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Science, constructivism and science education

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ABSTRACT

In this paper, constructivism is placed in perspective, through a presentation of its various aspects and concerns, with the aim of providing a general insight into it. The discussion focuses to show that constructivism, at its extreme, is not tenable in science education and that the version of it that is practised by educators in schools is akin to interactive learning. First constructivism's claims on knowledge are presented and their viability discussed in order to provide an introduction to the tenets upon which it is based. The psychological foundations of constructivism are then presented. Constructivism is linked to the various learning theories which inform it. It is shown that these same learning theories also provide the background for interactive learning, which is the notion of constructivism adopted by practising teachers. A discussion on science and its tenets follows, since an understanding of science and science education is useful prior to comparisons with constructivism. Science and science education are distinguished and the extent to which a constructivist philosophy fits each is discussed. The discussion then leads to the pedagogical influences and limitations of constructivism. The paper concludes with a discussion of how constructivism, as practised in the science classroom, has helped to advocate change in the science classroom and the extent to which this is viable.

Present day science education reforms in New Zealand are being attributed to 'constructivism'. It seems to be the theme by which to defend the curriculum reforms as well as create an opposition case to them. Constructivism is just a label which is used by many in the science education community to attempt to bring about change. Constructivism, as practised by educationists, is totally different from that which is advocated by those arguing for constructivism as a view of knowledge, especially knowledge of science. Constructivism appears to mean different things to different people. The debate on constructivism has encouraged many to reconsider their views on know ledge, on science, the student, instructional methods, and evaluation and assessment of learning and teaching. It has also created a need that science education should be developing a wide repertoire of teaching methods that are custom built for different aims and different clientele (Claxton, 1993). Some will argue that this has always been the case.

The practising scientists, so often labelled as 'objectivists', are opposed to constructivism because they do not agree with accepting knowledge constructions of students which are not in line with the ideas of the scientific community or, rather, with the currently accepted principles of science. On the other hand, constructivism has gained favour with many educationists not because they totally believe in its tenets, but because constructivism provides another method for attempting to make science teaching and learning different and hopefully interesting. Many teachers see constructivism, simply, as a highly interactive method of teaching. These teachers do not advocate the views on knowledge which are the foundations of constructivism, they are simply trying another interactive method since the vast literature on 'misconceptions' has proved that students do not, necessarily, learn what they are taught. These teachers are concerned with what they can do to help students obtain insight into science. The large number of students who are put off science are their concern. They want students to know how science works, so that they can understand and help build on it. They are interested in how they can help students develop accurate and robust understanding of the principles of science. They are simply trying to identify the best ways to facilitate learning.

Many constructivists advocate constructivism as the only way that students can effectively learn. When making comparisons, they seem to equate all other methods to didactic forms of teaching. They seem to miss the point that education has to do with the mind and motivation of wanting to learn. At its best, constructivism can only be a means towards motivating and helping the learner. Conceptual understanding, an aim which has always been the focus of educators (constructivist or otherwise), is strongly advocated. If the purpose of education is taken as imparting knowledge, as well as developing thinking skills, then constructivism can be considered as a mode for doing this. Constructivists, in the most extreme case, advocate the viability of any knowledge. They down-grade content and consider the process, only, as an important aspect. No education system can exist without an amount of domain specific content. Process, which constructivism and many educators emphasise, is in actual fact content as well and is commonly classified as procedural knowledge.

In this paper, constructivism is placed in perspective, through a presentation of its various aspects and concerns, with the aim of providing a general insight into it. The discussion focuses to show that constructivism, at its extreme, is not tenable in science education and that the version of it that is practised by educators in schools is akin to interactive learning. First constructivism's claims on knowledge are presented and their viability discussed in order to provide an introduction to the tenets upon which it is based. The psychological foundations of constructivism are then presented. Constructivism is linked to the various learning theories which inform it. It is shown that these same learning theories also provide the background for interactive learning, which is the notion of constructivism adopted by practising teachers. A discussion on science and its tenets follows, since an understanding of science and science education is useful prior to comparisons with constructivism. Science and science education are distinguished and the extent to which a constructivist philosophy fits each is discussed. The discussion then leads to the pedagogical influences and limitations of constructivism. The paper concludes with a discussion of how constructivism, as practised in the science classroom, has helped to advocate change in the science classroom and the extent to which this is viable.

Epistemology

At the heart of constructivism is the notion that knowledge is 'constructed' - meaning it is a personal creation within a social community that accepts the underlying assumptions. There is no right or wrong in any absolute sense. This is where many critiques of constructivism differ. Constructivism is based on the premise that no true reality exists, only individual interpretations of the world, and that these interpretations are shaped by experience and social interactions (Clements and Battista, 1990). The implication of this is that every person has a *reality* which cognitively exists and should be accepted. The cognitive reality does not have to match an independent reality, which can never really be known and is dependent on the current scientific knowledge. So, the only reality we-can know is the reality of our experience. Kilpatrick (1987) describes extreme constructivism, usually termed 'radical constructivism', as an *epistemology* that requires knowing as active and knowledge as subjective. He suggests that constructivist views are governed by the following two principles: 1.

Knowledge is actively constructed by the cognising subject, not passively received from the environment. 2. Coming to know is an adaptive process that organises one's experiential world and does not discover an independent world outside the mind of the knower. He goes on to say that "learning is seen to be a process Whereby the cognising subject through trial and error constructs a viable model of the world". The problem with this is as to how the initial experience or pre-requisite knowledge should be acquired if it has not been experienced (Osborne, 1994). The problem is whether 'viable' encompasses 'valid', or does it simply mean a belief system to suit which can be false in comparison with the principles of science. Supposing that a person believes that the gravitational field does not act above a certain height and decides to walk out from the highest floor of a 30 storey building without any aids? This should highlight the danger of considering every idea viable and not bothering over its validity in a setting.

Radical constructivism requires that efforts to know the world as it truly is are futile. It strongly hints or rather advocates the abandonment of search for objective truth. Constructivists ascribe validity to any viable theory, as long as it is dependent on personal experience. Strike (1987) states that "unless they [constructivists] wish to give expression to a kink of epistemic death wish, they must believe that some ideas are better than others because it is under the circumstances more reasonable to believe them." I wish to argue that all ideas might be viable, but are they valid? In science an idea which is viable is considered a hypothesis and is a starting point for development through research. Through rigorous research (empirical and theoretical), the viability may be changed to validity. In the process the idea might be accepted or rejected and will probably be refined. Here, then, lies the difference, science tries to explain and predict, while constructivism seems to just accept. The acceptance of all ideas as viable without test would be equivalent to practising what the scientists term 'pseudo science'. Scientists individually or collectively create new ideas and, as a group, critically assess these ideas to decide on their incorporation into the structure of science (Gardner, 1975).

The objectivist view acknowledges that people have a variety of-experiences and knowledge is seen as a product of a social structure. Objectivists attribute the experiences to the lack of identical understandings between individuals. Prior experience and intuitive interpretation are seen as leading to partial and biased understandings (Duffy and Jonassen, 1991), the goal is to strive for correct understanding in line with the currently accepted principles. Constructivism agrees with objectivism only in that there is a real world of experience and that meaning is imposed on the world by us rather than existing, independently, in the world. Constructivists advocate that there are many ways to structure the world and many meaningful perspectives for any event or concept. Constructivism denies the existence of objective knowledge and the possibility of communicating it by means of language (Suchting, 1992). In the constructivists' view, knowledge consists of subjective conceptual constructs. Objectivism holds that the world is completely and correctly structured in terms of entities, properties, and relations (Duffy and Jonassen, 1991). Experience holds no role in the structuring of the world, apart from providing helpful insight in structure creation. The goal of understanding, then, is in coming to know the entities, attributes, and relations that exist and form the world of science.

Within constructivism the task of knowing is compounded by the fact that meaning cannot be transmitted but must be individually constructed. Knowledge is not a commodity which can be communicated (von Glasersfeld, 1990). Knowledge is not something people possess in their heads, but rather something people do together (Gergen, 1994). Meaning is not conveyed, but evoked and is theory dependent. Know ledge is actually constituted by the language used to express it. Words are 'theory laden' and must be chosen carefully for effective communication. In other words we cannot transmit meaning, but must construct it ourselves (Wheatley, 1991).

Individual knowledge can be seen as arising from two sources (Pines and West, 1983). There is the knowledge acquired through interaction with the environment - termed intuitive, 'gut' or naive knowledge. This can be termed the belief system of the individual. The other sources of knowledge are formal instruction, discipline knowledge, school knowledge and so on. It is an interpretation of the world in accordance with the currently held principles of science. Radical constructivists are only interested in the former knowledge and do not consider the latter as important. Objectivists consider it important to integrate knowledge from these two sources through the social negotiation of meaning and understanding (Vygotsky, 1978). Collaboration amongst scientists is a means of testing ideas and evaluating alternative perspectives and arriving at an accepted choice. Recognising the potential validity of alternatives and being aware of the assumptions underlying the chosen and alternative world views is important (Cunningham, 1991). Extreme constructivism does not consider alternatives as important since only individual constructions are viable.

Knowledge can also be considered to be a continuum, from that which has undergone extensive social negotiation of meaning, to that, in which, meaning is still very much being negotiated (Cole, 1992). In the former case, it might most efficiently and effectively be presented more directly to the learner or through the use of more traditional instructional design. In this case, the knowledge would also be considered as that which the person should be striving towards. Other individual constructs should not be considered valid but may be brought into a discussion. There is theoretical support for teaching some material through direct instruction rather than hoping that students will discover it. The other end of the continuum would represent knowledge such as problem identification, problem solving and learning to learn (Perkins, 1991). At this end of the continuum, it is important to consider the viability of individual ideas. Even then, mere acceptance of individual ideas as viable is not sufficient for knowledge development and social acceptance. These should be taken into account and through testing and assessing, the meaning determined for social acceptance.

To quite an extent people have common concepts. The explanation for this could be that concepts are not individually constructed, but are reached together through some form of sharing (Strike, 1983). When students listen, understand and remember they are cognitively engaged, this has to be so since all three are cognitive activities. Constructivists label verbal transmission or any other form of passing on of information as passive learning and, in many cases, equate it to no learning taking place.

Psychology

The learner is seen as an active participant in the construction of his/her own knowledge in trying to make sense of the world. The sense made of any event is seen to be dependent, not only on the situation itself, but also on the individual's purpose and active construction of meaning (Driver and Oldham, 1986 and Gunstone, 1991). It is implied that knowledge is found or made according to a set of structural rules that are imposed on the flow of experience (Bruner, 1985). Knowledge is assumed to originate through the formation and/or evolution of mental constructs as the learner partakes in an activity. Wheatley (1991) states that constructivists believe that knowledge is intimately related to the action and experience of a learner in a contextual setting and is dependent on the learner. In such a learning environment, conceptual change is brought about by the student. Driver and Oldham (1986) suggest the five phases of *orientation, elicitation, restructuring, application* and *review* for learning to effect conceptual change. In the *orientation* phase, a program of activities, ideally initiated by the student, is chosen to uncover the conceptions of students and to build upon them. This gives students an opportunity to develop a sense of purpose and motivation for learning. During the *elicitation* phase, pupils make their ideas explicit. Claxton (1985) calls these ideas mini-theories, built out of experience over a long period of time in trying to make sense of the world. Elicitation may be done by having learners represent their constructions in written form or verbally. Representation in written form may be descriptions, pictures and diagrams, tabulations, headings and sub-headings for classification and concept maps showing the inter-connections and relations. In the *restructuring* phase clarification, exchange, construction and evaluation of alternative ideas is done through exposure to conflict situations. This is based on the premise that learning occurs when existing ideas are shown to be inadequate. White and Frederikson (1990) call this model transformation whereby increasingly more adequate models are formed in response to the demands of more complex problems or situations experienced by the student. The *application* phase gives students the opportunity to apply their developed ideas for consolidation and development. This allows the student further experiences which may be translated into concepts which then act as guidelines for new experiences. In the final *review* phase, students are invited to reflect on how their ideas have changed. This enables the newly acquired concepts to fall into place and to be integrated in relation to other previous knowledge. To encourage such conceptual change, Osborne and Wittrock (1985) suggest: (a) pupils be provided with opportunities to consider, contemplate and expand their views of the world and to develop their language whereby they can describe and explain their views; (b) encouraging, challenging and/or reflecting back to pupils the views they expound, to provide better understanding of their views and those of others and the basis for the views.

Osborne and Wittrock (1985) propose the generative learning model as central to the constructivist tradition. The other learning theories which feed into constructivism are the Phenomenological approach, Piaget's theory on substitution and integration, Ausubel's meaningful learning, Kelly's theory of personal constructs, the information processing theory, and the theory of schema acquisition (Singh, 1992, 1993). Each of these are briefly discussed to provide insight into the cognitive base of constructivism.

The fundamental premise of generative learning is that people generate perceptions and meanings that are consistent with their prior learning. Osborne and Wittrock (1985) stress the importance of knowledge which learners bring to the learning situation and recognise the active construction of meaning while individuals interact with the environment. The need to generate links and to actively construct, test out and subsume meaning requires individuals to accept a major responsibility for their own learning.

The Phenomenological Approach (Coombs and Snygg, 1959) sees a person as an organism, forever seeking greater personal adequacy. The search for adequacy or self actualisation is the driving force motivating all behaviour. Leaming is a function of need which is perceived as maintaining and enhancing the phenomenal self. It comes into play since learning is seen as student initiated. Students will learn and retain those concepts that become more self-related than those that are less self-related. The goals and values of an individual will affect his/her perceptions and provide a measure for judging self actions and those of others.

Piaget may be considered a constructivist in the sense that he was interested in how children constructed ideas while learning. He saw intelligence as the way in which the mind organises reality, stating "the essential functions of intelligence consists in inventing and understanding, in other words, in building structures by structuring reality". (Piaget, 1971 cited in Wilson, 1981). He saw mental growth as *substitution* where more mature ideas replace less mature ideas and *integration* where less mature ideas are combined and refined to arrive at more complex and abstract conceptions.

For Ausubel (1968) the single most important factor influencing learning is what the learner already knows. Constructivists stress the importance of ascertaining this prior knowledge and teaching accordingly by building on it. In Ausubel's meaningful learning, the principal content of what is to be learned is not given, but must be discovered by the learner before it can be meaningfully incorporated into his/her cognitive structure. The learner must rearrange information, integrate it with existing cognitive structure and reorganise or transform the integrated combination in such a way as to generate a desired end product. Upon completion of discovery learning, the discovered content is made meaningful through the process of internalisation.

Kelly's (1955) theory of personal constructs states that a person's past experience with similar and dissimilar elements, in comparison with the current elements under consideration, helps him/her to perceive similarities and differences in the formation of constructs. This is in line with the constructivist belief that past experiences are used to interpret current experiences. Learning is seen as a dynamic process, whereby students learn better through participation. A person uses constructs to summarise, to give meaning to, and to anticipate events.

The information processing model (Gagne, 1977) describes mental events in terms of transformations of information from input (stimulus) to output (response). It proposes that learning takes place through the usage of receptors and effectors eg. eyes, arms, hands, voice apparatus, muscles and glands. Participation increases the receptors and effectors in use during a learning session. Retrieval of information happens through response generation using cues provided externally or by the learner.

Schema acquisition is used in constructing, generating links and subsuming concepts. Rumelhart and Norman (1981) suggest that learning through schema acquisition can happen through:

- accretion which is the coding of new information in terms of existing schemata ie. adding new information or parts to existing schemata; and
- tuning or schema evolution to bring about the slow creation or evolution of new schemata.

They describe the following learning sequence:

- In encountering a new situation, a person seeks to interpret it in terms of existing schema.
- If the situation is successfully understood no new schema is created.
- When no existing schema offers a satisfactory account, one or more schema are restructured or tuned, or a totally new one is created.

All the learning theories and models upon which constructivism is based propose cognitive change through knowledge compilation from smaller to larger functional units which may be easily modified and adapted. Transmission learning or learning by being told also attempts to promote conceptual change. In terms of the learning theories, transmission and constructivism are not that different. An interactive learning environment of student-student, teacher-student and machine-student discussions is also based on all these learning theories. Interactive discussions do not propagate individual reality and this creates great opposition to constructivism. Although based to an extent on Piaget's developmental theory, constructivism ignores the age perspective. It assumes that anyone, irrespective of age, can learn anything. Interactive discussion does not make this assumption, it in fact assumes the contrary. It acknowledges the prerequisite knowledge required for further acquisition to be possible. It acknowledges that learners' interests, thinking processes and their constructions of meaning are inexorably limited by their level of cognitive maturity, experiences, use of language, and their knowledge and appreciation of the experiences and ideas of others. Osborne and Frey berg (1985) suggest similar limitations when discussing the generative learning model, showing that constructivism as practised in the classroom is similar to interactive discussion.

Interactions are well suited for cognitive feedback. Through interactive question-answer sessions a profile of the student's understanding and deep-seated apprehensions or misapprehensions may be constructed and corrective measures implemented (Webb, 1988). Examples and counter examples can easily be introduced to challenge, correct and clarify student concepts, and explanations can be provided through the sharing of various viewpoints. Discussion helps refine ideas successively through interaction. Furthermore, new information can be appropriately introduced and reinforced as the opportunity arises. Interaction can be exploratory, corrective, or reflexive, depending on the focus by the parties involved in the interaction (Singh, 1993).

An example of an interactive learning environment is problem solving. In such an environment, the student is provided with the opportunity and assistance to apply the correct principles.

Appropriate examples and problems need to be selected to ensure directional movement towards complexity in conceptual attainment. Problems can be graded from the 'cook book' type of simple textbook problems, requiring the application of an elementary concept, to general design-type questions requiring a complex linkage of inter-related concepts. As more problems are solved on the application of a concept, the concept is incrementally refined (Michalski, 1986). A problem-solving learning environment assumes that the chances of learning are enhanced in applied or contextual settings. What is, in fact, generated by a learning experience will vary tremendously from one experience to another. So, is it not better to use non-constructive methods which can provide a plethora of experiences through problem solving?

Constructivism assumes that learning will bring about the combination of experiences and coerce them into one unit. It is a fallacy to think that, when the traditional methods are used, the learner is not constructing. Compartmentalisation using surface features is a problem which is exacerbated by constructivism due to learning though context. Students are required to make their own connections, unlike in other methods where they can be shown the connections. We know that experts compartmentalise using broad principles. Students are hardly capable of understanding the concepts and adding the burden of making connections is too much. Knowledge is used in too many different ways for its use to be anticipated in advance, emphasis must therefore be shifted from the retrieval of intact knowledge structures to support the construction of new understandings, to novel and situation specific assembly of prior knowledge (Spiro et. al., 1991). This is where constructivism fails, since it does not account for prior knowledge structures - it merely propagates using viable belief systems. A person's existing conceptions comprise many different kinds of knowledge, such as anomalies, analogies and metaphors, exemplars and images, and past experiences (Hewson and Hewson, 1984). From the point of view of conceptual conflict the most important constituents of a person's conceptual ecology are his or her epistemological commitments to such standards as generalisability, internal consistency and parsimony. Constructivism does not include the need for these.

Science and science education

The classical objectivist view of knowledge assumes that science produces successive theories that progress closer to a description of reality (Davis et. al., 1993). Even though we might not achieve the final complete account, it is believed that genuine empirical knowledge involves universal logical structures (Johnson, 1987). Gardner (1975) states that the characteristic which most ·sharply distinguishes science from other disciplines is its attempt to formulate theories which yield empirically testable predictions. In the initial stages of a science, effort is expended on developing language systems, and classifying things, events and properties - these form the domain discipline. Gardner goes on to say that, as a science develops, more research effort goes into finding empirical relationships connecting the concepts and propounding explanatory theories to account for these relationships.

According to Gardner (1975) theories may be considered to comprise four substantive parts: 1. Theoretical concepts - terms, referring to non observable entities or processes which constitute the key terms. 2. Logical structure - operators relating the theoretical concepts in the form of equations or sentences. 3. Operational definitions - statements indicating how theoretical concepts may be correlated with their empirical counterparts where possible. 4. A model - a mental picture, analogy, or mathematical relationship permitting visualisation of theoretical concepts. The syntactical structure of theory - statements may also be considered to comprise four phases: 1. abduction: the process of inventing or borrowing concepts for the purposes of a new theory. 2. introduction - the process of reasoning used within the theory to generate statements of the relationships between the hypothetical constructs of the theory. 3. transduction - the process of connecting the theoretical concepts with the operational definitions. 4. production - the process of generating new and empirically testable predictions from the theory.

According to Popper (1963), it is the ability of a theory to be refuted that is the most important criterion for judging whether it is scientifically sound. The important aspect is not whether a theory is true, but whether it can be falsified. Using the viability concept of individual constructions within constructivism, it seems that falsification is not possible. Furthermore, not all concepts can be derived from experience - in many cases, especially in science, the concepts may be highly abstract. Then, mere experience will not enable an individual to attain these, without having experienced, or rather understood and come to terms with, related concepts. This is where constructivism fails where science is concerned. Constructivism, which considers every idea as viable without the test of validity, does not sit well with these generally accepted tenets of science. Know ledge, as accepted by constructivism, fails to fit with the substantive and syntactical structure of theory as discussed above. Constructivism does not require ideas to go through such rigorous tests for knowledge development.

The scientist does not replace the concrete by the abstract or the particular by the general. The particular is understood through the general. In the process, the uniqueness of the particular is not destroyed or changed in any way. There is nothing in science hostile to individuality and uniqueness (Passmore, 1975). Harré (1986) suggests that scientific knowledge is constrained by 'how the world is' and that scientific progress has an empirical basis, even though it is socially constructed and validated. Contrary to constructivist belief, science does not undervalue individual contributions. It does, however, ask that ideas be stringently validated to be made socially accepted.

Science education aims to prepare students for multiple roles: acquire a basic knowledge and understanding of ordinary scientific phenomena; develop the ability to generate fruitful and relevant questions and frame them in an effective way for investigation; learn to select and apply appropriate methods from a range of options in answering those questions and evaluate and synthesise the scientific information gained as a result (Burbules and Linn, 1991). For many years, science education has been seen as learning facts and technical vocabulary, as opposed to formulating and testing hypotheses. Traditional approaches to science education frequently assume a static view of scientific know ledge and present a single method that, purportedly, characterises all scientific investigation. There is a current trend which encourages the inclusion of history and philosophy of science in the science curriculum. It is felt that students should learn to find and integrate multiple converging sources of information. They should gain an appreciation of how achievements in science actually come about, including the recognition that the processes of scientific investigation are imperfect (Hodson, 1987). Constructivism has contributed to make educators more aware of this, but it cannot take the sole credit for doing so. It is hoped that this will promote a more accurate and realistic view of scientific knowledge and the scientific enterprise, by making the classroom process more like real scientific investigation. Constructivism can take the credit for making the learning process more social, and attempting to minimise the gap between students' activities in science classrooms and activities in life.

Constructivism advocates that the science learner can do any kind of science learning, at any stage, and can be like a scientist and operate at that level. · This, however, is suspect since there are limitations of the science learner in comparison with the scientist. The developmental capacity of students needs to be considered. Burbules and Linn (1991) state that practising scientists have considerable experience and a high degree of mastery over the actual methods of collecting, recording, and writing up research data. Students are inexperienced, and awkwardness, or impatience, might interfere with their being able to extract, from a discovery learning situation, any accurate or reliable results. However, it is important that students are allowed to pursue their curiosity, reflectiveness, and persistence.

What we do *not* want students to learn is that all points of view are equally valid. Common sense ways of explaining, which many with a lack of understanding of science employ, differ from the knowledge of science. Common sense reasoning is without explicit rules, while scientific reasoning is characterised by the explicit formulation of theories which can then be communicated and inspected in the light of evidence (Driver et. al., 1994). Constructivists encourage intuition, but it has been shown that intuition usage in science leads to misconceptions.

The New Zealand Science Curriculum Document (Ministry of Education, 1993) defines science as people exploring and investigating their biological, physical, and technological worlds, and making sense of them in logical and creative ways. The document is, in fact, trying to explicate what science education should be, but the distinction between *science* and *science education* is not made explicit. This is characteristic of constructivist pedagogy and curriculum development. It is perfectly acceptable for science teaching and learning to be done in an interactive way, but not for the practice of science which proponents of extreme constructivism claim should be done. They ignore the process of science, described in this section of the paper, and instead accept all constructions without applying the tests which science advocates.

If students have different meanings, does it mean that we start teaching a different science? It is good to know the different student' meanings and to help bridge the gap (Wheatley, 1991). Encouraging students to make the words of science meaningful to them should not imply encouraging their developing their own meanings for scientific words. As Wittgenstein (1958) pointed out "there can be no such thing as a private language. languages are by definition public."

In science education, we wish to help learners by providing them with structures, that have been found by scientists to be useful ways of ordering the world - for example Newton's laws of motion provide a helpful model for understanding the straight line motion of objects. It is unlikely that students will be able to re-discover Newton's laws without guidance. We also wish to teach the science processes of ordering, classifying, detecting relationships, clarifying problems, and most importantly, proposing hypotheses which are subject to reproducible experimental test, and providing a way of communicating concepts (Passmore, 1975). Constructivism encourages social negotiation within science education. To do that, learners need to master the basic skills and knowledge mentioned above. Without the basics there can hardly be any meaningful negotiation.

Novices learning science are limited in the extent to which they can reason in the abstract, as do scientists. Children tend to view things from a self-centred or human-centred point of view, they tend to endow inanimate objects with the characteristics of humans and other animals, and they tend to consider only those entities and constructs that follow from everyday experience (Freyberg and Osborne, 1981). Scientists construct conceptions for which there are no directly observable instances (atoms, electric fields) and conceptions that have no physical reality (potential energy). Such concepts have certainly increased the explanatory and predictive power of science. In working out these explanations, scientists have also found it useful to adopt a rather non-human-centred viewpoint and to endow inanimate objects with human and other animal characteristics only in a metaphoric sense. Children are interested in 'customised' explanations for everyday observables (Osborne and Freyberg, 1985). They will accept more than one explanation for a specific event, and are not too concerned if some of these explanations are self-contradictory. Nor do they distinguish between explanations which might be called scientific, in that they are testable and capable of being disproved, and non-scientific explanations. Children are not too concerned if two theories explaining two different situations are mutually inconsistent. On the other hand, scientists have become almost preoccupied with the embracing theories. How, then, do constructivists hope for individuals to learn science through personal constructions in the light of what has been discussed? It appears that constructivism fails even in assuring that all science education can be done in a constructivist way. It cannot be denied that there are aspects of science education which lend themselves to more interactive styles in order to make the learning process interesting, but this is where it all ends.

Rather than say that teachers should teach in a constructivist manner, which has been shown to have many problems, we should encourage teachers to teach interactively and, if some of this appears to overlap with constructivist tenets, then that is fine. Teachers should be encouraged to help children: to investigate and explore ideas; to ask questions to attempt to gain understanding;

to develop explanations in line, and coherent with, the currently held beliefs or principles of science, and to be interested in alternative explanations and how these have been obtained.

Pedagogical

Leaming may be broadly termed as the gaining of knowledge, comprehension or mastery through experience. It always involves the interaction between the learner's present understanding of the world and the knowledge input. A broad view of cognition and learning, put forward by George (1970), encompasses at least the properties of perception, recognition, recall, conceptualising, inference making, problem solving, thinking and the use of language.

One of the goals in science instruction is to encourage students to develop socially acceptable systems for exploring their ideas and their differences in opinion using the currently accepted principles of science. The students should also realise that the ideas of science are subject to change. We wish to know how learners define boundaries between ideas and why some ideas are combined and others are left isolated. How do we help them see knowledge as something that is made, as something that changes over time? (Burbules and Linn, 1991).

In line with the structure of knowledge theory, school subjects ought to reflect the structure of the academic disciplines. This is justified on grounds that school curricula should include content of the discipline, the aim being to teach the structure of the discipline, rather than disconnected facts. Gardner (1975) postulates that curricula which stress concepts and principles of high levels of generality (substantive structure) and modes of thinking and reasoning (syntactical structure) lead to more effective learning, have a greater chance of producing long term retention, and, hence, promote greater student interest. Constructivism on the other hand advocates students choosing that which is to be learnt (implying lack of structure).

Roberts (1988) outlines 7 curriculum emphases that direct science teaching namely: 1. An *Everyday Coping* emphasis to enable students to comprehend objects and events. 2. A *Structure of Science* emphasis to promote understanding in how science functions as an intellectual enterprise. 3. A *Science, Technology and Decisions* emphasis to provide the interrelatedness among scientific explanation, technological planning and problem solving, and decision making in society. 4. The *Scientific Skill Development* emphasis to promote conceptual and manipulative skills such as observing, measuring, experimenting, hypothesising, etc. 5. The *Correct Explanations* emphasis, which concentrates on the ends of scientific inquiry rather than the means. 6. The *Self as the Explainer* emphasis, which informs the student's understanding through the process of developing explanations. 7. The *Solid foundation* emphasis, which provides students with knowledge for future learning. Constructivist teaching promotes emphases 1 and 6, whereas the science community of educators would aim to promote each of the 7 emphases at some stage or other during the learning and teaching process.

Constructivism seems to be more relevant to curriculum theory than to instructional theory, for it is more concerned with decisions about what to teach than with how to teach it (Reigeluth, 1991). Constructivism advocates procedural skills over content, content is sidelined as unimportant, or something that will be constructed in the process. The question here is whether content is required prior to the development of procedural skills, which, in my opinion, cannot be divorced from subject content. Science education is of necessity a process of aculturation. The process of education should enable children to acquire and understand the powerful constructs and ideas of modem science. Constructivism on the other hand does not address the issues of content, concepts, sequencing, cognitive demand and the adjudication of competing theories. (Osborne, 1994)

Constructivists advocate simply relying on real world activities and experiences for science learning. This may not heal the problem of students lack of understanding and appreciation of science. diSessa (1988) suggests that simple exposure of students to real world experiences may have a detrimental effect on learning, if those experiences are not structured carefully. Experiences can exacerbate naive conceptions. Real life problems are complex and ambiguous in comparison with idealised experiments or textbook examples. Hence, the students need to be gradually led from the idealised situations to the real-life complex problems. Constructivists do not state what experiences are required, how many of them are required or how to ensure that the complex experiences can be made manageable to the students. Osborne (1994) asks what experiences can be provided to give a base of knowledge that children can use to build upon. Harre (1986) argues that theory is a device for focussing our attention. We need to introduce the child to the descriptive language of the scientist and the theoretical frameworks which will enable them to generalise from experiences.

Constructivists claim to offer an improved learning strategy for all, when, in fact, they only offer an alternative. Research on learning styles has shown that there is no single method for teaching and learning which is suitable for all students. Hence, the argument in this paper is that constructivism should merely be considered as an alternative which encourages interactive learning.

In constructivism emphasis is placed on providing students with opportunities to develop skills and knowledge which they can connect with prior knowledge and future utility through context. Merrill (1991) states that to insist on context never being separated from use is to deny the teaching of abstractions. At some point in the instruction these not only can, but must, be decontextualised, if the student is to gain the maximum benefit and ability to transfer. Instead of teaching a multitude of facts, processes of thinking and constructing relationships are stressed. It should be stressed that constructivism is not the only method which advocates such learning. However, this is acceptable if students are going to develop conceptual understanding of the principles of science and not just viable possibilities.

Science education should engage students in the legitimate scientific activity of finding out what has already been learned. Science instruction should include the skills necessary for finding and analysing secondary sources of available scientific information, for assessing the reliability and generalisability of new information and for reconciling competing claims. Leaming to look things up and evaluate the usefulness and relevance of the information gained is part of good science education (Burbules et. al., 1991).

Driver et. al. (1994) state that the role of the science educator should be to mediate scientific knowledge for learners, helping them to make personal sense of the ways in which knowledge claims are generated and validated rather than organising individual sense making about the natural world. Meaning depends on the individuals current know ledge schemes. Leaming comes about when those schemes change through the resolution of disequilibration. Such resolution requires internal mental activity and results in a previous knowledge scheme being modified. Leaming is thus seen as involving a process of conceptual change. Teaching approaches in science, based on this perspective, focus on providing children with physical experiences, which induce cognitive conflict and hence encourage learners to develop new knowledge schemes, which are better adapted to experience. This is in line with the interactive method advocated in this paper. Driver et. al. do not advocate purely viable knowledge schemes, but encourage conceptual understanding, hopefully in line with the accepted principles of science.

A path which constructivists do not so often talk about might be called *conflict deferred.* Here learners would be invited to bracket their intuitive models for a while and just learn a new way of thinking and talking about the phenomena. When the new way of considering the phenomena has become familiar and consolidated, the instruction turns back to the naive model and explores relationships between the two (Perkins, 1991). This provides students with the fundamental and prerequisite knowledge to learn in an interactive manner.

While the aim is laudable, often constructivist learning situations throw students suddenly and almost wholly on their own managerial resources. The high cognitive complexity of many constructivist learning settings exacerbates the problem. Having students select or develop their own learning strategies and often their own goals and objectives is rather naive, even though it diminishes the problem of relevancy. Students do not even know what knowledge exists which they can draw upon. It is the case of asking a blind man to see. Clark (1982) has pointed out that students often choose unwisely, since they tend to prefer less effective instructional methods than those that might be prescribed for them. Students will not know when they have reached conceptual understanding.

Constructivism and the classroom

Constructivism has made educators aware that students have well developed theories. It has made teachers try to gain a deeper understanding of the teaching and learning processes to help student attain improved understanding. Teaching and learning science involves being initiated into scientific ways of knowing. Currently, teachers give a variety of examples to aid students in organising their schemas in ways which will enhance transfer of learning. Traditional methods focus the responsibility for learning on the teacher, while constructivism makes the learner responsible for their learning.

Students vary in preferred learning styles and a learning environment based on a single perspective might not meet the needs of some students. If students are asked to operate in the constructivist environment, they will become bored, just as in any other environment. We need to teach students to ask why, how come, why not that or this and not just try to accept knowledge as truth and making superficial sense. 'Making sense' can mean being critical or just having a single rational acceptance, or merely learning by rote (ie making sense of meaning between things in a sentence). It is a good exercise to discuss and argue with students, just as it is good to sometimes provide written material, exercises, problems, experiments, investigations, demonstrations, computer simulations and so on.

The teacher's role is to provide interventions that are helpful (Duckworth, 1987). Teachers should ask questions such as: What do you mean? How did you do that? Why do you say that? How does that fit in with what she just said? Could you give me an example? How did you figure that? These are ways to understand what the other is understanding, in every case the other's thoughts are engaged. Constructivism does encourage these and, in fact, this is its strong point. Leaming science involves young people entering into a different way of thinking about and explaining the natural world, becoming socialised, to a greater or lesser extent, into the practices of the scientific community with its particular purposes, ways of seeing and ways of supporting its knowledge claims. For this to happen, individuals need to engage in a process of personal construction and meaning making. Leaming science involves both personal and social processes. On the social plane it involves the process of being introduced to the concepts symbols and conventions of the scientific community (Driver et. al., 1994).

The common denominator in the majority of advanced learning failures is oversimplification, and one serious kind of oversimplification is looking at a concept or phenomenon or case from just one perspective (Spiro et. al., 1991). There is an alarming tendency in education circles to oversimplify complex problems and, as a direct consequence, assume simple solutions in which very little counts unless it can be put over simply (Beer 1975). This is what students will do if they are in charge of their learning as advocated by constructivism. Giving students greater independence in learning is different from making them solely responsible for learning. Constructivism as practised in the classroom is merely used as a form of interactive learning. Examples are provided below to substantiate this claim.

An example is teaching science from a problem-centred perspective. Problem centred learning (Wheatley, 1991) has three components: tasks, groups and sharing. In preparing for class a teacher selects tasks which have a high probability of being problematical for students - tasks which may cause students to find a problem. Secondly, the students work on these tasks in small groups. Finally, the class is convened as a whole for a time of sharing. Groups present solutions to the class, not to the teacher for discussion. The role of the teacher in these discussions is that of facilitator and every effort is made to be non judgemental and encouraging. A rich educational activity should: be accessible to everyone at the start; invite students to make decisions, encourage 'what if? ' questions, encourage students to use their own methods; promote discussion and communication; be replete with patterns; lead somewhere; be enjoyable; have an element of surprise; be extendable. Obviously students in a class will vary greatly in ability. A strength of problem-centred learning is that since activities are problem-centred, students can operate at their own cognitive level using their preferred learning style in line with constructivism practice. Some students may solve a problem using sophisticated methods while others may use methods which seem strange. During class discussions, students see alternative methods which prompt them to compare methods and develop a broader perspective which will subsequently influence how they think about new tasks.

Another example is an interactive learning environment. As a participant in the learning environment, the teacher or tutor acts as provider, facilitator, enhancer, enquirer and guide (Singh, 1993). In these roles, the teacher attempts to replace irrelevant ideas and to evoke ideas to which new ideas can be related. In doing this the teacher needs to have an understanding of the:

- nature and structure of the subject domain knowledge to be of useful assistance in providing help and guiding students to the host of ancillary knowledge required to interpret a concept appropriately when requested. Presently, the student is not made aware of the connections and is expected to make them. Without experience the average student fails to do so.
- student's prior knowledge. Teachers need to interact with the students to learn of their conceptions, the knowledge they bring to the classroom and to probe their understanding.
- student's strategies in acquiring knowledge and problem solving to provide explanations and help at the correct level when requested. Chi et al (1989) suggests refining and expanding the conditions of student actions, explicating the consequences of their action, providing a goal for a set of actions, relating the consequences of one action to another and explaining the meaning of a set of quantitative explanations.

The goal of a good teacher should be to make themselves continually less necessary to the learner. The teacher must take pains to ensure that they do not dominated the learning environment and that the student should be the central figure in the interaction. Anderson et al (1990) and Webb (1988) advocate that a teacher or tutor should provide suitable feedback at appropriate times to enhance learning. They stress that feedback given should take into account the history of the student and the errors made. Feedback need not only be error correction, but can be in the form of:

- assigning appropriate remedial or strengthening work;
- helpful hints and suggestions on where to look for subject material for application;
- how to make relational links from text or other material.

A teacher, preferably in consultation with the student, should basically select an educational objective, make changes in teaching strategy, evaluate the effectiveness and update the strategy to suit the student. Within an interactive learning environment the teacher needs to keep the following in mind:

- Start from the existing knowledge of the students.
- Interact with students at a rate which is consistent with their ability.
- Enhance the learning of the students by providing hints.
- Encourage students to diagnose their learning.

- Provide opportunities for students to apply and test the knowledge acquired.
- Provide knowledge through transmission when the need arises.
- Have an open mind and be willing to learn as well.

Regardless of the development of instructional systems and technological advancements (eg. computer-assisted instruction, films and curriculum materials) which enable the student to work independently, classroom learning will continue to be mostly spent in group instruction with a teacher (Singh, 1993). In view of this, somewhat constructivist interactive teaching strategies, which teachers have developed are:

- Making learners' conceptions explicit.
- Focussing on problem areas where misconceptions are rampant.
- Highlighting inconsistencies within the learner's conceptions.
- Create situations where learners restructure the way they see things.
- Creating and showing structuring links to help the learner

The aim of exposing students to the various strategies and knowledge is to move them from the inexperienced problem solver (novice) state to the experienced (expert) mode. Davis (1989) suggests five stages of performance from novice to expert. Stage one (novice) uses context-free facts and rules to produce actions based on these facts. Stage two (advanced beginner) learns to recognise elements not defined in terms of context-free facts. Stage three (competent) learns to organise thoughts in terms of plans and goals. This involves choices and decisions. Stage four (proficient) intuitively recognises a familiar situation and the goal. Stage five (expert) has the ability to intuitively know the sense of the situation and from prior experience knows what to do.

Conclusion

The epistemological, philosophical and psychological foundations of constructivism have been presented. A discussion on *science* and *science education* has been provided to show the difference, since many constructivists seem to confuse the two. It has been argued that the tenets of constructivism cannot be used to replace the practice of science. However, it has also been argued that constructivism does provide an option in the way that science can be taught. Constructivism has contributed in making educators aware of some issues involved in conceptual teaching and learning. These were previously hidden and constructivism has helped to highlight them. Using examples, it has been shown that the brand of constructivism practiced in the classroom is akin to interactive teaching and learning and that many educators, who claim to teach in a constructivist manner, are merely using interactive methods. To teach in a constructivist way, educators would not need any curriculum or guidelines apart from those provided by the tenets of constructivism and the experiences of the learners.

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