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Beyond Constructivism

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During the past decade 'Constructivism' or one of its many variants has become the dominant ideology in science and mathematics education. A casual, disinterested observer might be shocked at the rate at which this school of thought has permeated research communities across the globe and at the grip that it holds on their work. In this paper, I wish to concentrate on the notion of Constructivism prevalent in science education as defined by the the Generative model of learning (Osborne and Wittrock 1985), Driver's (1985) account of a constructivist approach to curriculum development and White's (1988) position on the learning of science.

Constructivism has its roots in a reaction against the naive inductivism and deterministic Piagetian developmental stage-model of cognitive growth. In developing its case it has focussed very strongly on the resiliance of learner's beliefs and the social construction of reality. Inevitably, when these features are in focus, there are other features which are blurred and out of focus, if not out of the picture altogether. The concentration on these issues has led to the neglect of important epistemological and psychological concerns. Also, to the extent that the personal and social has been given priority over the obdurateness of the natural world, my contention is that there is a danger of a slide into relativism, if not idealism, and a devaluation of science through an overemphasis on the learner's inductive interpretation of phenomenological experience.

Thus, whilst these versions of constructivism have had some limited pedagogic success, they suffer from basic epistemological weaknesses which will always restrict its potential as a theory of knowledge acquisition. In addition, constructivist psychological is currently an inadequate theory lacking a hard core of ontological commitments that enable it to be either tested, or assist in the development of successful learning strategies other than at a general or meta-level. Many of the learning techniques proposed by these and other authors also make assumptions about the preferred learning styles of students which research does not support. The result is that the narrow focus on this research paradigm will ultimately limit the development of an effective science education.

Instead, the case is advanced that the realist epistemology of Harré (1986) provides a structuralist view of knowledge necessary for the consideration of issues of development and progression within the curriculum and, that to combine this epistemology with a more organic view of learning which recognised it as multi-faceted process and unique to each individual, would be more productive.

CONSTRUCTIVIST EPISTEMOLOGY

One of the fundamental tenets of constructivism is that cognition is adaptive and serves the organisation of the experiential world. Thus the key postulates of the generative model of learning (Osborne and Whittrock 1983) are that:

- The learner’s existing ideas influence what use is made of the senses and in this way the brain can be said to actively select material
- Learner’s existing ideas will influence what sensory input is attended to and what is ignored
- The input selected or attended to by the learner has no inherent meaning.
- The learner generates links between memory store and sensory input to actively construct new meaning.

Hence the learner must be active and exposed to a wide variety of sensory input from which they can construct personal meaning. But what is the nature of this sensory input and more importantly, how are new meanings constructed? On this matter, Osborne & Whitrock are notably vague stating that a teacher needs to ‘provide opportunities for pupils to consider, contemplate and expand their views of the world’ and to ‘have new experiences and to ask questions’.

The emphasis placed by this model on sensory experience is an unfortunate one. For, whilst sensations are important in constructing descriptive and explanatory schema, particularly for the young child, the model fails to recognise that one of the most important means of generating new meanings is through a process of reflection and reorganisation of the internal symbolic representation of sensations. Thus Galileo’s creative achievement was to reinterpret the sensation of the oscillating pendulum as an idealisation in which the mass was concentrated at the centre and with no frictional forces acting, meanings which are not accessible by sensation. The cultural capital of western scientific thought is these symbolic representations of experience and the key issue for science education is how these may be effectively acquired by students.

Secondly, the epistemology of science depends on both a methodological and ontological component. The emphasis on sensation and experience in constructivist writing is in danger of reducing the methodological component to the epistemology of empiricism and inductivism which sees the scientific enterprise as one of investigating the world and trying to make sense of their sensations and experiences. Thus writing in the UK Association for Science Education handbook for teachers, Asoko et al (1993) argue that 'learning involves the learner in making sense of things in terms of their existing ideas' though they do acknowledge that 'this will sometimes involve moving beyond their current interpretive framework to one which is better able to make sense of their experiences'. Similarly White (1988) argues that biology and Earth Science can be learnt by students concentrating on observing and describing. Only later would general principles be taught. Tobin, Butler Kahle et al. (1990) argue for a phenomenological approach based on extensive experience in science classrooms in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and teachers. In all these accounts, considerable emphasis is given to the value of direct experience and observation, that is to an empiricist approach to learning science, and insufficient stress is given to the process of acquiring new frameworks for reinterpreting experience and transcending commonsense reasoning. The consequence is that empiricism cast a long shadow over the constructivist camp.

Driver herself comes near to confronting this issue when she states

> "The theoretical models and scientific conventions will not be 'discovered' by children through their practical work. They need to be presented. Guidance is then needed to help children assimilate their practical experiences into what is possibly a new way of thinking about them."
>
> (Driver 1983)

But in her later seminal paper on a constructivist view to curriculum development, this matter is avoided as we are told that 'we can specify the experiences which students should be exposed to' but are given no principles on which to make such judgements other than 'knowing where students are starting from' and a reliance on the teacher's intuitive knowledge of classroom realities. The curriculum process itself contains an evaluation phase where pupils test a range of ideas 'including the scientific one if they have suggested it.' But what if they have not - on this issue the authors remain silent. Only Millar (1989) addresses the problem directly by arguing that in constructivism "there is no ideological requirement to wait until pupils ‘discover’ the scientific idea themselves....classroom activities are organised to maximise student’s opportunities to articulate their personal constructions”.

However, most student’s personal constructions, and for that matter adult ones, are fundamentally empiricist in their nature and, from a scientific perspective, erroneous. That this is so can be found by examining the vast body of literature on the topic consisting of books (Osborne and Freyberg 1985) (Driver 1983) (Driver, Guesne et al. 1985) (Black and Lucas 1993), articles (Gilbert and Watts 1983) and bibliographies (Pfundt and Duit 1988) (Carmichael 1990). Ideas and theories are commonly based on everyday observations out of which are formulated a set of 'scripts' (Schank 1982) or as has been argued by di Sessa (1988), a set of phenomenological primitives. The common consequence is a lack of any coherent theory and a resort to contextualised observation, often resulting in conflicting explanations for similar observations (Osborne, Black et al. 1990) (Durant, Evans et al. 1989). In contrast, the great success of modern science has come from individuals who have transcended intuitive reasoning and used their imagination to devise new ways of conceiving of how the world might be (Chalmers 1982). The physics of motion provides one of the best examples of the counter-intuitive and the majority of idea of science are essentially unnatural (Wolpert 1992) and arise from attributing properties *to* objects rather than drawing properties *from* the objects.

However only recently has the essential fundamental weakness with the epistemological position taken by constructivists been exposed in some detail by Matthews (1992) and Suchting (1992). The former argues that the position taken by radical constructivists - that it is impossible to know anything not accessible to direct experience, illustrated by the following extract, is nothing more than an empiricist view of science.

> “If our concepts are derived by abstraction from experience, there are no grounds for belief that they could capture anything that lies *beyond* our experience.”
>
> (Glaserfeld 1991)

Firstly, such a position would imply that the only accessible meanings are those of which we have direct experience, essentially the view of the logical positivists. Furthermore, it would deny the role of language in the sharing of experiences of others and the negotiation and generation of common meaning. For instance, I know that South America exists, that it has a large river flowing through it called the Amazon etc. All of these pieces of information enable me to develop a detailed geographical concept that I associate with a continent of which I have no direct experience, such that for myself and all other individuals the ontological status of South America is not in doubt. South America exists, is real and tangible although I may only know a limited sets of its attributes. Thus the important distinction to be made from this example, is between real objects and the theoretical structures we hold, a nuance which continues to elide constructivism which places an emphasis on knowledge as a personal construction, rather than as an objective entity which exists in its own right - an objectivist view of knowledge elaborated by Popper (1972).

The inevitable tendency is that it leads to a slide into relativism where all concepts are equally valid since any idea which is derived by abstraction must be considered as legitimate as any other. No basis is provided by a constructivist epistemology for adjudicating the merits of competing abstractions. Ptolemaic science is a very legitimate attempt to abstract from experience which made eminent sense yet we choose not to teach such ideas for the very good reason that such ideas have shown to be inadequate and crucially, open to falsification. Most importantly for science educators, this relativist stance fails to recognise any distinctions in the complexity and difficulty of theoretical descriptions of real objects, or that some of the 'idealisations' of science describe objects which are *not accessible* to sensation or experience e.g. energy. The consequence is that a constructivist epistemology remains silent on the essential issues of sequencing and progression in the content of the curriculum. This failing is *the major omission and crucial weakness* of constructivist theory.

Typically it has led to dangerous attempts (McKinley, McPherson Waiti et al. 1992) to justify the inclusion of scientific traditions of other cultures on the basis that these are scientific enterprises as valid as the tradition of Western cultural science. Since much of this knowledge was derived by trial and error techniques driven by technological need and is profoundly empiricist in its origins, these constructivists are at least being consistent with their view of science as knowledge which is derived from experience. However, such science often lacks a theoretical base and this omission has severely limited its explanatory and predictive power, precisely the qualities that have made Western science so successful. This is not to say that such attempts at the scientific enterprise by other cultures should not be taught but the a social anthropological approach should be used which recognises the achievements of their scientific and technological endeavours and crucially, their limitations.

Consequently current interpretations of constructivism in science education, by placing emphasis on experience and sensations from which children are expected to 'make sense' are in danger of leading to an empiricist and relativist approach to the curriculum which ignore the fact that science education is of necessity a process of acculturation. This is not to argue that the process of education should be one of transmission, but simply that it must enable children to acquire and understand the powerful constructs and ideas of modern science and that any comprehensive theory of education should address the issues of content, concepts, sequencing, cognitive demand and the adjudication of competing theories. The epistemological weakness of constructivism is that it has little to offer the curriculum developer on these issues.

REALISM REVISITED

In contrast to the empiricist and interpretations of constructivism, Harré (1986) argues for a modest position of 'referential realism' whose epistemology offers science education a position which at least enables it to define what might be an appropriate curriculum and possible pedagogy. Essentially his position is that there are three types of entities that we experience in the world which require not a *singular* theory of science but a *triadic* one. Realm 1 theories enable the classification and prediction of macroscopic objects which are tangible and accessible to sensori-motor experiences; thus a typical realm 1 theory is Newtonian kinematics. Realm 2 theories are iconic in the sense that they represent unobservable entities which are only accessible to our senses through instrumentation such as bacteria and viruses. The vast majority of scientific theories are of realm 2. Finally realm 3 theories describe theoretical entities for which there is no direct evidence of their existence such as quarks and black holes whose descriptions are essentially mathematical.

In arguing for a referential realism, Harré states that our interaction with, and sensory feedback from macroscopic objects allows us to know what the attributes of such entities are. Their ontological status is not in question but the notion that we ultimately can know the ‘truth’ about such objects is sensibly dismissed. Interaction, testing and feedback enable us to know more and he argues that the idea that the truth about an object, in the Platonic sense, could be known is a fruitless search. Thus he argues for a realism based in material practice where scientists ask questions of the form 'Do things, properties, processes of this sort exist?' and then attempt to find exemplars within the limitations of technology. This form of realism is epistemically modest and makes no assertions that there are 'incorrigible existential claims.' All that it attempts to show is that the ontology of scientific investigation is relatively stable as opposed to the cluster of beliefs that we may hold about it. Consequently what Lister observes as 'loose cells' in an infected wound and

Pasteur describes as external agents of infection exist and can be referred to through material practice. Referential relations and our descriptive vocabulary can be revised but the basic ontological sketch is not in question. For instance, the heart and the circulatory system existed before Harvey first described them in 1628.

Realms of experience

Experiences of such macroscopic objects are those which the child uses to construct explanatory schemas of physical and biological phenomena, albeit fragmented and lacking any theoretical description other than an intuitive mechanics (Mariani and Ogborn 1991) (Bliss, Ogborn et al. 1989) (di Sessa 1988) and an intuitive biology (Carey 1985). If so, an early science education should attempt to build on and extend children's experiences of macroscopic phenomena, introducing the child to the descriptive language of the scientist and the theoretical frameworks which enable them to generalise from such experiences. For as Harré argues 'theory is a device for focussing our attention. Theory precedes fact....because a theory determines where in the multiplicity of natural phenomena, we should seek for *its* evidence.'

Such an approach would encourage observational activities of a wide range of common macroscopic phenomena. For instance the fact that all liquids can be made to 'disappear' and 'reappear' and that such properties are what scientists call 'evaporation' and 'condensation'; that all animals have a mechanism for taking in oxygen and exhaling carbon dioxide; that springs and rubber bands stretch and that they a share a common pattern in the way in which they stretch. i.e. the sole purpose of such an education at this stage would be to enhance their descriptive language and to show that, with such a language, all phenomena are not uniquely contextualised but share universal properties. Moreover, such an approach would place a greater emphasis on introducing the theoretical description *prior* to observation and experience rather than a vain hope that the the child might spontaneously discover the scientific explanation from an interpretation of their empirical data.

From here, science education would move to examine the theoretical entities of science for which there is instrumental evidence, Harré's realm 2 entities. Typically, this would require an exploration of the particle model and the evidence to support such a model; the evidence of microscopy for the internal structure of plants; the evidence of dissection or models for the internal mechanisms of the body; the evidence for charged nature of matter, the nature of the Solar System etc. All are entities whose ontological existence is inferred from the evidence of instrumentation. However, their existence can be directly related through such evidence to realm 1 macroscopic objects and these are entities of possible experience.

Realm 3 entities are the abstractions of the human mind for which there is no instrumental evidence. As such these entities are inferred to explain certain experimental results - the neutrino and quarks are both classic examples. However at a more mundane level, quantities such as speed, acceleration, current, charge, energy, the mole, molecular biological mechanisms are such abstractions. As such they can only be constructed on a sound scientific understanding of realm 1 and 2 entities. Hence the idea of speed is constructed out of the pupil's experiences of motion and the measurement of time and distance, both realm 1 entities; the idea of current constructed from observations of the brightnesses of bulbs and simple causal relationships. Cognitively such ideas are more demanding because it requires the ability to envisage and manipulate imagined entities and their symbols for which there is no direct referent.

Such a view would provide an epistemology which is superior to the naive empiricism of some constructivists. Firstly because it would avoid the relativist pitfall of the radical constructivist who would ascribe validity to any theory that encapsulated personal experience. More importantly, it would enable the curriculum developer to make decisions about content, a matter on which a constructivist epistemology says nothing. Yet quite plainly we choose not to teach children about special relativity, quantum mechanics, molecular biology and the electronic configuration of chemical bonding because we know that such knowledge is not accessible to them till they have understood a wide body of other factual and theoretical information. The epistemology of constructivism provides no reason why this should, or should not be done. In fact, empiricist interpretations of constructivism would almost deny such an understanding to pupils as the capacity to abstract from experience and develop such concepts requires a supreme intellectual effort of which historically only very few are capable.

The essential failing is that the theoretical base in Ausubelian psychology and that of Kelly has never been developed into a model which would enable predictions to be made of what material will or will not be accessible to learners. The much quoted statement of Ausubel (1968) is essentially nothing more than a statement of good common sense and the success of constructivism has been in reminding teachers that children are not atheoretical subjects and that their thinking is the foundation on which new meanings must be formulated. The generative learning model developed by Osborne & Whitrock (1983) suffers from the similar criticisms and is ultimately a restatement about the nature of perception developed by Hanson

(1958) and Polyani (1958). The most serious criticism of the constructivist theory is that it provides no well-defined mechanism by which the individual can develop new constructs with which to see the world. From whence come the ideas with which the individual is to interpret their sensory perceptions? Where for instance is the role of analogy and metaphor which are the vehicles for extending our thinking and ideas and reorganising our internal symbolic representations? For example, to observe Brownian Motion in a smoke cell a student has to be provided by a teacher with a construct which will enable them to make sense of their perceptions prior to observation. This can only be done through the use of a taught analogy or comparison. Without this, the common experience is that the student's attention is needlessly focussed on other elements in the microscope.

The commonly proposed model of 'cognitive conflict' as a mechanism for the production of new knowledge is only a partial solution. Reformulation of sensation will only occur by reflection and reorganisation of the representations. This view requires a consideration of whether the student has the cognitive tools to undertake the manipulation of symbols and whether there is age-related development in such facilities - a developmental perspective which is totally omitted from constructivist accounts of learning.

Faced with the problem of the determining content, one can only conclude that constructivism has eschewed the issue. Instead, they have resorted to an individualistic approach, arguing that opportunities must be provided for the learner to externalise their understanding and this must then be challenged by critical incidents which generate conceptual conflict (Driver and Oldham 1985) in such a manner that the new ideas are 'plausible, intelligible and fruitful' (Hewson and Hewson 1984). Given that all the major ideas of science, from the basic idea that the Earth moves around the Sun to the idea that the speed of light is invariant with the speed of the observer, are not commonsense interpretations of experience but in essence unnatural (Wolpert 1992) this could be regarded as an act of self-deception reflecting a failure to understand the nature of science.

CONSTRUCTIVIST PEDAGOGY

If constructivist epistemology is seriously flawed then surprisingly perhaps, constructivist pedagogy has had some successes. The strong message of this body of research has been to expose the difficulty large numbers of children experience in internalising the explanatory models of science and applying them correctly. Such data has inevitably raised the dilemma of how to respond to this evidence and since student difficulties were inevitably the product of conventional pedagogy of a didactic or 'guided discovery' nature, the challenge was to devise an approach that was distinctive with a different emphasis.

Didactism places the focus and responsibility for learning on the teacher, examining the quality of their explanation, the use of analogy, the appropriate use of language and the effective use of apparatus and other materials particularly for experimental demonstrations all for the purpose of transmitting a body of knowledge. Constructivists rightly turned their attention to the learner arguing correctly that the learner is responsible for their own learning (Osborne and Wittrock 1985) (Novak and Gowin 1984) (Pope 1985) (White 1988). Here, after all, in the learner's mind, was where new meanings had to be formulated and understood. This could only be achieved if the learner was an active participant in the learning process. Hence, their pedagogy has concerned itself with formulating a programme of activities from which knowledge can be formulated or acquired. These tasks focus on the learner, asking the individual subject to articulate and use their reasoning in a set of structured exercises. In all of these, they have implicitly or explicitly placed their belief in the idea that language is socially constructed and that many words are signifiers for concepts or referents. An understanding of the concept signified only comes through the opportunity to practise and discuss the appropriate use of language in the relevant context. Or as Vygotsky (1986) puts it

> 'The development of the scientific concept, on the other hand usually begins with its verbal definition and its use in non-spontaneous operations - with working on the concept itself.'

Constructivism has encouraged teachers and curriculum developers to alter their perceptions of children from epistemic subjects who are atheoretical and unknowing to cognisant individuals who have well-developed theories. Formal elicitation of this knowledge as proposed by Driver and Oldham (1985) becomes important for two purposes - to encourage the child to clarify and articulate their own understanding and as a process of formative assessment by the teacher to ascertain the teaching and learning needs of their students. Many of the earlier schemes made good use of group discussion and poster making for such purposes (Nussbaum and Novak 1981) (Cosgrove, Osborne et al. 1984) (CLIS Project 1987) and such processes enable the social construction of meaning. Further work by many researchers in the field has led to the production of a wide range of structured techniques that require the active participation of the student and one recent book (Baird and Northfield 1992) gives details of more than 80 such techniques. Notable amongst these structured strategies are predict-observe-explain sequences (White 1988), further elaborated in White and Gunstone (1992); discussion of instances of physical phenomena (White and Gunstone 1992); word association (Shavelson 1974); active reading techniques commonly called DARTS (directed activities related to text) (Davies and Greene 1984) and concept mapping (Novak and Gowin 1984). So far there is only limited research evidence for their value - for instance in a recent meta-analysis of 18 studies of concept mapping that met strict criteria of well-defined experimental models with controls, Horton (1992) found 16 of the studies produced positive learning gains for the experimental groups. For the sake of establishing their case, more empirical studies of this nature are essential to justify constructivist approaches to teaching and learning.

White (1988) has probably made the most effective approach to derive a theoretical base for a constructivist pedagogy and psychology relevant to science education. His approach is essentially that of the schematists who see knowledge and its organisation as a hierarchy of schemas induced from experience. From this perspective, highly content specific schema are overlain by progressively more abstract and general one. In his analysis of the acquisition of knowledge and understanding, he argues that there are seven types of memory elements: strings which are learned by rote; propositions which are the description of concepts and statements of their relations; images which are retained mental pictures; episodes which are records of our experience; intellectual skills which are a modified subset of the intellectual skills proposed by Gagné (1968); motor skills and cognitive strategies which he conceives of as a set of identifiable and learnable skills, each of which can be applied to a specific task. Thus unlike propositions and intellectual skills, cognitive strategies are not subject specific but a powerful set of general purpose procedures which include the ability to analyse, reflect and generalise. White acknowledges that these strategies are difficult to elaborate and study but that our expectations should be limited as only a small amount of research has been undertaken. He sensibly concludes that a perspective that argues for the importance of cognitive strategies requires schools to turn from sifting knowledge and attend more to its production. In a world, where didactism is still the essential model of teaching and learning, the case for such an argument is incontrovertible.

What is omitted from White's and the other constructivist accounts of learning is an attempt to relate specific strategies to a general theory of learning. For instance, the term 'metacognition' is used to describe the thinking generated by active learning. Yet the lack of any theory that adequately describes such activity inevitably leads to more unanswered questions. Are all pupils capable of metacognitive activity or just some? Is there a critical age below which children can not be metacognitive? Is all such activity beneficial? To the latter question applied commonsense answers 'yes', yet such a response exposes the weakness of the psychology of constructivist pedagogy. Is there anything more to it than the notion that the pupil should be active - a thinking metacognitive subject.

At this juncture, the question of content inevitably reemerges, for the question that needs to be asked is ‘meta-cognitive about what? To the teacher and the curriculum developer such decisions are the bread and butter of their daily lives as they attempt to order content to form a coherent introduction to science and select material which stimulates but is not overdemanding. On this issue, constructivist accounts of science education have nothing to say other than the familiar Ausubelian refrain.

STYLES OF LEARNING

Finally, there is another critique of such a single-minded approach to teaching and learning which needs to be considered. Essentially this is that students differ in their preferred learning styles and strategies and, just as an over reliance on a didactic style can be unappealing to some students, so can an over-reliance on the techniques of a constructivist pedagogy which place an emphasis on co-operative, discussion-based activities for the production of knowledge. Such an approach to learning is preferred by some, but not all students, and likewise, is effective for some but not all.

The literature on learning styles is extensive. Brophy and Good (1974) explored the effects of diverse cognitive styles and personality characteristics whilst Good and Power (1976) examined the effect of affective characteristics e.g attitudes, interest and motivation. However, some of the most interesting work has been undertaken by Pask (1976) and Entwistle (1981). Pask identified two main types of learning strategy used by different individuals: ‘the serialist’ who deployed a step-by-step strategy which examined one hypothesis and then the next in a simple linear progression. In contrast, the ‘holist’ took a more global approach to problem solving, considering multiple-hypotheses simultaneously and used a more individualistic approach to learning. Pask found that both groups of students were capable of reaching the *same* level of understanding but that their ways of attaining that understanding were *very different*. Holists prefer to start by forming an overall picture of what is being learnt whilst serialist attempt to integrate separate topics in a piecemeal form. Hence whilst the holist is concerned with comprehension learning, constructing descriptions of ‘what is known’, the serialist takes an operational approach attempting to master procedural details.

One of the most important experiments conducted by Pask, which those who wholeheartedly advocate a constructivist pedagogy should note, was to match and mismatch sets of learning materials with student's learning styles. The students in the matched conditions were able to answer most of the questions about what they had learned, whereas the mismatched students generally fell below half marks.

Entwhistle's work explored the personality factors that correlated with academic success in undergraduates. He identified three distinct personality types whose approaches to learning were all significantly different. The first group were motivated students who were emotionally stable and were spurred by competition to demonstrations of intellectual mastery. The second group were the antithesis in that they were unrealistically pessimistic about their ability and haunted by the fear of failure. Driven by anxiety, these students had unconventional, though effective, approaches to studying. The final group were predominantly arts-based students and combined high verbal aptitude with good study methods and long hours of study.

The important conclusion to be drawn from this research is that students vary in their motivation and preferred learning styles and that a teaching scheme based on a single perspective will only meet the needs of a subset of any group of students. Within science education itself, there are a number of studies which support such an interpretation.

Kempa and Martin-Diaz (1990a) (1990b) in a study of 390 Spanish 15 year olds identified four types of motivational patterns in students who are motivated out of a desire to a) achieve, b) to satisfy their curiosity, c) to fulfil or discharge a duty and d) to affiliate and interact with other people. These he calls respectively 'the achievers', 'the curious', 'the conscientious' and 'the social'. Using an 80 item Likert-type preference inventory, he then examined the relationships that existed between these motivational patterns and different instructional procedures and features. The main findings are summarised in Table 1.

A constructivist pedagogy and its metacognitive activities rely heavily on practical activities (non-experimental) undertaken in groups. An examination of the table shows that such activities appeal to the social and partially to the conscientious and achievers but not to all. Further evidence that this is so can be found in the report of the PEEL project (Baird and Northfield 1992) where a pupil comments:

> "It's about us learning about, and comprehending the work that teachers set....help students learn better by revising the day's work, and writing down in your diary what you have done....I didn't like doing it - I stopped about the second week we did it - it wasn't interesting"

That not all pupils find such an approach to their liking is important as this implies that *there is no one* strategy that will achieve success with all pupils. Kempa and Martin-Diaz argue that the only practicable solution to this problem is for teachers 'to use *as wide a range* [1] of instructional procedures as possible, instead of limiting themselves to one or two.' Yet the danger in constructivist pedagogy is an assumption that it offers an improved learning strategy for all pupils. Its major strength lies in offering an alternative - challenging teachers wedded to a didactic model of transmission by offering variety and diversity.

[1] Emphasis added

Instructional Procedure	Motivational Trait			
	Achievers	**Curious**	**Conscien-tious**	**Social**
Knowledge Acquisition Mode Didactic Teaching	-	-	+	-
Use of Books		+ +	- -	
Discovery Learning	+	++		(+)
Working Arrangements Individual Work				- -
Group activity			(+)	+ +
Practical Work Doing Practical Work		+ +		(+)
Experimental work with instructions		– –	+ +	
Organisation of Teaching Opportunity to pursue one's own enquiry.	+	+		++
Evaluation Teacher assessment			++	
General dislike of being tested				++
Risk-taking		+		

Table 1: Summary of relationships between students' motivational traits and preferences for instructional procedure. (Strong preference are indicated by '++'; '--' denotes the opposite. Moderate preference trends are indicated by '+'; '-' denoting moderate dislike. (+) indicates a moderate preference trend due to an indirect, rather than a direct relationship between preference and motivational trait.)

Further evidence for this view that varied approaches are needed to meet differing individual needs is to be found in the work of Muthukrishna, Carnine et al. (1993). They point to the fact that in a number of studies that address ‘alternative frameworks’ directly, the success rate, which ranges from 28% to 69% of children changing their ideas, is limited and argue that their research, using an approach based on explicit instruction with a laser videodisc, which eliminated over 90% of common alternative frameworks shows that the ‘common hypothesis that meaningful learning can not result from explicit instruction may possibly be an overstatement’.

Thus the evidence from research on learning styles argues that there is *no single, effective method* for teaching and learning as students differ in their preferences. From a philosophical perspective and an examination of the aims of teaching science, Claxton (1993) argues convincingly that a single-minded emphasis on conceptual development in science is inappropriate for all children. Instead science education should be ‘developing a wide repertoire of teaching methods that are custom-built for different aims and different clientele.’ Consequently the only tenable position to hold in science education is one which sees it as an organic process where the epistemic biography of each individual is unique and also, uniquely determined.

CONCLUSIONS

No doubt there will be many who will dispute the many points made in this critique. Some will find the notion of a realist epistemology per se difficult to accept, even a referential one. For others its clear relationship to the structuralism of genetic epistemology will engender doubt in many minds. However the essential point is that there are essentially three sources of human learning which are a) daily experiences of the world, b) specialised experiences provided by institutions such as schools and c) culturally transmitted knowledge and information. Constructivist research has been seminal in exploring the learning outcomes resulting from the first category and begun to explore the nature of the experiences that would enable the student to reinterpret their experience from the standard scientific world view. However, it has ignored the important role of the third category and in doing so fails to acknowledge sufficiently the critical role played by theoretical constructs in reinterpreting experience. From whence are students to gain such understanding? The unfortunate tendency within much constructivist writing to emphasise sensation and experience, coupled with a relativistic view of knowledge, gives the impression that it will emerge magically from a process based on a form of Baconian empiricism where children make sense of their experiences. The argument made here is that this flawed pedagogy is an inevitable consequence of a flawed epistemology.

Thus we read in the UK Association for Science Education Teacher's Handbook (Ramsden and Harrison 1993) that teachers must start by 'finding what the learner' knowledge and understanding are' and give them 'opportunities to actively test and refine...their understanding'. Yet in the long list of learning activities e.g raising questions, making observations, using practical skills, small group discussion etc, not one mention is made of an activity which would enable students to be provided with a scientific theory. Yet as Hodson (1990) so elegantly argues-

> 'the simple matter is that theoretically uninformed observations *do not*[2] and *cannot* lead to the acquisition of new concepts. The claims for theory-free experimentation are nonsensical on both epistemological and psychological grounds.....In short, theoretical considerations must *precede* experimental enquiry.'

However, since the reality of the classroom experiences throughout the world is predominantly didactic (Lewin 1993), many would argue that constructivist pedagogic practices are a valid attempt to redress and extend the balance and mixture of learning experiences for students. The evidence for such an argument is irrefutable and there are sound psychological arguments for attempting to build on the learner's existing knowledge (Ausubel 1968). However, the uncritical adoption of constructivism has led to the evolution of arguments which attempt to deny the value of some didactic processes to some students, an epistemology which has no statement to make about developmental sequences or curriculum content and a pedagogy which lacks an adequate theoretical underpinning. Thus at times, it is hard to escape Suchting's (1992) conclusion that for some 'certain words and combinations of words are repeated like *mantras*[3] producing a feeling of enlightenment without the tiresome business of intellectual effort'. However, an improved science education will only come through the critical review of arguments and research evidence and by the adoption of a pedagogy which places a value on variety and diversity and not on a singular ideology.

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[2] Hodson's emphasis

[3] Suchting's emphasis

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