success or failure although there does seem to be an interaction between the type of study approach used, the mode of assessment and the the student´s personality, values and ability which more accurately predicts success.

To a considerable extent openness to such an orientation is the theoretical starting point of Pask and Thomas [267] Both obviously share a commitment to certain cybernetic ideas and for both there is an intimate link between theories of experimental methodology, cognition, learning and effective (self) instruction. Pask asserts the conversational nature of both a realistic experimental paradigm and the teaching/learning situation and each have developed their own basically similar conversation theories. Both use various technological or conceptual tools to elicit from learners their view of the universe of discource and encourage a "conversation" on that to facilitate understanding. A conversation may be viewed as an interaction between two persons, a person and machine or within one person (or machine), (and in theory more agglomerated entities).

For example Pask identifies certain common strategies for the material he presents, namely "serialist" and "wholist" and shows that material matched to the

learner´s dominant strategy is learned better. However some learners could be moved to a more "versatile" [268] style adjusted to the particular nature of the material and some arrived at the experimental/learning situation able to use a mixture of styles appropriately.

While Pask´s work concentrates on helping the learner move around specific knowledge structures educed from experts Thomas generally deals with wider fields of learning and the conversational interaction is usually less constrained. The emphasis is generally on getting learners to examine the effectiveness of their own approach and on modeling their own learning processes. Obviously both writers are clear that conversations can take place at a variety of levels from the most specific facts to the most general strategies and meanings.

To apply Pask´s approach lock stock and barrel to cybernetics would involve the elicitation of "entailment structures" from a variety of experts, an enormous task for which aspects of this thesis provide a preliminary approach. Pask emphasises that there may be an infinite number of legitimate entailment structures even when there is general agreement on the field. Thomas and Harri-Augstein´s repertory grids for areas which the student finds problematic has obvious uses; however

problems perceived (or not perceived) by students do not necessarily reflect those judged to exist by lecturers and a limited use of such methodology might lead to an elision over certain student problems. At a higher level if the teacher´s authoritative view of the subject matter were to some degree rescinded it could lead to precisely the dilemmas of conceptualisation and interpretation which are addressed as a part of this thesis.

Nevertheless there is an obvious influence of the themes of Pask, Thomas and their co-workers in the method of data collection used in the next chapter.

5.4 Discourse analytic approaches

There has been an increasing amount of attention among linguists to larger linguistic structures than simply the grammar of the sentence [269]. Initially this attended principally to elucidating the structure of dialogues and simple narratives such as children´s stories. Basic underlying features were found to be operating which suggested a larger scale analogy with Chomsky´s posited "language acquisition device" [270] [271] which posited

innate "deep structure" recognition devices which enabled us to operate a grammatical structure although the "surface structures" used were obviously specific to particular languages.

Winter [272] from an analysis of percentages of different types of links between adjacent sentences argued that scientific writing had a distinctive semantic structure. However simply counting the number of connective adverbs denoting,- logical sequence (eg. thus therefore), contrast (yet however), doubt/certainty (probably clearly) and the less frequent categories identified can only give a superficial analysis of structure and inevitably ignores the structure of relationships between non-adjacent clauses or sentences.

Hoey [273] provides a technique which demonstrates coherence and elicits structure over a paragraph or two. However such objective techniques are laborious.[274] To analyse ten short scientific passages can provide the essential content of a Ph.D. thesis [275]. Moreover similarities in style and structure tend to be intuitively obvious so that while it is useful to know that such notions can have an objective reference they probably do not in themselves provide the most economical approach to identifying either the cohesion, structure, uniqueness or

similarity of cybernetic texts. Thus while observer evaluations are justifiable on the grounds that they are open to disconfirmation such estimations of homomorphism are probably only significant in the context of additional supporting material.

However given the evidence that such structures are "computable" linguists have pointed to higher order semantic structures. Hoey [276] gives evidence of structure between paragraphs and van Dijk´s concept of macrostructures [277] offers an approach to eliciting more global semantic relationships. (It should be noted that van Dijk distinguishes macrostructures, which are semantic from superstructures which pertain to schematic "form" e.g. the "summary, aim, method, results, discussion, conclusion" format of some scientific papers. Although superstructures are of interest in themselves a macrostructure would embody such intuitive notions as "gist", "theme" or "topic".) Van Dijk speculates that the formation of macrostructures could be either linear or parallel and concludes that it is linear but that representations are hierarchical [278]. Hoey [279] supports an opposite conclusion about global text organisation, minimising the extent of hierarchical organisation and emphasising cross links somewhat reminiscent of Pask´s

network-like entailment structures. Until facilities are available to process texts automatically and perform a deeper analysis than the relatively elementary automatic parsers at present available progress in proving such contentions will be slow, and it will be just as laborious to establish similarities or differences between cybernetic and other texts or concepts as was suggested in chapter two.

5.5 Cognitive Science Approaches: A.I. and Information Processing

Cognitive science may be regarded as traditional cognitive psychology enriched particularly by concepts from linguistics and computer science in its broadest terms. The demand that theories be potentially simulable on computer has brought greater rigour into theorising and although a person is clearly not the same as any currently functioning computer it may be the best metaphor we have.

Thus one could begin by asking how one might create a computer like mechanism which would simulate a facility with cybernetic concepts. The immediate caveat would have

to be that at some level of simulation the performance could be achieved in an infinite variety of ways. There is no necessary relation between computer architecture and the output of a program. Knowing the input and output does not enable one to deduce the construction of the computer, and to a less obvious extent the same applies to the construction of the program. Simon´s argument that the human intellective component may be relatively simple and that apparent complexity may be driven by the environment [280] also suggests that we may benefit from considering task requirements at a fairly abstract level rather than worrying too much about feasible performance mechanisms, but such an argument is not proven. Nevertheless despite such considerations one can hypothesise about problems likely to arise and indicate certain classes of solution. Such an analysis at least alerts us to the possibility that actual individuals may successfully arrive at and handle cybernetic concepts in different ways.

Another consideration is that many A.I. and computer science concepts imported into cognitive science are themselves closely related to or exemplars of cybernetic concepts so that there is a danger of a circular process of reification if the separate levels are not rigorously kept sight of. A further level of circularity

is suggested by Norman [281] in that the institution of Von Neumann architecture was influenced by the then current ideas of how the mind operated.

Arguably the range of plausible models is pruned by the principle that human cognitive systems have been subject to the constraints of evolution and growth demanding their viability at each stage of development and also by what we actually know neurologically although George [282] pointed out that simply by conceptualising some area of the cortex as a set of uncommitted flip flops one had an available mechanism to model any system which one was able to specify. Such proofs of neural potential and plasticity are likely to be constrained by considerations of computing time however, when one moves from abstract principle to practical example.

Munro´s discussion of plasticity in relationship to the concept of critical periods for particular perceptual and cognitive developments [283] argues from his model that, "increasingly longer sensitive periods may be expected for the development of higher cognitive functions". This would corroborate the possibility that if postponed too long the introduction of cybernetic concepts could meet with greater difficulty although obviously too early an introduction of higher abstractions creates

difficulties.

If then one posits as a major goal of cybernetic understanding the ability to construe similarities in processes between different organisations one is faced with the need for feature abstractors, a coder of relationships between features which is capable of development, a device for comparing patterns of relationships between different organisations and a large data base. These minimal requirements are no different from the requirements of any concept forming device capable of abstraction and generalisation although we may argue that such demands are greater in cybernetics than in most areas and note that however easy it is to state the broad features of a system which construes cybernetic concepts, common sense and psychological research tell us that people are not generally very good at high levels of abstraction.

Even assuming that initial feature extraction was not problematic a hypothetical program could obviously not code for all the relationships between features, hold the infinity of derivable patterns and then test each new collection of features (however that was bracketed) for the occurence of all previously derived patterns. Clearly with simple serialist techniques there is a computational complexity explosion to identifying new sets of patterns on

higher levels, except to some extent where those patterns are simply a reapplication of previously recognised patterns at a new level (which fortunately is all that is required in some situations, but this has its dangers).

With elementary connectionist models the analogous point arises that it is physically impossible to connect all basic modules, and indeed some degree of isolation is generally necessary for their effective functioning [284]. Hence it is unsurprising that conceptual development seems to be guided by such principles as propinquity and co-variation. Thus the more widely distributed the elements of a system the greater the cognitive demands. Also the usual usefulness of strong "co-variation filters" suggest links with the frequent human intuitive weaknesses relating to concepts of probability, correlation and confirmation bias. When the principle of propinquity is considered at the level of successively higher relationships it becomes obvious that whatever the theoretically "raw" input or "elementary data" (theoretical fictions) it becomes clear that major reformulations of a system´s conceptual framework is going to demand greater computational costs than modifications or straightforward reapplications of existing frames or schemas.

The same appears to be true of connectionist

systems which emphasise their dispersed nature. Thus for holographic and hologram like systems [285] proposing information storage through interference effects, previously stored information is reaccessed through similarities in the present input pattern, a process making for the consolidation of previous concepts, interpreting the new in terms of the old though not inherently prohibiting the creation of new formulations by inspecting and separating out elements of earlier data.

Likewise Edelman´s selectionist theory of distributed neural networks [286] depends on development from previously familiar input patternings. Rumelhart, Hinton and McClelland [287] state that non-hierarchical structures are in principle better problem solvers than hierarchical ones. However the acceptability of their arguments about the restriction of interaction in hierarchical systems possibly rests on a narrow conception of problem solving which only for example considers the specific relatively elementary situation requiring solution rather than the choice of what problem is to be solved and frequently the sequential activation of problem solvers towards a solution. The paradigm of a PDP system relaxing towards a solution through iteratively seeking to satisfy a large number of weak constraints may allow for initial

relatively arbitrary connections to be made but generalisations are rather too easily made from existing recognition structures and there is a problem of keeping similar elements separate. [288] The relaxation model also suggests a degree of fuzziness in our understanding of any (cybernetic) concept.

Clearly Simon´s arguments as to the evolutionary advantage of loosely hierarchical systems [289] apply both to the cognitive structure of the nervous system and to the ease with which loosely hierarchical concepts are cognised by that system. Given the ubiquity with which such structures are encountered (eg. biological growth, fractal concepts, "viable systems" [290], the evolution of matter [291]) a biased nervous system may be an advantage but the point that it would present difficulties for the emergence of other novel viewpoints still stands and could lead to a glossing over of the subtleties of interaction in extant loose hierarchies.

Given the forgoing overview it is unsurprising that cognitive science has not yet addressed itself to the instantiation of specifically cybernetic concepts although it may modify our expectations of what is easy and difficult.

5.6 Experimental Approaches Relevant to the Cognition of Cybernetic Concepts

The range of experiments relevant depends mainly on ones presuppositions or speculations about the elements of cybernetic understanding. As already indicated too microscopic a view might be at the wrong level of understanding. Thus there are plenty of experiments about how elementary associations are made and concepts formed, none with unambiguous implications for higher order concept formation. Richardson [292] reviewing experiments of concept formation concluded that while the weight of opinion was that concepts were coded on the basis of the independent cues or elements composing them, given the opportunity, it was relationships between elements that were coded. Richardson demonstrated this reasonably well with his own experimental stimuli but all we can conclude from the data is the probable plasticity between modes of cognition for the same input. Pask´s comments on the impact of the subject´s personal interpretation of the experimental situation [293] on what we can deduce from the responses apply increasingly where the subject may have

some degree of conscious control.

Closer to the processes we are considering is the work of Berry [294] and Broadbent [295] and others [296] briefly mentioned in chapter 4 section 3.3. Their series of experiments has involved subjects interacting with a computer model of a complex system, for example; a city transport system, the economy of a country, a sugar factory and human interaction. Typically one or two input variables were involved in controling one or two output variables. The output variables would be some function combining the input variables previously chosen, possibly lagged, so that the relationship was not immediately obvious. The recurring feature was that performance in actually controlling the model was negatively correlated with a capacity for verbal description of the relationship operating. Broadbent suggests that there may be a conflict between implicit and explicit learning in understanding a system although both can be involved in a complex learning task. He proposes that implicit learning (possibly by building up in parallel large numbers of contingencies available in some internal "look-up table") comes into play increasingly "as tasks become more complex and as the number of possible alternative hypotheses which require evaluation becomes unmanageable." [297] The salience (lack

of lag between input and output) was one factor encouraging explicit learning and which correlated with operational ability and with situations where there was transfer of training. Only instruction as to which variables to concentrate on improved performance where relationships were non-salient.

Berry and Broadbent´s implicit/explicit dimension was introduced earlier by, among others, Dienes [298] who suggested that "internal dissection" of one´s own insights encouraged the explicit mode and the search for practical application the implicit mode. He went on to suggest these two strategies were linked to the development of mathematicians as either formalists or constructive intuitionists. Vygotsky reports how young children who could not verbalise the actions and relationships among objects in a picture were well able to communicate the dynamic features in pantomime.[299]

Recent experiments on complex learning by Shute et.al. [300], in which students interacted with a computer program to discover principles of economics in a micro economic environment, showed large individual differences in what was learned. The most successful used a variety of strategies relevant to the tasks in order to test the degree of generalisability in related situations. However

different researches in the same volume suggest the idiosyncratic nature of complex learning according to the learner and the particular tasks [301].

Another interesting study relevant to the cognition of cybernetic concepts is that of Finnie, "Is top down natural? Some experimental results from non-procedural languages."[302] It concluded that the kind of global thinking required for top down programming did not come naturally to novices and that "top down" was inappropriate for short programs. However it was characteristic of experts who tended to "chunk" more in writing a program.

Bliss and Piaget´s investigation of children´s understanding of a positive feedback situation [303] also mentioned in chapter 4 section iii is the most direct investigation of a cybernetic concept. The children viewed an apparatus in which marbles zig-zagged down four stretches of slope but their release was controlled by a pivot bar stretching from the upper to the lower slope so that when a marble struck the bar on the lower slope it released the next marble at the top slope. (For a photograph of a replication of this apparatus see page 135.) The simple point that the marble hitting the bar at the bottom caused the next marble to be released was reportedly understood by children from the age of seven or

eight although Bliss and Piaget were not satisfied with their explanation of the fact that the pivot bar swings back to its resting position under gravity. Until the age of eleven or twelve they were not happy with children´s explanations of how something which happened at the bottom could cause an event at the top; however it could be argued that what they sought to elicit went beyond an understanding of the basic circularity of the process. (This investigation was discussed on PP21 and 22 of Dewhurst´s M.Sc. dissertation op.cit.)

g) Investigations oriented towards higher level academic understanding

We may also look for guidance on how people grasp cybernetic ideas in the work of writers concerned with how (mainly) secondary pupils grasp concepts in other subjects.

Hart [304] led a team studying secondary pupils´ grasp of maths concepts using about ten thousand children in fifty four schools and extensive interviewing. They collected a wealth of pedagogic data about common misconceptions within particular maths topics and a few loose but useable generalisations. They sought, by a variety of criteria, to group secondary maths performance

into conceptual levels in each of nine topic areas.[305] In some topics they found an obvious facility gap between clusters of items. They also used the criteria of their own judgement of the existence of a fair degree of mathematical coherence to test items. Also the groups had to be reasonably scalable in that success at a higher level implied success at lower levels. Test items bearing none of these characteristics appear to have been dropped. For seven of the nine topic areas the items were grouped into four levels. Up to 20% of pupils at 15 failed to reach the lowest level. Two topics more conveniently coalesed into six and seven levels. There was no exact match between topic levels although unsurprisingly performance between tests was correlated. Inspection of the range of children performing at each level suggests enough usefulness of the concept to be a guide to the teacher as to when to leave off development of one topic area and move to the lower end of the same level in another topic.[306] Hart suggests little to characterise stage one and two ("stage" and "level" are used indistinguishably) but stage three is characterised by, "the appearance of the first level of abstraction" [307], movement away from concrete referents and the emergence of strategy. Stage four, "involves abstraction as well as the application of a fund of knowledge" [308]. The percentage of 15 year olds clearly

attaining stages one to four was respectively, 22%, 28%, 22% and 8%; although Hart indicates that most stage three fifteen year olds can begin some stage four problems.

Hacker [309] studied behaviour in 864 science lessons covering the twelve years of compulsory Australian education. He used 3751 pupils and 144 teachers in unstreamed or occasionally middle range classes. His system of analysis delineated twelve levels of intellectual ability practised (from "acquiring, recalling or confirming facts" to "inferring from observed or recorded data") and combined it with nine modes of learning (eg. teacher questions, pupil interacting with science resource materials) out of which a hierarchy of six levels of intellectual development in science was produced. These were related to the observers' post lesson written summary of content. Hacker argued that classroom behaviour gave a better view of the inevitable interaction between pupil and subject material rather than either abstract subject analysis or theoretically preconceived logical stages reified by experiment.

His categories are unsurprising and each loosely characterise an age range in Australian education from lower primary to upper secondary. Group five (lower/upper secondary) embodies, "Development of progressively more

abstract theoretical constructs. Emphasis on the data summarising characteristics of these constructs and their application." Group six (upper secondary) begins with, "Emphasis on the hypothesis-generating characteristics of theoretical constructs. Formulating hypotheses about significant scientific problems and designing controlled, multivariate, empirical tests."

The groups were obtained by cluster analysis which is a controversial statistical technique.[310] [311] More significant perhaps is Hacker´s conclusion that, "For the abilities studied, the results are generally consonant with the notion of gradual, quantitative changes in pupil thinking, rather than with the notion of discrete, qualitative stages with emergent intellectual functions." He notes that almost all of the twelve intellectual abilities practised occurred in classrooms at all levels. If anything there appears to be an early and late emphasis on science process skills with a middle years emphasis on acquiring facts although there is a greater use of the higher intellectual abilities in the upper age groups.

Kuhn, Amsel and O´Loughlin [312] might fall at what Hacker would regard as the learner polarisation of the division of theories between learner evolution and logical acquisition of the prescribed material. However Kuhn

et.als.´ conclusions from small sample experiments with pupils and adults also play down the existence of global intellectual stages but do show that levels of logical sophistication are initially tied to particular subject areas experienced and then may generalise to related areas while being absent in others for most adults.

They formulate three key abilities for scientific thinking; "the ability to think about a theory rather than with it, the ability to represent information to be evaluated apart from the representation of the theory and the ability to ignore personal views and assess evidence objectively in terms of what it means for the theory."[313] Individuals show a gradual increase in the degree of these abilities from third to ninth grade but non college adults perform about the level of sixth graders and worse than the average ninth grader. [314] They conclude, "Late elementary and early high school are probably the most critical in terms of science education and development of scientific thinking skills. There may be a potential during this age range for facilitating development of ways of thinking about evidence and theories that is absent before this time and diminished afterwards," since limited strategies once formed are hard to break down. [315]

Chapter 6

Investigations into the acquisition of cybernetic concepts

The previous chapter explored ways of approaching the cognition of cybernetic concepts. Clearly we can not advance in all directions at once. The first steps need to avoid too many presuppositions and be feasible while throwing as much light as practicable on some significant set of the possibilities raised. The main investigation involved an examination of various groups´ understanding of and facility with the concept of feedback, utilising methods of introducing the concept which experience and theory had suggested wculd be most effective. As well as its intrinsic cognitive interest the investigation was chosen to highlight the balance in the cybernetic problematic between conceptual and cognitive problems.

6.1 Investigational rationale

It has been argued by a number of writers [316] [317] [318] [319] [320] [321] that the scientific study of situations involving human consciousness poses special problems. Briefly the traditional experimental requirement of "ceteris paribus" is difficult to impose since a mind will place its own construction on the stimuli or environment in an experimental situation which may be different from that of the investigator. However a move towards the more ethnographic or conversational end of social science data collection is open to the danger of subjective contamination by the observer/experimenter not to mention the problem of demonstrating that such dangers were minimised.

Frequently moreover there is a tension between the reliability of results obtained and their broad significance or generalisability. This is particularly likely to be so in the early stages of conceptual development of an area where there is no widely accepted paradigm (in T S Kuhn´s sense [322]) so that a tight mesh of theory could give limited empirical findings a much

wider range of significance. Clearly then the development of an area requires a trawl for possible hypctheses and connections in the hope that a tighter structure will emerge capable of more refined testing. It is worth noting that mainstream practice in experimental psychology still falls short of what statisticians generally regard as desirable. [323]

Thus initial data collection attempted to follow the format of the open ended interview, i.e apart from the initial question the interviewer proceeds by seeking as much elaboration as possible of the interviewee´s responses and avoids cueing for any of his or her own hypotheses. Three former Brunel cybernetics MSc. students, and one doctoral student, were asked, "What problems did you find that you had with cybernetics concepts?" Seven lecturers or past lecturers in cybernetics, from four universities, were asked, "What problems did/do you find students had/have in learning about cybernetics?" With the ex-students it was possible to maintain the open-ended format throughout. With a minority of the lecturers it seemed probable that they would "run dry" after a few minutes so responses were elicited by more leading questions. A number of interviewees produced their most interesting comments after the formal interview was over in

a conversation involving a mutual exchange of ideas.

It would not be worth doing significance statistics on the contents of these interviews. However issues emerged or were confirmed which probably pruned the number of hypotheses seriously entertained by the interviewer. A wide variety of points were raised but the main ones have emerged already. Only one of the ex-students seriously considered that problems might exist with themselves; one saw considerable problems in the cohesion of the subject matter and the variety of approaches, one said there were no problems and the third felt that any problems were minor. The doctoral student would have liked a more structured introduction to cybernetic concepts and felt that at best the link between certain areas was left too implicit. The majority of lecturers felt that there could be problems for students in the degree of abstraction and generalisation required. Two felt that there might be problems inherent in the cybernetics "program" which would then present as problems for students. On differing criteria the background of students was proposed as significant for success; the proposed criteria were possibly linked to the type of course taught. Fellgett´s comments about the poor grasp of fundamentals in maths and physics among A-level applicants for cybernetics supports

this theme.[324]

A second preliminary investigation took the form of a series of written questions capable of systems oriented answers which were given to three groups of about twenty for a written reply. No suggestion of the type of answer required was given although when asked, the specified length of each answer was given as, "A few lines." The first was a class of 11 to 12 year olds who had been exposed to a term's teaching using the work cards illustrated in my M.Sc. dissertation. The second group were from the same year without any formal cybernetics teaching although they had been exposed to computer programing and had seen elementary robctics work. Both groups wrote out their answers without consultation during lesson time. The third group were teachers in the same school who were asked to return their answers in their own time. Four did so. The highest proportion of systems oriented explanations came from the class which had been taught systems and cybernetics concepts, considerably less from the control class and least from the adults. Some of the non-respondents said that they fcund the questions too difficult to give time to. All this investigation shows is that children can be taught a way of looking at things which is not characteristic of some (most?) educated

adults. Incidently the writer also tried teaching cybernetic concepts to children without the practical exercises and discussion indicated in his M.Sc. dissertation and found the results embarrassing in terms of the distorted concepts formed and accordingly stopped wasting their time and perhaps putting them under illegitimate intellectual pressure. Thus a number of propositions have so far coalesced for consideration.

i/ The universe may simply not be constructed so that seeking similarities between complex entities can be very fruitful.

ii/ All or most human beings may be so constructed that they are poor at identifying what systems similarities exist. (Both i/ and ii/ would have implications for a/ the current development of the subject and b/ people's ability to understand it.)

iii/ Most current educational and social environments inhibit or fail to facilitate the grasp of systems and cybernetics concepts.

iv/ There may be a split for many individuals between their implicit and their explicit understanding of cybernetic concepts and/or processes.

v/ There is a critical stage after which it is far harder for individuals to develop systems and cybernetic concepts.

vi/ Cybernetics is par excellence an interdisciplinary subject. However there are strong sociological forces operating to maintain existing subject demarcations (autopoesis?). Hence cybernetics has failed to achieve the "critical mass" to acquire the resources to develop a sufficiently impressive body of work to justify the cognitive demands for many people.

vii/ Any combination of any degree of the above factors could lead to certain cybernetics concepts having been poorly formulated.

viii/ Hence many cybernetics concepts are superficially easy but fundamentally problematic.

ix/ The existing lack of focus enables individuals to project peripheral concerns into the fora of cybernetic discussion thus compounding the confusion.

x/ Detailed investigation is crucial to scientific development. Inevitably that detail must be applied in a specific more concrete subject area. Hence developments triggered by a cybernetic orientation will tend to be

regarded as an attribute of that speciality rather than of cybernetics and as a corollary linked to ii/, iii/ and iv/ the greatest payoffs for cybernetics will come from expertise in at least two specialities apart from cybernetics (although this limitation is reduced by interdisciplinary team membership).

xi/ Student´s comfort with cybernetics courses is a function of the match between their academic background and the emphasis of the course eg. physical science based/ non-physical science based.

xii/ Current teaching falsely assumes access to a large data base of exemplars of the abstractions taught. Therefore more examples need to be given along with techniques for generating such exemplars.

Some of these propositions are clearly difficult to test although arguments have been marshalled. It was decided that the most accessible initial approach was to examine a range of individuals´ facility in handling a particular cybernetic concept, namely feedback.

6.2 Outline of Procedure

The investigation was designed so as not to unduly restrain subjects range of response and prevent the emergence of new insights, while rendering some aspects of the results amenable to statistical analysis. The procedure is influenced by Vygotsky´s notion of the "zone of proximal develcpment" [325] and Pask´s "steady state or null point technique" creating a particular "operating region" [326] (so that task demands were modulated so as to maintain genuine coupling to the task and not underload or overload an individual´s operating capacity).

Individuals were tested for their ability to understand three concrete situations involving feedback, their tendency to abstract the characteristic of feedback in those situations, their claims to understand the concept once it was offered and their ability to generate further examples of feedback given cueing with three further less concrete exemplars of feedback. A standard creativity test (uses for a brick) was also given for comparison.

The subjects were five groups of eight, each half male and half female. The three groups of children were

aged 10, 12 and 14-16 respectively. The two groups of adults were non-graduates and graduates. Apart from graduates the subjects were recruited over a range of social classes and to avoid the predominance of any particular level of academic success. Children were recruited from two middle schools and one secondary school and (due to time pressures during term) by extended informal chains of acquaintance. The latter method was used to recruit adults. All subjects were asked if they would like to take part in an experiment. One fourteen year old was reluctant and was not pressed. All subjects were unpaid.

Subjects were told, "I am trying to find out how different people think about or look at different things." When asked for more information the answer given was, "I don´t want to tell you any more before the experiment in case I influence you to give me my ideas instead of yours."

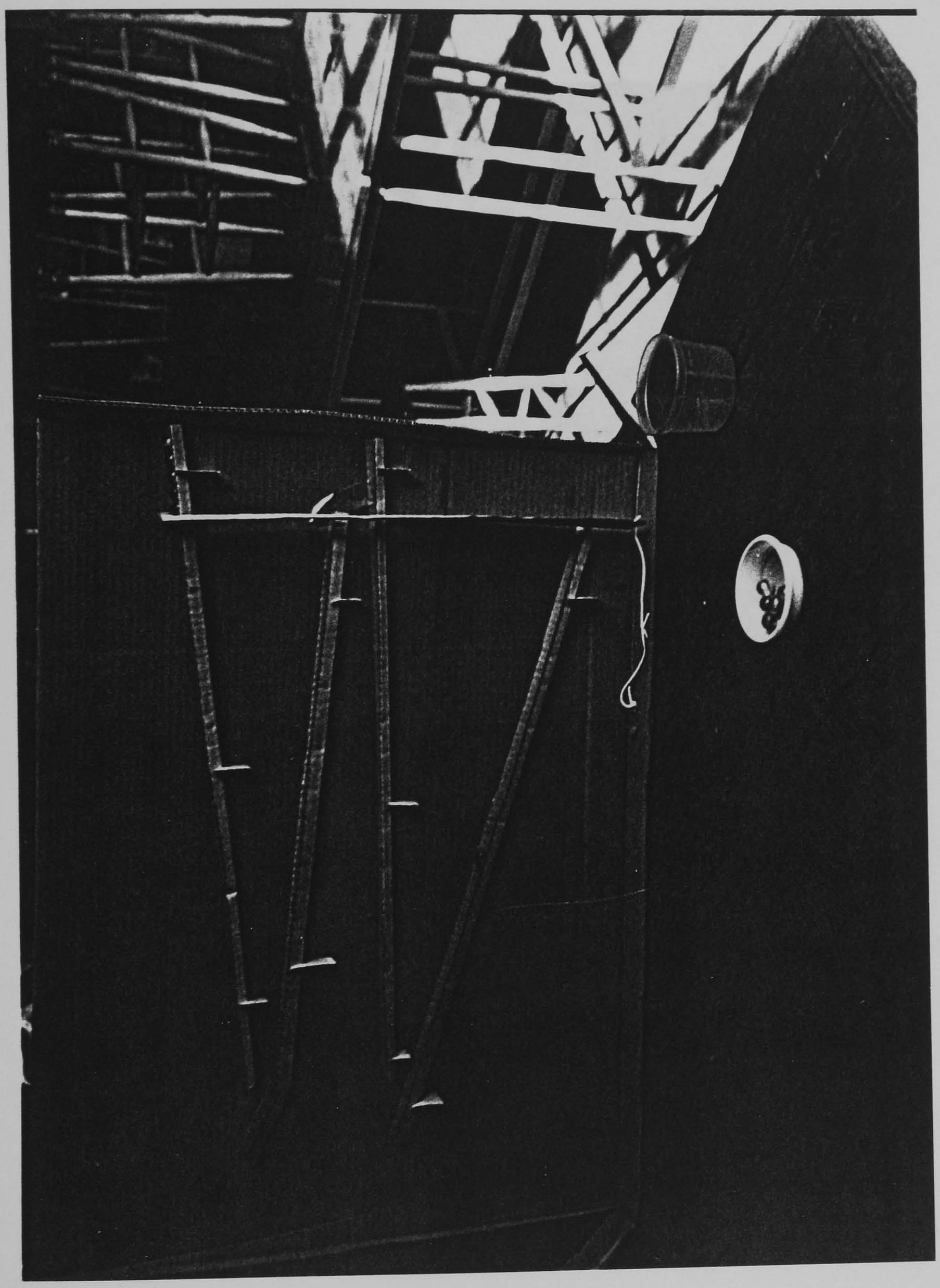
The first exemplar of a form of feedback involved a partial replication of the previously cited investigation of Joan Bliss in which a marble ran down a series of slopes triggering a pivoted bar at the bottom in such a way that the next marble was released from the top and so on. A photograph of the apparatus constructed is on page 134.

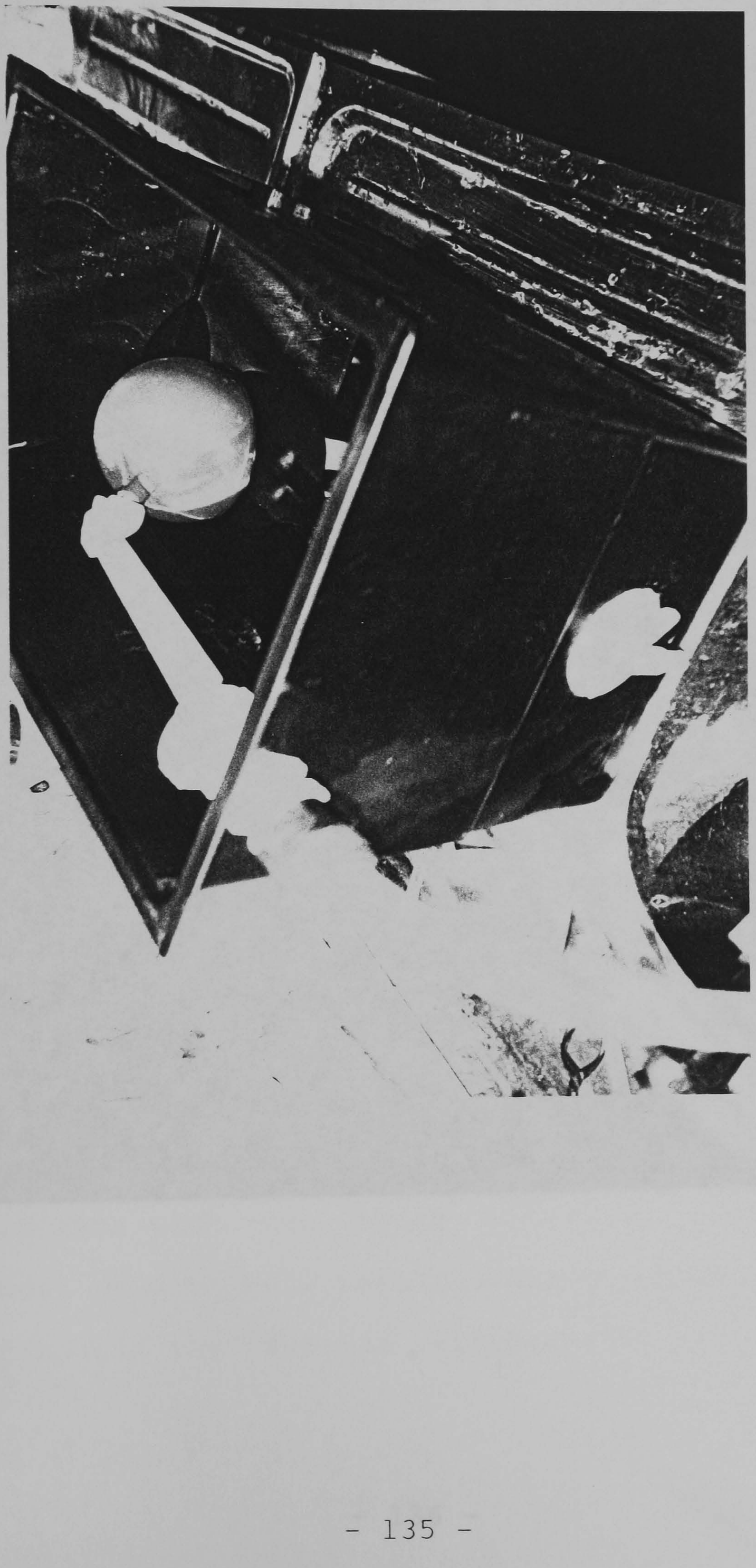
After the demonstration the subjects were asked to explain how it worked. The criterion of understanding was that subjects stated that the marble hitting the bottom of the bar released the next marble and so on.

The second exemplar was a small tank (photograph page 135) with a ball cock mechanism and at the base a tap. The ball cock mechanism was connected to an open tap so that subjects first encountered the tank with the water level static, the intake being choked off by the ball cock lever. They were asked to examine the system to explain what was going on. It was pointed out to them that they could turn on or off the tap at the bottom and gently try and move any other part of the system. If subjects came out with a factually inaccurate statement about what happened they were asked to test it. Where subjects were still failing to arrive at an accurate explanation whether they had made any factually inaccurate statements or not they were asked, "If the water level was down to here (a point below the resting level was indicated) and the tap (indicating the tap of the tank) turned off what would happen to the water level?" If they simply indicated that it would go up they were asked, "Where to?" and then if reasons had not been volunteered, "Why?" Subjects had to indicate awareness that the water would always return to

the same level and that this involved the level of the ball controlling the inflow of water. The three individuals who did not achieve an explanation were then given one.

The third exemplar involved a small Lego buggy (photograph page 136) which subjects were asked to guide along a straight line for between one and two metres and then explain how they did it. They were restricted to holding the pull cord about ten centimetres from its connection with the steering wheel. Where an explanation was incomplete they were prompted with the question, "If the buggy goes off course to the right of the line what do ycu do to get it back on course?" and then, "If the buggy goes off to the left what do you do?" Where the words "left" and "right" were ccnfusing "towards you" or "away from you" were substituted.





The criterion of understanding was that subjects volunteered that the buggy had to be pulled in the opposite direction to the one in which it was going off course.

The next step was to ask subjects if they could think of any way in which all three situations were similar. This question was repeated until they ran out of suggestions. Then they were asked if there was any way in which just two of the situations were similar. This question was repeated for any pair the subject offered until they ran out of suggestions. With two subjects, a graduate engineer and an economist, the classification that they all involved feedback was made and the next step was omitted.

Clearly only the second and third exemplars involved negative feedback and this was the concept of feedback which was presented to the subjects. Subjects were given the following description or a close paraphrase. "What I am most interested in is how with the tank and the buggy you've got something controlled so that it comes back to where you want it, or some particular situation. The water comes back to the same level; your brain and arms with the buggy bring it back on to the line. Now people call this feedback. (With adults and 14-16s "This is the idea of feedback.") It means that

whatever the system does to go off course you get the right adjustments to bring it back to where it should be, some kind of fairly stable situation." Subjects were allowed to ask any further questions until they felt they had got the idea (but no further examples were given at this stage). One subject, aged 10, did not feel he understood at this stage but the procedure was continued with, at the end of which he gave a plausible example and declared that he understood.

They were then asked to think up their own examples cf feedback but were told that they could ask fcr some more examples when they needed help with ideas. The first example involved playing a guessing game in which the subject had to find the number from 1 to 100 that the investigator was thinking of (viz. 35). At each guess subjects were told if they were too high, to low or correct. With each example given by the investigator the subject was asked tc explain how this involved feedback and if they had difficulties the experimenter gave the explanation.

The second example was that of a central heating thermostat. If the mechanism by which it could operate was problematic for the subjects they were shown a simple device in which heating or cooling created a movement which

could in principle turn a heater on or off. (A conical flask with a cork with a glass tube through it and a balloon on the end which inflated or deflated when hot or cold water was run over the flask.)

The final example involved a demonstration started by the investigator in which he closed one eye and raised his little finger held almost at arm's length and began to approach that little finger with the little finger tip of the other hand with the avowed aim of bringing it to touch the more distant little finger tip exactly. But before moving very far the investigator asked the subject to try it very carefully for themselves and notice what happened.

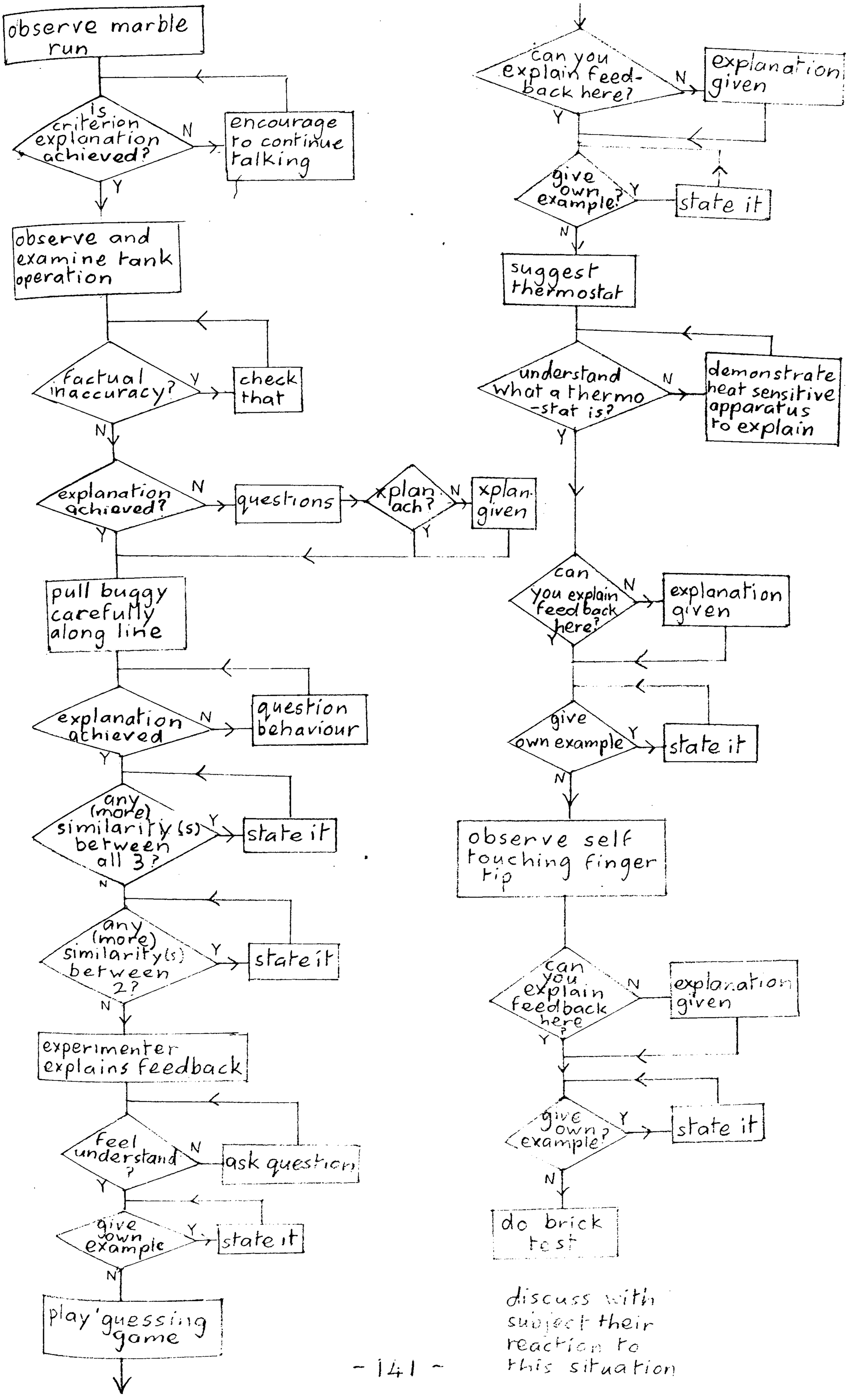
Occasionally subjects suggested the thermostat example before the investigator was due to give it. In this case the fact was mentioned and the next example given.

When subjects' own examples were ambiguous or inccrrect they were first asked to explain how feedback was involved in that situation and if the rationale fell short of criteria this was pointed out and the criterion repeated.

Once subjects had produced all the examples they felt able to they were told that they had four minutes to

write down (or dictate if they wanted) all the possible uses they could think of for an cbject they would be told. Once that was clear they were told "a brick" and timing began.

6.3 SUMMARY OF PROCEDURE



6.4 Tables of Results

6.4.1 Key

The summaries of subject's performance are grouped by age and then adults and graduates. The first column indicates a code for subjects' names; m or f denotes sex; with 14 to 16 year olds age is given and with older people a rough indicator; adults' jobs are shown and graduates' degree subjects.

The second, "Criterion" column indicates with a tick cr a cross whether the subjects were able to explain the slope and marble, the tank and the buggy to criterion. Underneath, the figure 3 comes before a summary of any factors which subjects felt all three situations had in common and the figure 2 precedes a summary of what they felt any two had in common. Where the category does not make it obvious which two situations were referred tc the letters; s, t, or b are used tc indicate the slope and marble, tank and buggy respectively.

The widest column gives as brief as possible a characterisation of each example of feedback the subject

produced. Mistaken examples are placed inside square brackets. Inside rounded brackets are marked the points when the additional examples were given; (G) for the "guessing" game (the figure in front shows the number of guesses to criterion), (T) for thermostat and (f) for the finger touching example.

The next four columns indicate how many feedback examples were given at each of the four possible positions before, between or after the various cues, " - prompt" means befcre any prompts were given, " + guess" means after the guessing game but before the thermostat, " + therm" means after the thermostat and before the finger and " + finger" means items given after the finger example.

The next column "Classes" indicates how many different classes of feedback examples were offered. The ten classes arrived at were; steering, human-machine, human goal seeking/purposes, human interaction, physiological, computer/robctic, electronic and/or mechanical, ecological, economic, and sociological/political. Clearly these are not exclusive classes from a logical hierarchical point of view, but they do reflect the way subjects appeared to make asscciations. Any given example is put intc the most specific class for which it qualifies even if logically it cculd belong to a wider category; for example no computer

examples would be counted in the electronic and/or mechanical category.

The penultimate column "Feedback" gives the total number of feedback examples and the final column "Brick" the total number of uses of a brick generated.

10 Years

Criterion: Slope ✓ Tank ✓ Buggy ✓

Mif — 2 automatic m+b guidance — (5G) 1/hide & seek [factory screwing tops on toothpaste] (T) [foil] (f) 2/driving 3/landing plane

Tof — ✓ ✓ ✓ — 3 movement — (9G) [tape recording] (T) 1/kettle (f)

Vam — ✓ ✓ ✓ — (4G) (T) (f) 1/steer motor bike 2/drive car [train]

Lof — ✓ ✓ ✓ — (6G) (T) (f)

Rym — ✓ ✓ ✓ — 2 round turns hand made — (8G) [turning light on] (T) (f) 1/body self repair

Jof — ✓ ✓ ✓ — (8G) (T) (f)

Mam — ✓ ✓ ✓ — 3 turning — (4G) (T) (f) 1/reassembling ripped up paper

Didn't understand feedback explanation

Ham — ✓ ✓ ✓ — 3 straight movement 2 s+t. triggers — (8G) 1/cutting out with scissors (T) (f) [opening books] 2/steering car without bumping

	prompt	guess	therm	finger	Classes	Feed bk	Brick
Mif	0	1	0	2	2	3	
Tof	0	0	1	0	0	0	
Vam	0	0	0	2	1	2	
Lof	0	0	0	0	0	0	
Rym	0	0	0	1	1	1	
Jof	0	0	0	0	0	0	
Mam	0	0	0	1	1	1	2
Ham	0	1	0	1	2	2	5
population standard deviation					.83	1.126	
sample standard deviation					.78	1.05	
mean					.875	1.125	

12 Years

	Criterion slope [illegible]		prompt	guess	rhem	finger	Classes	Feedbk	Brick
Sp f	✓ ✓ ✓	1/drawing a car (3G) (T) (f) 2/baby care 3/building a house 4/adjusting tape volume 5/tuning radio 6/tuning TV to video	1	0	0	5	3	6	11
Sp m	✓ ✓ ✓ 3 everyday objects 2 automatic s+b touch start	1/computer request 2/swimming, head above water 3/adjusting tennis shots 4/reading, monitoring concentration (5G) 5/ship radar closing down on an object 6/forming a picture 7/find the thimble (T) 8/making a fire (f) 9/searching 10/adjusting rifle sights 11/comfortable golf line up 12/looking round then focusing 13/using telescope 14/adjusting anything till you are comfortable	4	3	1	6	3	14	
Ar m	✓ ✓ ✓ 3 movement, if do one thing effect somewhere else	[wheel with weight] (3G) 1/adjusting cursor 2/tuning wi. compact disc (f) 3/car driving 4/setting watch 5/walking somewhere 6/riding bike 7/navigate plane (T) 8/train auto stop system 9/car auto safety checks 10/radio controling plane 11/pain response 12/tuning radio 13/trip response 14/making coffee 15/checking spelling 16/tooth treatment cycle 17/filling & changing bin 18/fault finding 19/machines to cut out humans 20/bird migration 21/body cell defences [ball rolling] [buoy marking quicksand] 22/keeping a balance of forces	0	2	5	15	7	22	
An m	✓ ✓ ✓ 3 levers round	(3G) (T) (f) [flat battery] 1/kettle whistle 2/auto. kettle 3/record player stop & restart	0	0	0	3	1	3	
Ka f	✓ ✓ ✓ 3 human action to start	(5G) (T) (f) 1/steer car 2/steer lawnmower	0	0	0	2	2	2	
Br m	✓ ✓ ✓ 3 all got sthng running continuous process, roundness, need operator	[recycling newspaper] (6G) 1/selling price in business (T) 2/automatic off switch computer 3/fridge temp. (f)	0	0	3	0	2	3	
Di f	✓ ✓ ✓ 3 move, 2 mt run through sthng s+b dry automatic	(5G) (T) (f) 1/walking around 2/searching for right no. maths card 3/finding you've dialed the wrong no. 4/having maths marked 5/correcting, adjusting watch 6/mending bad stitching 7/ or knitting 8/writing, spelling check	0	0	0	8	3	8	6
Da f	✓ ✓ ✓ 3 turning	1/going somewhere (3G) (T) (f) 2/in eye test	1	0	0	1	1	2	1
		population S.D					1.91	7.13	
		sample S.D.					1.785	6.67	
		mean					2.75	7.5.	

14 - 16 Years

	Criterion: Slope ✓	Tank ✓	Buggy ✓		prompt	guess	+therm	+finger	Classes	Feedbk	Brick
Sam 16	3 movement, cld be continuous, cld power things, 2 automatic, s+r cld be timers, s+b stop			1/ mike-L.S. 2/steering 3/pouring cereal (4G) 4/conversation 5/word association game 6/riding bike (T) 7/iron temp. 8/kettle 9/auto. solar mirror (f)	3	3	3	0	5	9	8
Adm 16	3 one force vs. another, 2 automatic, s+r vertical movement	✓	✓	1/car steering 2/windmill rudder for sails 3/landing plane 4/sports 5/pulling pint 6/controling fuel level 7/controling car speed (7G) 8/adjusting mortar 9/adjusting lights 10/teacher questions 11/2 players wi. ball 12/controling bank balance 13/finding word in dictionary 14/bouncing ball 15/getting slates for roof (stock control) (T) 16/ecosystem controls (f) 17/use of pain 18/dribbling [lining up dominoes] 19/walking to objective 20/writing & using records	7	8	1	5	7	20	10
Mar 15	3 purpose built mechanisms	✓	✓	(4G) (T) (f)	0	0	0	0	0	0	5
Sur 15	3 hand pole controlling 2 automatic	✓	✓	1/Info. exchange through computer 2/steering car/bike (5G) 3/explaining to someone (T) 4/adjusting alarm clock (f) 5/finding way	2	1	1	1	5	5	6
Elf 14	3 triggering responses	✓	✓	(6G) 1/going out in a boat, tactics 2/steering boat 3/speed control (T) 4/oven temp. 5/controling fuel level [fire water] 6/finding way with road signs [traffic lights] 7/getting info. for project 8/some fire alarms 9/taking medicine	0	3	2	4	5	9	6
Brim 16	2 automatic	✓	✓	(7G) (T) (f) 1/cycling 2/working with deadline 3/compiling information 4/political research 5/insurance levels 6/group influence 7/checking called out service arrives 8/house prices 9/press office decisions 10/experimental process 11/letter guessing comp. pgm. 12/IF..THEN GOTO structures 13/response to flame 14/alternate channels with sensory failure 15/cat & mouse comp. game 16/heat seeking missile 17/all eye hand co-ord. 18/discovery learning	-	-	-	18	8	18	
					0	0	0	0	0	0	
Lif 15	✓	✓	✓	(5G) (T) (f)	0	0	0	0	0	0	6
Anin 16	2 automatic, use gravity	✓	✓	(6G) (T) (f)							
									3.2	7.98	1.83
									3.07	7.465	1.67
									3.75	7.63	6.83

population S.D
sample S.D
mean

Adults

	Criterion: Slope	Tank	Buggy		prompt	guess	†therm	†finger	Classes	Feedbk	Brick
Ja 29 nurse f	✓ 3 triggers opposite reaction, 2 s+b round	✓	✓	1/heating in house 2/street lighting info. [alarm clock] (5G) (T) 3/fridge temp. 4/iron temp. (f)	2	0	2	0	2	4	6
Cl 24 marketing f	✓ 2 automatic, t+b can interfere with	✓	✓	1/driving 2/most decision making 3/crossing road (4G) 4/conversation (T) 5/kettle [alarm clock] [traffic light] (f) 7/human co-ordination, picking up 8/watering garden 9/banging in nail 10/getting up time 11/adjustments during cooking	3	1	1	5	4	10	9
Te 46 trainee plasterer m	✓ 2 s+t gravity driven, s+b no proper control	✓	✓	1/tank to carburettor control [air lines fish tank] [washing machine] (6G) 2/argument 3/this experimental situation (T) 4/motor cut out switch	1	2	1	0	2	4	11
Ab 28 YOPs course decorating m	✓ 3 parallel lines in mechanisms, 2 t+b come to a line	✓	✓	(2G) (T) (f) 1/feedback marble 2/studying 3/phone message record system 4/using tape measure 5/conversation 6/plasterboard fitting	0	0	0	6	3	6	14
Al 30 clerk f	✓ 3 pressure involved	✓	✓	(2G) [electricity] (T) 1/starting faulty car 2/computer interaction 3/interviews 4/this experimental situation (f) 5/learning 6/using books, encyclopedias, dictionary 7/brain system 8/chess 9/child rearing	0	0	4	5	5	9	4
Da 42 stall operator m	✓ 3 involved in a reaction, 2 automatic	✓	✓	[lock] (3G) (T) (f) 1/keeping plane level 2/car on road 3/cycling	0	0	0	3	2	3	9
Ma 43 florist F	✓ 2 automatic (continual flow), t+b manual effort	✓	✓	1/hoovering 2/driving vehicle 3/pushing pram 4/supermarket trolley (3G) 5/computer signal entry level [light time switch] (T) 6/regulating gas to simmer (f) 7/threading needle	4	1	1	1	3	7	12
Jo 38 computer parts controller	✓ 3 pivots, 2 automatic	✓	✓	[blood transfusion] (10G) (T) (f) 1/steering car 2/swimming 3/walking 4/mobile platten on printer [fixed bias compensator] 5/electronic compensator in disk drive 6/readjusting sail 7/any steering 8/couple relations 9/population control [expansion rollers at end of bridge] 10/survival of tree as environment changes	0	0	0	10	4	8	13

population standard deviation 1.12 2.22 3.45

sample standard deviation 1.05 2.64 3.23

mean 3.13 6.625 9.75

	Criterion Slope Tank Buggy	Graduates	prompt	guess	rhem	finger	Classes	feedbk	Brick
Ja 36 History f	3 non obvious but understandable, round, watchable, 2 rolling	1/smiling at a baby 2/general N.V. behaviour [seesaw] 3/driving car (10G) 4/decision rhombi (T) 5/body temp. control 6/finger nail length 7/ecological population control (f) 8/following a star pattern in a mirror 9/mike-L.S. 10/eating & hunger	3	1	3	3	7	10	17
Ca 38 Education + Humanities f	✓ ✓ ✓ 3 compensation, movement, 2 automatic t+s manufactured	1/driving 2/word processing 3/punters' response to fruit machine (5G) 4/baby crying 5/quality control 6/automatic ticket control process [light switch] (T) 7/balancing on bicycle 8/throwing pots 9/kiln temp. 11/learning swimming 12/plant care 13/class teaching & learning (f) 14/threading needle 15/getting through width restriction 16/key into lock 17/playing new instrument 18/learning to dance 19/pupil reflex 20/response to burning	3	3	6	8	6	20	13
Pa 34 English + Psychology f	✓ ✓ ✓ 2 s+t need priming	1/drive car 2/dog walking 3/redirecting child 4/straightening typing paper 5/sewing seam (3G) [blood pressure gauge 6/adjusting tyre pressure (T) (f) 7/any ball game 8/dieting 9/packaging filling [damming] 10/courtship 11/research 12/length of answer 13/school performance 14/photography	5	1	0	8	4	14	18
Ri 35 General Engineering m	✓ ✓ ✓ 3 feedback, mechanical 2 s+t gravity s+t more integral	1/driving 2/gear changes with revs. feel 3/water level in washing machine 4/temp. control in same [T.V.] 5/this experimental situation 6/teaching situation 7/reading, meditating re-read 8/word processing 9/underground auto. train controls 10/controling cash level [bell on bus] 11/tuning radio 12/picking up women 13/talking to friend 14/interviewer notes, subject response 15/learning cricket (all learning) 16/expert system adjusting data base (stated principle G) 17/ 3 way split counterfeit coin problem (T) [pressure cooker valve] 18/many safety systems 19/IF..THEN → controls (f)	16	1	2	0	7	19	8

Graduates continued

	Criterion Slope	Tank	Buggy		prompt	guess	+therm	+finger	Classes	Feedbk	Brick
Br 40 Law m	✓	✓	✓	1/steering car 2/steer boat 3/cycling 4/walking on brick wall 5/readjusting wood being sawn 6/adjusting book to stop draft turning page 7/radio volume control with background noise (7G) 8/this interview 9/persuading judge 10/diplomatic approaches 11/reasoning with a child 12/chatting up (T) 13/changing clothing because of effort or weather 14/TV channel flicking 15/home ventilation (f) 16/finding washing line with my sight 17/painting wall 18/tightening screw 19/washing up 20/cleaning 21/adjusting TV angle with light change 22/asking whether to go on 23/cooling tea to drink 24/deciding to tell another joke 25/children's play 26/orienteering strategy 27/ distance runner gauging speed	3 circles							7	5	3	12	4	27	14
	2 s+t circuit-like																
Ka 33 Physics f	✓	✓	✓	1/Schmidt oscillator 2/amplifier 3/school reports 4/hosting 5/post match analysis 6/what done using eyes to perceive environment 7/driving (6G) 8/designing the best barbecue 9/human interaction 10/research process 11/raising & implementing a proposal 12/heating systems (T) 13/optical system controling car park 14/lift, weight safety device 15/monitoring customer's behaviour to raise shop profits 16/questionaires from the bank 17/browsing, blurb decisions 18/running software telling computer what to do (f) 19/co-ordinating touching nose with two fingers 20/advertising and getting toys for playgroup 21/house safety alarm systems 22/riot & authorities' reaction 23/buzzing when ring radio station with radio on 24/quiz answering 25/neighbours request quiet 26/illness & prescription 27/airport checks 28/sensors at baby's birth, heart 29/pulse 30/contractions 31/judging to join or leave queue 32/letter complaint if too slow	3 mechanisms, an initial input,							7	5	6	14	8	32	22
	2 automatic, s+t gravity driven,																
	t+b to predetermined norm																

Graduates continued

	Criterion Slope Tank Buggy				prompt	guess	rhem	finger	Class	Feedbk	Brick
Ap 29 Computer Science Engineering m	3 circles 2 set triggered	✓	✓	✓	7	4	2	5	6	18	9
AL 32 Economics m	3 feedback, movement, purposeless, hinged 2 automatic	✓	✓	✓	5	1	0	2	2	8	10

1/production line checks 2/amplifier 3/any industrial process 4/manager's orders check 5/teaching as children respond 6/controling car speed 7/deciding if woman interested in you (5G) 8/adjusting screen brightness 9/actor responding to audience 10/footballer ditto 11/introducing new regulation, discuss first (T) 12/oven controls 13/computer self checks (f) 14/physical training (how much) 15/studying and being marked 16/approaching hot object 17/manufacturing iron bars, width control 18/any business

1/thermostat 2/economic models 3/tax rate policy 4/fiscal drag 5/prices (6G) 6/mike-L.S. [photochromic lens] (T) (f) 7/autopilot boat 8/autopilot plane

population standard deviation	2	8.11	4.88		
sample standard deviation	1.87	7.58	4.57		
mean	5.5	18.5	13.875		

6.5 Statistical Summary

subject groups	10s	12s	14-16s	Adults	Grads.
		FEEDBACK EXAMPLES			
means	1.125	7.5	7.625	6.625	18.5
standard deviations	0.78	6.67	7.46	2.64	7.58
		CLASSES OF FEEDBACK			
means	0.875	2.75	3.75	3.125	5.5
standard deviations	0.78	1.78	3.07	1.05	1.87
		BRICK EXAMPLES			
means	5		6.83	9.75	13.875
standard deviations	3.52		1.67	3.23	4.56

ERROR RATIOS
(total examples of feedback offered : number of mistakes)

0.4	0.077	0.047	0.172	0.045

overall 0.086

Feedback - significance of difference of means
by randomisation test [327] (1-tailed),
adults and graduates: p = 0.0079

Feedback - significance of difference of means
by randomisation test (1-tailed),
12 years and 10 years: p = 0.0154

Feedback - significance of ratio of variances (F score)
15s and adults F = 2.238 -not significant at 0.05 level

Grads. and adults F = 7.857 -significant at .01 level

Brick - significance of difference of means by randomisation test, (1-tailed),
14-16s vs. 10s and 12s: p = 0.0909

Brick - significance of difference of means by randomisation test (1-tailed),
14-16s vs. adults: p = 0.3150

Joint probability continuously rising brick score, from multiplying previous two p s = 0.0286

Brick and Feedback correlation, Pearson product-moment coefficient

	10s & 12s	14-16s	Adults	Grads.	All
	.92	.91	.03	.07	.65
significicnce level [328]	>.05	>.01	-	-	>.01

mean feedback score: girls 2.9
boys 7.9
t value for significance of difference of two means 1.38
significance level 2 tailed test c. 0.2

mean feedback score: women 13.25
men 11.875

6.6 Discussion of Results

Firstly the results indicate that given concrete exemplars of feedback most people can grasp the concept and from the age of about twelve generate a reasonable number of examples. The population as a whole can provide a considerable variety of responses. Giving people more examples helps the majority to generate more of their own. However there is no demonstrable improvement between 12 and adulthood (in contrast to performance on the brick test). This corroborates Kuhn, Amsel and O´Loughlins´[329] findings that for most people some scientific thinking skills either did not improve or actually declined from adolescence to adulthood. It is interesting that this pattern of ability · occurs for productivity with a particular scientific concept (feedback) as well as with Kuhn et.als.´ tests in skills of using scientific concepts and methodology.

There is then some evidence for the "critical stage" concept but hardly one specific to cybernetics as this particular investigation does not show cybernetic thinking to be significantly different in its maturation

from other components of scientific thinking at the conceptual level investigated. Presumably the apparent plateau or decline with most adults could be changed by more teaching of systems and cybernetic concepts along the lines previously demonstrated as well as by greater efforts in general science teaching to ensure that general abstractions can be related to a wide range of practical activities.

The relative productivity of graduates does not of course prove that there is no conceptual difficulty for them with cybernetic concepts; maybe their success is due to their "shaping" with this particular investigational method with this particular concept. However the conceptual difficulty thesis remains experimentally unproven.

The lack of correlation between brick scores and feedback scores for adults indicates that for them the task was not simply one of "divergent thinking"[330] although it is worth considering how far a component of creativity may simply be the capacity to abstract and then search a data base for exemplars of that abstraction. The correlation with children may indicate a common mechanism or it may be that the two abilities are linked to a common individual maturational factor. For the fourteen to sixteen year olds

the fact that the brick test was always easier accounts for some of the correlation. Inspection of individual scores indicates that performance on one would be a poor predictor of the other; in other words the effect size is low.

Finally, despite appearances there is no proof of a sex bias in the children´s feedback scores. Arguably either the technological emphasis with the examples or the sex of the investigator might have created an asymmetry. Thus it is worth bearing in mind the possibility of a type II error.

6.6.1 Discussion of Verbal Responses

The brief summaries of each example of feedback offered may sometimes seem inappropriately characterised as right or wrong. In ambiguous situations the subject´s explanation of the existence of feedback determined if it was categorised as an error. Occasionally the individual appeared to have the germs of a good idea but lacked the skills to justify it. This may be related to Broadbent and Berry´s "implicit" understanding.

The errors in exemplifying feedback highlight some of the problems with the concept discussed in section

4:3:3. The "wheel with weight" error referred to the boy´s observation of a free bicycle wheel coming to rest with the valve lowest. Similarly the "blood pressure gauge" example referred to the way in which the mercury bounced around on its way to a stable resting point. Both are analogous to categorising the pendulum as feedback which was mentioned in the, "Fuzzy concepts of Feedback," section. A related dilemma to gravity driven stability was raised by the General Engineering graduate who initially categorised all three introductory situations as exemplifying feedback but later changed his mind about the marble run on the grounds that it was simply delayed falling under gravity. Other examples of feedback being identified with any stabilising situation were the, "fixed bias compensator," the "expansion rollers at bridge end," and the "photochromic lens."

A common misconception with twelve year olds when the concept of feedback is introduced without any concrete situation to manipulate is that feedback refers to any serial process. This was exemplified by the, "screwing tops on toothpaste in a factory," example and that of the washing machine. (Obviously a washing machine may be viewed not as a series of operations but as incorporating feedback with temperature and water level controls, but

this was not the case in the example cited.)

Another class of error seems to be to identify feedback with something that gives imperatives, a buoy, traffic lights, an alarm clock, without being able to say how output affects input in some kind of control situation.

Perhaps surprisingly there is only one obvious error due to feedback being identified with any circular process, in the example of recycling newspaper.

The largest remaining category of error lies in superficial analogies from identified feedback situations; the ten year old who justified, "opening books," as feedback because there was a straight line where the pages joined and there had been straight movement in the first three situations, or the trainee plasterer who said he suggested air lines to a fishtank because of the movement through a pipe in the ball cock set up. However the possibility referred to initially remains, that some examples are arrived at unconsciously for better reasons than are used to justify them. The ten year old may have had intimations about searching backwards and forwards for a page number; the trainee plasterer may have been working on the analogy of controling the use of an essential fluid,

which would cover his previous example. However it would be asking too much of an initial study of conceptualisation of a cybernetic concept to demonstrate a model of partial access to unconscious processing.

The similarities suggested between the first three situations demonstrated show a widespread capacity to identify common elements although some were superficial eg. all items contained something round. The automatic/non-automatic distinction is widespread but about thirty per cent also came up with some generalisation which could be at least nascently related to feedback; guidance, triggering, remote effects, continuous process, reaction, compensation, circuit like, moving to a predetermined norm.

It is noteworthy that capacity to formulate a high level abstraction does not necessarily imply ability to propose a large number of examples of that abstraction. Three of the graduates volunteered that they knew there must be many more examples but it was hard to provide them. No subjects had immediate access to all ten of the classes of feedback situations in which subjects´ responses fell. The highest scorer taught microelectronic design and contrasted the emphasis of her education as a scientist with that as a designer with its concern to identify

options. As suggested before, the move from the concrete to the abstract is highly valued by the educational system but the skill of applying abstractions in concrete situations is generally less emphasised. Thus it may be possible for discourse to take place in a "high level language" without any notion of reality checking at the level of implementation. Presumably a language level can be regarded as autopoetic, and there is a warning here for many fields of study.

The examples given by subjects show some obvious influences from their jobs or degree subjects but there is little evidence of their using a single style or strategy to generate examples. Some of the youngest children were only able to give examples of steering and other subjects at times produced chains of close analogies, although it is worth considering that what may be a close analogy for one person may be a considerable intellectual leap for another. The broader strategy of searching within larger classes is generally apparent. As with the bricks task, at times subjects gazed around the room or oriented to distant noises in an apparent search for examples. What other mechanisms of internal search were going on was simply not apparent but it is plausible that the variety of individual experience that people draw upon is going to reduce the

payoff for attempts to characterise them as a particular type of respondent.

Chapter 7

Implications

7.1 An Evolving Perspective of Cybernetics

The results of the previous section indicate that while there are some problems in the actual cognition of cybernetic concepts they can be reduced by directed attention to the cybernetic features of a variety of hardware artefacts and that giving more examples increases most individual´s ability to apply cybernetic concepts.

However the ability of most people to engage with the task of understanding a key cybenetic concept strongly suggests that the problems voiced in chapter one can not simply be attributed to human intellectual weakness and to that degree some misgivings about the subject per se are strengthened. The earlier part of this thesis demonstrated that while an identifiable cluster of ideas composing cybernetics exists it is a somewhat ragged one with elements of its history suggesting missed opportunities and

sloppiness.

With regard to the five areas of controversy addressed, the machine model of human beings and the mechanistic accounts of purposiveness were judged as research orientations worthy of pursuit, while the concepts of feedback and information theory, beyond a limited range, contained ambiguities for users and within themselves which needed clear articulation. The concept of requisite variety, at least outside a narrow range was judged to be misleading.

The examination of avenues towards the cognition of cybernetic concepts has shown an area wide open to investigation through a variety of models. The specific investigations undertaken in the previous section show the area´s tractability at even a fairly low level and confirm the evidence in the related literature of the fruitfulness of basic experience with concrete examplars, provided attention is actually drawn to the abstractions concerned. Adults´ ability to handle cybernetics concepts, like the concepts of scientific procedure themselves, would almost certainly be better with better earlier training.

That there do exist common systems phenomena in a variety of areas was affirmed by the lists of exemplars

given in Chapter 4, Section 2. However their very ubiquity in the toolkit of most scientists calls into question the need for a separate subject. This is reinforced by the tendency of general concepts to emerge from empirical investigations rather than vice versa. Whether more useful generally applicable concepts about the organisation of complexity will emerge (as did catastrophe and chaos theory) is an empirical question. As they have in the past we can not demonstrate that it is unreasonable to look. Whether such concepts will emerge from a self conscious search within the field of cybernetics at a high level of generalisation is another empirical question. It is worth noting that the lower level and more concrete the research the more easily guaranteed and apparent is the payoff. However while we may be sceptical about the productivity of cybernetics at a high level of generality, whatever its convenience as a toolkit or classification scheme, the example of Boolean algebra and symbolic logic, which appeared initially useless but made computers possible, suggest that we can not dismiss the possibility of fruitful returns from such a strategy. Possibly a greater determination within cybernetics for rigorous self criticism will make that development more likely.

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