Abstract - A special session at the 2007 Frontiers in Education Conference was devoted to the question “Can philosophy of engineering education improve the practice of engineering?” In supporting a positive answer to this question it is argued that philosophy can contribute to better educational decision making, as for example in the screening of aims and of objectives. If that is the case then every engineering educator should have a defensible philosophy of education.

The intention of this paper is to argue the case for screening using the example of the constructivist-realistic debate that has pre-occupied teaching in science during the last twenty-five years. It is argued that at the epistemological level the stance taken by the educator has implications for the teaching of ethics. At the pedagogical level the differences are minimal although constructivism has caused consideration of “negotiated curricular” that has consequences for the design of project work. Realists have pointed out that in certain circumstances rote learning is likely to be necessary. Both theories support the contention that too much is covered in the curriculum. Brief mention is made of constructive alternativism. It is concluded that the learning procedures used will depend on the objectives to be obtained. It is argued that this discussion supports the contention that the screening of aims using the philosophy of education is a valuable exercise.

Index terms –Constructivism, constructive alternativism, Curriculum-overloading of. Philosophy, Realism, Screening - of aims and objectives

INTRODUCTION

(1) Screening

The term “screening” is due to E. J. Furst one of the authors of The Taxonomy of Educational Objectives. He argued that it is very easy to generate long lists of aims and objectives that come to be just as self-defeating as long lists of content. Unless objectives or outcomes are strictly limited their number is likely to overload courses as their teachers struggle to obtain them. Applied to the goals of an institution Furst pointed out that “some goals will be more important than others, and some will be inconsistent in that they call for contradictory patterns of behaviour.” [1] These lists have to be “screened” for consistency. In the first place they should be screened by the educational and social philosophy to which the institution (department, school) is committed.

Secondly they have to be screened by a psychology of learning [2]. Thus, teachers need to have defensible philosophies, and theories of learning. The paper examines the relevance of two contrasting epistemologies for the curriculum and pedagogy.

(2) Constructivism

The Penguin Dictionary of Philosophy defines constructivism as “the theory that knowledge is not something we acquire but something we produce; that the objects in an area of inquiry are not there to be discovered, but are invented or constructed.” [3]. Unfortunately it is not quite as simple as the definition would lead us to believe. Distinctions have to be made between psychological, social and sociological determinism.

This theory of knowledge (epistemology) came to prominence in science education in the early nineteen-eighties as part of a renewal in school science studies. It challenged the premises of realism (associated with traditional methods of teaching), and asserted that instruction in science should adopt different methods of teaching derived from this new epistemology. In engineering the need to reappraise how concepts were taught was highlighted by Clements who in Engineering Education and the American Journal of Physics had shown how undergraduates often had misconceptions of fundamental concepts and principles in mechanics and, moreover, despite remedial action they continued to persist [4]. Some of the research that supported this new epistemology had shown that children acquired such misconceptions at a very young age. Driver’s work became a seminal text for those working in the field [5]. Clearly, if that is the case, then engineering educators have a vested interest in the k - 12 curriculum particularly in how and what is taught in science and mathematics, and the epistemological foundations that underlie that teaching.

Constructivism is in the intellectualism tradition of empiricism of which it might be regarded a special case and is part of the long debate between empiricism and realism that can be traced back to Aristotle [6]. Constructivism in science education has its origins in Piagetian psychology (psychological constructivism). Michael Matthews points out that this tradition divides into two paths. One follows the subjectivist and personal approach of Piaget, the other follows the social constructivism of Vygotsky which stresses
the importance of language and language communities for the cognitive constrictions that individuals make [7].

There is also sociological constructivism that has influenced much thinking in educational circles. It is based on the view that reality is a social construct, and our construction of that reality depends on prior experience. Durkheim argued that "thought has its aim not the reproduction of a given reality but the construction of a future reality." [8] Sociological constructivism is not concerned with what individuals believe but with how the social structure (environment) of those individuals determines what they believe, and it is clear from Berger and Luckman that science is not an exception [9].

DEVELOPMENTS IN EDUCATION

In the latter part of the twentieth century constructivism as a theory of knowledge became very popular among school educators, and there was a flurry of literature on the topic. One of the leading educational societies in America produced a book called Constructivist Classrooms aimed at popularising constructivism in all the subjects of the curriculum [10]. Other texts that covered the spectrum of subjects were also published [11]. There are many variants of constructivism, Matthews counted fifteen [12].

While some research workers across the educational spectrum begin their reports with statements to the effect "that this study is undertaken from a constructivist perspective" it is not always clear what that perspective is. In some cases, it may be that teachers are simply telling us that they teach according to the pedagogical premises of constructivism without much thought being given to the epistemology itself. In engineering the continuing debate between anti-realists and realists is relevant to the science, design and ethics areas of the curriculum.

PIAGET AND CONSTRUCTIVISM

The idea that children’s cognitive development takes place in fixed stages is probably the best known aspect of Piaget’s work [13]. From time to time there have been concerns that college students of engineering and science had not yet reached to final stage of abstract thinking at entry to college [14]. However this is of no concern here rather it is with how the mental structures of the mind become organised and develop.

Piaget who describes himself as a ‘genetic epistemologist’ had in pursuit of a doctorate in zoology observed that mullusks and other organisms continually adapt to their environment. Human beings, he thought, were no different and part of the process of adaptation was their intellectual activity. The organizing mental structures of the mind develop in stages that are invariant. That is, a person has to go through each of the stages. The process is sequential.

The basic framework of thought is the schema. Beginning with a few elementary schema (frames of reference) the child progresses through the stages, reorganizing old schema and acquiring new and more complex schema. There are three structures that help the child assimilate to changes in the environment when they require a change in existing structures. These are (1) Assimilation -- the ability to incorporate new ideas and experiences. (2) Accommodation -- the ability to change one’s schema in order to introduce new ideas and experiences thereby obtaining congruence between external reality and the child’s mental structures. (3) Equilibration: -- the adjustive process required for assimilation and accommodation -- restoring equilibrium between thought and experience. As the child interacts with the world so it constructs its own knowledge base. The child is an active agent in trying to understand the world [15].

THE PREMISES OF PSYCHOLOGICAL CONSTRUCTIVISM

The premises on which psychological constructivism is based are thus:

1. “Knowledge is actively constructed by the cognizing subject, not passively received from the environment.”
2. “Coming to know is an adaptive process that organizes one’s experiential world: it does not discover an independent pre-existing world outside of the mind of the knower.” [16]

Constructivists hold that we make the facts and they do not exist independently of us whereas the realist position is that facts exists independently of us. Realists maintain that a statement is true if it corresponds to a state of affairs independent of the statement. It is a correspondence theory of truth. In contrast constructivists maintain a coherence theory of truth. That is, a statement is true if it fits with other true statements. The implications of these contrasting theories for teaching and learning in ethics should be readily apparent. [17].

Driver, a leading constructivist, wrote- “an implication of this view of knowledge as constructed that has to be taken seriously by educators is that to know something does not involve a correspondence between our conceptual schemes and what they represent ‘out there;’ we have no direct access to the real world. The emphasis on learning is not on correspondence with external reality, but the construction by learners of schemes that are coherent and useful to them”. She went on to quote von Glaserfeld thus: [This view of knowledge] “has serious consequences for our conceptualization of teaching and learning [...]it will shift the student’s correct replication of what the teacher does, to the student’s successful organization of his or her own experience.”[18]. There are, therefore, major differences between the two theories both in terms of what they regard truth to be and what knowledge is.
Driver and Oldham suggested that constructivist teaching takes place in steps [19]. These are: (1) Elicitation (in which the students find out where they are situated). (2) The restructuring of ideas in which students clarify meanings together. (3) The construction of new ideas in the light of these discussions. (4) The evaluation of these ideas by thinking them through, or by experiment. (5) The application of these ideas in different situations; and review them i.e. reflect on them. They liken this last stage to learning how to learn or meta-cognition as understanding how we learn is now called.

A summary of constructivism but applied to engineering education was made by Miller and Olds who described how a constructivist view had influenced some of their teaching at the Colorado School of Mines. “As presently taught, the Course [a unit operation laboratory in chemical engineering] relies heavily on a constructivist approach- that is, the cognitive theory suggesting that learners construct their own internal interpretation of objective knowledge based, in part on formal instruction, but also influenced by social and contextual aspects of the learning environment and previous life experiences. This view suggests that students “make their own meaning” of what they are learning by relying on mental models of the world, models that may be correct or may contain strongly held misconceptions. Rather than acting as acknowledged authorities transmitting objective knowledge to passive students, laboratory faculty use coaching and Socratic questioning techniques to help students understand complex technical phenomena by constructing mental models which perceive reality as perceived by acknowledged experts while minimising models containing significant misconceptions. Use of constructivist pedagogics creates an ideal context for assessing students’ abilities to complete authentic engineering tasks rather than relying on artificial examinations which emphasize non-contextual recall of facts and closed-ended problem solving”[20].

While Miller and Olds position is clear about what to do with students when they have a misperception this may not always be the case, particularly at school level. Michael Matthews raised the issue of what does the teacher do when he or she finds there is a misconception? Is it accepted as an alternative framework? Does the teacher try to change the student’s understanding? He pointed out that while Driver and Oldham claimed that the curriculum is a programme of activities from which knowledge and skills can be derived, it is still necessary to say what that knowledge and skills are [21]. This is essential for students who wish to pursue careers in engineering and science. Hence the importance of engineering educators helping those who wish to introduce engineering studies in the k – 12 curriculum.

Matthews also pointed out that the constructivist approach to teaching is not unique. Many teachers actively engage students in learning and do not require a particular epistemology to support their endeavours; and some would follow the steps or make similar steps to those described by Driver and Oldham above.

Within this context a particular issue of interest to engineering educators relates to the teaching of design. Designs are necessarily “constructed.” Does constructivism mean that students need not be taught how to design! This was a major issue in the curriculum for Engineering Science A level examination in England. It was held that students’ could pursue design and complete practical projects without any formal instruction in engineering design. If design is a social process as Bucciarelli argues, then surely students would have to acquire some understanding of that process.

As presented these theories argue that knowledge is not absolute but relative although there are constructivists who claim not to be relativists [22]. In science education the position of von Glaserfeld, a leading constructivist, is that of a relativist.

CURRICULUM NEGOTIATION

One of the most interesting ideas to arise from this theory is that of curriculum negotiation - for given, that the reality we have is a result of our environment then, in these circumstances, the students with their teachers should design a curriculum that is real to them. In this sense the curriculum should be negotiable and worked out to meet the individual needs of students. Those who espouse this view believe that the review of the curriculum that this perspective recommends should be thoroughly critical.

The degree of negotiation and its characteristics varies among teachers, curriculum and controlling organizations. However they all start from the premise that negotiation should give the students ownership of their learning for: “people tend to strive hardest for the things they wish to own, or to keep and enhance things they already own.” Cook contended that one of the reasons why the transmission model of instruction is maintained is that teachers believe that in practice students are not capable of the ownership principle [23]. This view may be turned into a question that can be put to engineering educators thus: Are engineering students capable of ownership of the curriculum? Is there room for negotiation in the engineering curriculum? Traditionally when a teacher selects a topic it is agreed that the students should be made aware of why they have to study this topic. However with negotiation the students produce a design that will enable them to tackle the problem that requires answers to these questions: “What do we know already? What do we want to know and need to find out? How will we go about finding out? How will we know, and show, what we’ve found out when we’ve finished?” [24].

Cook recognised that this is a common sense progression, and that it is similar to the scientific method as commonly characterised. The questions in Wales and Stager’s guided...
design method are similar [25]. In this way, skills in engagement, exploration, and reflection are developed.

**Criticisms of Piaget and Constructivism**

Finally, it is of some importance to draw attention to a criticism of constructivism in science education by Philip Matthews who provides a realist perspective. He challenged two of the basic premises of Piagetian theory. First, that there is a general cognitive facility that governs all aspects of human learning, and second that concept development is the result of progressive construction, initially out of the sensori-motor experience of the child. Matthews argued that research in the area of linguistics and cognitive science demonstrated that human cognition is a function of domain specific mechanisms in the brain and perceptual systems. Matthews suggested that one reason why children find science difficult to understand is because these innate modules filter the information from our senses and interpret it automatically. This is done in a mechanism that is not available to consciousness “in a way that one can describe as naïve physics and biology”[26]. If this is the case, then a lot of naïve science may not be learned i.e. constructed. He went on to argue that it may not be possible to change these modules by learning, or to integrate them into a domain general-aspect of cognitive functioning as suggested by Piaget. Moreover, many aspects of naïve physics and biology are likely to persist. Matthews wrote that if these naïve understandings are, “intuitive features of the world, then individuals will rarely feel them to be problematic and in need of explanation.” Solomon suggests that to change one’s naïve understandings, a high level of motivation would be required [27].

In a later paper Matthews used Anderson’s theory of intelligence to describe the processing involved. In Anderson’s theory intelligence consists of a basic processor. It is supplemented by a number of specific processors that act on particular types of information e.g., verbal information, visuo-spatial information. Limits are set on the specific processors by the action of the basic processor. Variations in the speed and efficiency of the basic processor cause variations in g with consequences for the actions of the specific processors. Matthews adapted the theory in this way. Two routes are followed in which knowledge is created. One of these routes responds to knowledge acquired without conscious thought. He included modules for maths, science, language, and space. The other responds to knowledge acquired from conscious thought. He called these routes 1 and 2 respectively. He described the process of conceptual change thus:

“In many cases, conceptual change can be viewed as a process by which additional cognitive structures are built that, once firmly established can over-ride rather than merge with, the functioning of competing innate structures. In such cases, learners should acquire facility in the use of appropriate language, and establish the fundamentals of key concepts by rote learning. The expectation would be that once fundamental aspects of knowledge are established in the learner, there is a basis for by-passing competing innate structures.”[28]

To illustrate his point, he used as an example, the fact that magnetic action violates one of the principles of naïve physics that says there is no action at a distance. Using his model of Anderson’s theory of intelligence he said:

“For an untutored person there is no path for explaining magnetic action through route 1, thus from the earliest ages humans recognise such events as discrepant. For an individual left without the guidance of someone acquainted with physics or magnets, a coherent explanation of magnetic action is hard to find. However the fundamental difficulty facing the learner is not an understanding of magnets per se. Rather it is to accept that action at a distance occurs, and that science accounts for such events by invoking the notion of invisible forces. There is reason to doubt that learners will ‘construct’ this knowledge for themselves, or that such knowledge is best acquired through non-directive teaching techniques. In particular, if as suggested earlier, established cognitive structures can act as pseudo-modules for filtering information, it is desirable to promote the establishment of a routinised structure for forces acting at a distance. This may be achieved by using highly directive teaching techniques, including rote learning to help the learner adopt key concepts and associated linguistic terms [ ].”[29]

This is the exact opposite of that proposed by the constructivists. Moreover, it is in keeping with the general idea of a received curriculum. Support for this view can be obtained from Schwartz and Bransford who found that in certain circumstances teaching by telling can work well [30]. Neither, they or Matthews take the view that this spells the end of constructivism. But Matthews and Solomon argue that future research should be more critical of constructivist theorising.

**Curriculum and Instructional Overloading**

Whether or not a constructivist or realist position is taken it is clear that teachers have to pay considerable attention to the methods of teaching of concepts if misperceptions are to be avoided and understanding achieved. This may mean that curriculum content has to be reduced and greater emphasis placed on the understanding of key concepts. Unusual indirect support for this view comes from Brown [31]. In a discussion of physiological parameters and learning in engineering, he suggested that one of the reasons why there is so often a mismatch between teacher expectations and student performance is that teachers’ may be trying to pump too much information down a band-limited channel in too short a period of time. He recorded that his own lecture notes contained 3000 Bits per minute, whereas humans could only absorb about 12 Bits per minute over periods of
very directive

Such evidence as there is suggests that some teachers are directive in the time available or with the knowledge to hand. Where then does all this leave the curriculum leader in extremis. Many teachers in both groups are considered to be directive because there are some things that cannot be discovered, at least in the time available or with the knowledge to hand. Brown quoted Lemanick thus: “we think of learning and memory as separate functions; in fact they are not. Both are processes by which we acquire and store new data that makes them retrievable later on.”

**CONSTRUCTIVE ALTERNATIVISM**

This discussion of constructivism and realism has been simplified considerably and there have been several omissions. Surprisingly one of them that is seldom referred to in the literature of the philosophy of science education: it is George Kelly’s philosophy of “constructive alternativism” that is the basis of his personality theory [33]. He argued that each one of us create constructs or patterns of meaning, that enable us to understand the world. We use these constructs continually to make predictions about events, hence his model of the “individual as scientist.” Our behaviour is determined by these predictions so if we can understand a person’s constructs we can understand his behaviour. The Repertory Grid Technique was developed by Kelly to determine an individual’s constructs. From the perspective of engineering education it is a powerful research instrument that could be used to reveal student understandings of engineering. It has been used to provide a personality dimension in the task analysis of engineers at work [34]. In his therapeutic work Kelly also used role-playing that has pedagogical implications for the development of intra and interpersonal skills.

**DISCUSSION**

Where then does all this leave the curriculum leader in engineering? The answer to this question, in the absence of definitive conclusions, can only be approached pragmatically. It is clear, however, that there is confusion between epistemology and pedagogy, and it is misleading of the constructivists to attack realists on the ground of pedagogy. Even constructivists have to transmit knowledge because there are some things that cannot be discovered, at least in the time available or with the knowledge to hand. Such evidence as there is suggests that some teachers are very directive in their approach and that others are very non-directive. The majority lie somewhere in between these extremes. Many teachers in both groups are considered to be effective by their students. It is also clear that some of the objectives of education may be better obtained by directive teaching methods while others will be better obtained by non-directive methods. That is, what we do should be determined by the objectives we wish to obtain. This is a point that is well illustrated by Shulman’s study of psychology and mathematics education [35]. An understanding of concepts and principles is required if there is to be an effective transfer of learning, and methods appropriate to acquiring this understanding should be used. In so far as the curriculum is concerned it is clear that it is never completely received. Teachers continually adapt and find alternative ways to teach as well as incorporate new ideas so the curriculum is continually restructured in small steps. Both theories support the view that too much is attempted in the curriculum and that content needs to be reduced.

It is hoped that this discussion has demonstrated the value of philosophy in screening objectives, and that teachers should have a defensible epistemological position. In the case of constructivists and realists it would seem that both sides of the fence have produced useful ideas on which to base pedagogy and curriculum, and especially the loading of the curriculum. But this discussion is not meant to be the last word on the issue.

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**NOTES AND REFERENCES**


[7] ibid

[8] ibid


[12] loc. cit Ref 6


Assuming that such tests are reliable and valid this would have consequences for first year programmes and their teaching a fact that also assumes that Piaget’s developmental theory is correct [a]. Other work suggests that children are capable of abstract thinking, in their own terms (language) from a very young age and that it may be the curriculum that kills off that potential. (See [b] below).

[a] In the UK for example tests have been criticised by Collinge, J. N (1994) Some fundamental questions about scientific thinking. Research in Science and Technological Education 12, (2), 161 – 174.

[15] See Shiner, R (1995) Piaget. P 619 In Audi R (ed) Cambridge Dictionary of Philosophy. Cambridge University Press for a discussion of Piaget’s epistemology. The four elements of the theory are, biological maturation, experience with the physical environment, experience with the social environment and equilibration. “Our epistemic relations are constructed through the progressive organization of increasingly behavioural interactions with physical objects” Equilibration may be said to co-ordinate the influence of the other three factors.


[21] loc. cit ref 6


[24] ibid


[29] ibid