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A Critique of Constructivist Theory in Science Teaching and Learning

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ABSTRACT The objective of this concept paper is to critique constructivism in teaching and learning. This is a concept paper that reviews and critiques constructivism as epistemology and a learning theory and how teachers can apply this approach in the classroom. Based on research evidence, constructivism contributes significantly to the teaching–learning processes in schools. This concept paper will benefit teachers, learners, policy–makers and researchers in their quest to improve the quality of classroom learning in schools.

INTRODUCTION

Constructivism refers to the idea that learners construct new knowledge themselves with the teacher's guidance during the learning process (Gelman 1994; von Glasersfeld 1984). Dewey (1939), Piaget (2001) and Vygotsky (1986) among others, were some of the main proponents of constructivism who advocated for this form of learning in the classroom. In this approach, the teacher acts as a facilitator or guide during the learning process (Shumba 2011). Although this approach seems ideal in the classroom, some teachers in our schools appear not to know what constructivism is and hence find difficulties in applying this approach during the teaching–learning process (Hewson and Thorley 1989). Constructivism contributes significantly to the teaching–learning processes in schools, and hence this article will benefit teachers, learners, policy–makers and researchers in their quest to improve the quality of classroom learning in schools.

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Constructivism has had considerable success and profound influence on the learning process within the classroom (Mathews 1992, 1994; Phillips 1995; Osborne 1996; Staver 1997; Shumba 2011). The types of alternative learning strategies it offers, and has since generated, have made an important contribution to our understanding of the learner and the learning process within the classroom (Ausubel 1963, 1978; Mushoriwa and Shumba 2002; Staver 1997). Constructivism in science education can be traced to a reaction against two features dominating science curriculum reforms in the 1960s and 1970s. First, as an epistemology based on a naive empiricism (Harris and Taylor 1983), and second, as a developmental stage model of cognitive growth, constructivism has been interpreted as implying deterministic limitations to students' capabilities. Reactions to these two schools of thought have been initiated by Driver and Easly (1978: 8) who argue that 'achievement in science depends to a greater extent upon specific abilities and prior experience than general levels of cognitive functioning'. This implies that in order for learners to perform in the classroom, they should have certain specific abilities and prior experience. Constructivism focuses on the resilience of the learner's beliefs and social construction of reality (Shumba 2011). However, Osborne (1996) argues that concentration on these issues has led to serious epistemological flaws in these constructivists' conceptions of science in the manner in which new science knowledge is generated.

Staver (1997) identifies constructivist's critics (for example, Mathews 1992, 1994; Osborne 1996; Phillips 1995) who have since acknowledged its contributions. Critics of constructivism (Mathews 1992, 1994; Phillips 1995; Osborne 1996; Staver 1997) maintain that as a learning theory, while it serves the purpose of (a) moving epistemological issues into the foreground in discussions of learning and curriculum development; (b) providing empirical data to enhance our knowledge of difficulties in learning science (Osborne 1996); (c) fostering the development of innovative methods of science teaching (Matthews 1992; Osborne 1996); and (d) increasing our awareness of how people learn science (Osborne 1996), it has notable weaknesses. These critics observe that constructivism (a) is a flawed instrumental epistemology (Osborne 1996); (b) tends toward relativism (Matthew 1992; Phillips 1995); (c) fails to break away from a traditional empiricist view (Matthews 1992), and (d) does not accurately portray the practice of science (Osborne 1996). As a paradigm, constructivism has had considerable success in its critique of didacticism. The types of alternative learning strategies it offers, and has since generated, have made an important contribution to our understanding of the learner and learning (Staver 1997; Mushoriwa and Shumba 2002). However, as a referent, Tobin and Tippins (1994) argue that constructivism suffers from flaws that will always restrict its potential and any claims to universality.

Constructivism as a method has had considerable success in the classroom because the types of alternative learning strategies it offers have contributed immensely to our understanding of the learner and learning process. As such, constructivism "has generated a large body of empirical data that has been seminal in improving teachers' knowledge and conception of students' scientific thinking, its origins and its development" (Staver 1997: 501). The strategies that constructivism advocates for are a challenge to teachers in the classroom. It is against this background that this paper sought to review and critique constructivism as epistemology and as learning theory; reviews learning theories, constructivist teaching methods and cognitive developmental theories; concepts and percepts formation; learning theories; constructivist teaching approaches; conceptual change model; and constructivist teaching–learning and teachers' concerns. This approach has been adopted in this paper because it exposes and sequences all the key issues that relate to this important approach that is not normally available to researchers in this detailed form.

CONSTRUCTIVIST TEACHING APPROACHES

A meta–analysis of several studies on innovative teaching approaches based on the constructivist perspective suggests that teaching approaches that challenge students' pre-instructional conceptions generally are significantly superior to approaches that do not take students' conceptions into account (Guzetti and Glass 1992; Shumba 2011). There is substantial research evidence indicating that science instruction either supports students' old (alternative) conceptions or even causes new misconceptions (Duit and Treagust 1988). Admittedly, misconceptions can be provided by teachers, textbooks or other teaching media. Teachers seem to hold major misconceptions especially those who do not have adequate background and training in science. Therefore, it is necessary for such teachers to be in-serviced on these misconceptions on constructivism so that they can be able to handle the misconceptions that students bring to the science room.

An old pedagogical principle involves starting from the students' point of view or "teaching from the known to the unknown", simple to complex, easy to difficult, or familiar to the unfamiliar (Mushoriwa and Shumba 2002). Common students' conceptions are now known in main areas of science and these allow teachers to investigate their students' conceptions and understanding (White and Gunstone 1992). Changing from students' concepts to science concepts can be affected through instructional approaches, analogous to Kuhn's (1970) evolutionary and revolutionary changes in the conduct of science. First, are the continuous approaches which start with students' conceptions that already are in general accord with science concepts or that can be reinterpreted from the Sciences. Second, are the discontinuous approaches, which usually contain, at some stage, the cognitive conflict strategies (Scott et al.

1992). These studies identified three primary kinds of (a) students' predictions in an experiment and its actual outcome; (b) students' and teachers' conceptions; and (c) conceptions of different students. This implies that teachers need to accommodate the learners' conceptions and views as a starting point during the learning process.

The use of these cognitive conflict strategies requires some considerable caution. The initial consideration is whether or not students see the conflict, because what might appear as a conflict in the teacher's opinion may not be seen as a conflict by students from their point of view. Brown and Clement (1989) developed an approach that tries to find a continuous passage from the students' conceptions to the science concept. The approach starts with those aspects of students' existing conceptions that are mainly in accord with the science view. Thereafter, they employ a series of intermediate situations as stepping–stones that are designed as bridging analogies. In other words, learners make use of their prior knowledge in order to accommodate any new knowledge to be learnt during the learning process. One other set of meta–cognitive approaches is based on the constructivist perspective that students' and teachers' conceptions of the learning process play a key role in learning. Novak and Gowin (1984) propose the use of concept maps that are now used widely to probe students' understanding of science concepts.

White and Gunstone (1992), in a concept map, found that students write down the key concepts of an area and indicate the ways in which the concepts are interrelated. This enables students to become aware of their own understanding and hence increase their meta–cognitive skills. This process leads to an increase of their meta–cognitive skills because learners relate their new knowledge to what already exists in their mind (their schema). Baird and Mitchell (1986) also presented yet another approach for improving students' and teachers' views of learning and for improving their meta–cognitive skills in science instruction. The approach involves, for example, asking students to keep a "learning diary" and to regularly complete questionnaires that lead to reflection about their learning progress following lessons – a form of conceptual change model. Such an approach assists learners to keep track of events during the learning process on a daily basis. Besides, it also helps even slow learners remember what they will have covered in their previous lessons.

CONSTRUCTIST TEACHING METHODS AND COGNITIVE DEVELOPMENT THEORIES

Research shows that 'constructivism' is now a catchword in educational circles applied to how people learn, and to the nature of knowledge (Staver 1997; Shumba 2011). The major premise upon which this concept paper was mooted is to draw appropriate applications from the constructivist approach to the practice of science teaching and learning. As such, teachers' conceptions of knowledge acquisition seem to play a key role in their understanding of this knowledge growth within a constructivist perspective and in the refining of their own teaching and redesigning of the teacher education programme (Winitzky and Kauchak 1995).

Constructivist theorists maintain that learning is more effective when teachers use constructivist methods that typically involve more student–centred, active learning experiences, more student–student, and student–teacher interactions, and more work with concrete materials and in solving realistic problems (Shuell 1996; Shumba 2011; von Glasersfeld 1984). Empirical studies in the field of psychology indicate that humans in general tend to observe only what fits their conceptions and to ignore counterexamples (Baird and Mitchell 1986). Results of studies in science education show clearly that students often do not see what is obvious from the point of view of the presenter of the experiment for example (Duit and Treagust 1988). Although it has been acknowledged that students still create their own meaning based on the interaction of their prior knowledge with instruction, the meanings they make may not be the ones that the teacher had in mind. No matter how constructivist instruction works, "learners can and do find interpretations that differ from those intended by experts" (Gelman 1994:502). Thus teachers may create constructivist experi-ences for their students based on what they (teachers) consider salient; but what is salient to the teacher may not necessarily be salient to the student. This implies that as long as the teaching style of the teacher and the learning style of the learner are not congruent with each other, then learning becomes difficult for learners (Shumba 2011). In other words, the teaching style of the teacher should match the learning style of the learner in order for learning to understand what the teacher is teaching. It should therefore, be acknowledged that students can create any number of meanings or conceptions, intended, expected, or otherwise, out of the same learning experience which differ in some subtle way from those of the teacher. Such a scenario is often a challenge to both teachers and learners.

Research shows that the constructivist theory "does not challenge the practice of science, but confronts the wishes of science head–on, by providing an alternative epistemological paradigm to explain, interpret, and use science as a way of knowing what we have learned through science" (Gelman 1994: 503). This implies that for constructivists, obser-vations, objects, events, data, laws and theory do not exist independent of observers (Staver 1981). Staver argues that, the lawful and certain nature of phenomena, are properties of us, those who describe, not of nature, what is described. Thus, constructivism simultaneously points out the utility and boundaries of what we can know, whether our primary aim is to account for cognition, for the total of our mental facilities (von Glaserfeld 1995), or to understand knowing (knowledge acquisition) through language (Gergen 1995). This implies that constructivists begin their work without first assuming an independent reality.

The history of research on students' conceptions of science has since acknowledged the insight that students' pre–instructional concepts play a key role in the learning process. Documented evidence that detail the development of such studies date back to as early as the 19th century and this includes studies by Hall and Browne in 1903 (Duit and Treagust 1988). In the middle of the century in 1947, Oakes presented an extensive review of studies in this field (Duit and Treagust 1988). Science educators were forced to rethink science instruction following the design and evaluation of science curricula of the 1960s and early 1970s. The realization that the acquisition of new knowledge is very much influenced by conceptions already held by the learner became a key idea in a variety of fields. For example, in the philosophy of science, the idea that conceptions guide observation and determine understanding became prominent. Hanson's (1965) (in Duit et al. 1988) idea of theory–laden observation, in which observations are shaped considerably by the concepts which an individual holds, and Kuhn's (1970) seminal analysis of the impact of old ideas on the development of new ones in the history of science, can be taken as paradigmatic examples (Bordner 1986). Notable developments in various other fields, such as research on self–organizing systems, contributed to the appeal of this view in a large variety of domains. In various other fields and in science education, the idea is labelled "constructivist view" and has been of some significant influence in assisting teachers' understanding of students' learning difficulties and in developing new teaching and learning approaches.

Von Glasersfeld (1984: 21) sums up the constructivist model as: "knowledge is constructed in the mind of the learner". On the other hand, Bodner (1986: 873) aptly explains:

learners construct understanding. They do not simply mirror and reflect what they are told or what they read. Learners look for meaning and will try to find regularity and order in the events of the world even in the absence of full or complete information (Bodner 1986: 873).

In a similar vein, Cobb (1983) interpreted the constructivist model as one in which knowledge is assumed to fit reality in the same way a key fits a lock. Such concepts only help to illustrate how radically constructivism differs from the traditional view of knowledge. Bodner (1986) would, however, argue that, if we allow knowledge to "fit" reality the way a key fits a lock, we find ourselves in a very difficult position because many keys, with different shapes, can open a given lock. This implies that what would sound logical and conclusive about the constructivist model as an instrumental view of knowledge acquisition is that each of us builds our own view of reality by trying to find order in the chaos of signals that impinge on our senses that leads to the formation of concepts and percepts.

CONCEPTS AND PERCEPTS FORMATION

The constructivist perspective has also been traced to the writing of Giambattista Vico of 1710 (von Glaserfeld 1984). Since then, Piaget and

Vygotsky have been singled out as the first true constructivists because their view that "knowledge is constructed in the mind of the learner" was based on research on how children acquire knowledge (Vygotsky 1996). In his view (Vygotsky), knowledge is acquired as a result of a life–long constructive process in which we try to structure and restructure our experiences in the light of existing schemes of thought, and thereby gradually modify and expand the schemes. This implies that learners acquire knowledge through their interactions with other people within and outside their settings (experiential learning).

On the other hand, von Glaserfeld (1984), a leading proponent of radical constructivism, set forth in 1995 several principles which describe knowing and knowledge in their development, nature, function, and purpose (Staver 1997). Von Glaserfeld stated that knowledge is actively built from within by a thinking person; knowledge is not passively received through the senses or by any form of communication. This implies that effective learning occurs through active involvement of learners in the learning process. Second, von Glaserfeld described social interactions between and among learners as central to the building of knowledge by individuals. Third, the character of cognition is functional and adaptive. This implies that in order for learning to easy and meaningful, learners need to assimilate their new knowledge to their schema during the learning process. Fourth, von Glaserfeld described the purpose of cognition as to serve the individual's organization of his or her experiential world; cognition's purpose is not the discovery of an objective ontological reality. All in all, meaningful learning occurs only when learners are in charge of their own learning during the teaching-learning process.

In a similar vein, Piaget contends that objects appear "permanent" or "in–variant" as a result of the individual's coordination of experimental data and the subsequent projection of these co-ordinations into the world that lies beyond our senses. On the one hand, Bodner (1986) argues that the data we perceive from our senses and the cognitive structures or schemes we use to explain these data both exist within the mind. Yet on the other hand, von Glaserfeld (1984) would maintain that assimilation occurs when what we perceive (percept) is adjusted to fit the conceptual structures (concepts) we have already assembled. Thus, when our experiences do not fit our ideas, equilibrium can occur by adjusting our schemes (concepts) to fit the sensory insights we perceive (percepts) and in this way accommodation takes place. Letwin et al. (1959) in Ogunniyi (2000) have since established that assimilation does not find recurring patterns of sensory data but imposes patterns by ignoring differences between what is perceived and what is expected, such as between the visual patterns of a bead or air–gun pellet (Bodner 1986). Such are some of the complex interpretations of how we perceive and conceive ideas and knowledge – a process during which (mis) conceptions can become embodied in our knowledge structures. The above studies appear to imply that the way people interpret and understand issues depends on their prior experiences (Ausubel 1963, 1978).

LEARNING THEORIES

Meaningful Learning Versus Rote Learning

Various studies in psychology, sociology and anthropology acknowledge that humans live, think and act on the basis of ideas and embodied experiences resulting from the reciprocal interactions between their nervous systems and their environments (Ogunniyi 2000). According to Ogunniyi, meaningful learning occurs when there is a successful interplay between students' thinking faculties or cognitive structures and the environment that triggers off the process of adaptive behaviour. It appears that both the nervous system and the environment in which it functions should be in a state of dynamic and reciprocal relationship. In a similar vein, constructivists view meaningful learning as a cognitive process in which individuals make sense of the world in relation to the knowledge they have already constructed (prior knowledge) and this sense-making process involves active negotiation and consensus building (Ausubel 1978; Fraser 1998). In other words, the fundamental constructivist idea that knowledge is constructed in the mind of the learner on the basis of pre–existing cognitive structures or schemes provides a theoretical basis for Ausubel's distinction between meaningful learning and rote learning. As Ausubel (1978: 251) puts it:

If I had to reduce all of education psychology to just one principle I would say this: The most important single factor influencing learning is what the learner already knows.

This implies that learners learn by building new knowledge on their pre-existing cognitive structures or schemes (Ausubel 1963, 1978). Bodner (1986: 877) further expands Ausubel's conception, thus:

To learn meaningfully, individuals must choose to relate new knowledge to relevant concept and propositions they already know. In rote learning, new knowledge may be acquired simply by verbatim memorization and arbitrarily incorporated into the person's knowledge structure without interacting with what is already there.

This implies that learners make sense of their new learning by relating it to the schema or prior knowledge unlike in rote learning (Ausubel 1963, 1978).

STRUCTURAL COUPLING

Ogunniyi (2000) cites Maturana and Varela in Foley (1997) as suggesting that learning takes place when a student is able to achieve "structural coupling" – a process involving interactions or congruence between an organism and the environment, often accompanied by adopting the learner's mental, physical and emotional state to environmental demands. Such a structural coupling gives rise to ideas or knowledge of science whose expression (understanding, explanation and interpretation) is mediated by socio–cultural experiences and practices. In Ogunniyi's (2000) view, the process of learning goes beyond the stimulus-response (S–R) mechanism of behaviorism implied by the structural coupling theory. Ogunniyi contends that learning entails reflection and creativity-a complex physiological/logico-metalogical process similar to the Darwinian natural selection or Mendel's dominance-recessive phenomenon. For example, during the learning process, two or more competing ideas may result in new knowledge construction (Foley 1997). Reflection involves conscious and sub-conscious intellectual and affective activities by which an individual learner explores his/her experiences of formal science to derive meanings, understandings and appreciations. This implies that during the learning process, learners 'negotiate and navigate a complex array of conflicting states' (Ogunniyi 2000). As such, the learner's background or prior knowledge plays a major role during the learning process. Learners without prior knowledge on a particular concept are likely to have difficulties in conceptualizing any new content being taught.

CONCEPTUAL CHANGE MODEL

The review of the conceptual change model proposed by Hewson and Thorley (1989) emphasizes four conditions for conceptual change to take place: there has to be dissatisfaction with existing ideas and the new concept must be intelligible, initially plausible, and fruitful. Admittedly, the first and last conditions appear difficult to address because students are frequently satisfied with their everyday conceptions and there is often no dissatisfaction with the old ideas from the students' point of view (Brown and Clement 1989; Gelman 1994) Besides it might not be easy to persuade students that the new science conceptions are more fruitful than the old ones. The intelligible, plausible, and fruitful conditions – are indicators of what Hewson and Hewson (1992) call the "status" of a conception. This implies that science teachers need to also consider students' point of view and should learn better from such conceptions. As such, this perspective of the aim of science instruction is to increase the status of science conceptions and not to diminish them.

CONSTRUCTIVIST TEACHING SEQUENCE

The teaching sequence model described by Driver (1988) is paradigmatic for many other approaches. Driver argues that students usually become aware of their own and others' point of view through some kind of elicitation of their conceptions (involving exploring their own ideas, discussing the differences among ideas of different students, carrying out experiments, and trying to explain the observed phenomena). Students' ideas can be clarified, challenged, and exchanged through discussions with others, or the teacher can promote conceptual conflict through the use of a disconfirming experiment or demonstration during the restructuring phase. The scientific view can be introduced by the students or the teacher and the different ideas evaluated against experience, through experiment, or by thinking through the implications. Students are given the opportunity to consolidate and reinforce new conceptions by using them in both familiar and novel situations in the application phase.

In the review phase, students compare their new views with their earlier ones. A major tenet of the constructivist teaching sequence is the phase that involves contrasting students' ideas with the science conception. The role of the teacher is that of a facilitator of students' construction processes and not a transmitter of the science view. For example, some students might be unable to see the differences between their view and the science view, and younger students would prefer to know the right answer than to waste time comparing ideas over and over. What the teacher considers as salient in the teaching context may not be viewed by students as salient. Very often in the teaching sequence misconceptions arise. The term misconception refers to a conception that is wrong from the science point of view.

For example, students could be engaged in an Environmental Science lesson experiment where they could work together using the above steps in the following topic: Water Pollution: Students need to first conceptualize what water pollution is from their own backgrounds; what pollutes water; forms of pollution; causes of water pollution; effects of water pollution; why it is necessary to control water pollution; and how to control water pollution. Students will discuss in their groups what pollution is and how water can be polluted; what pollutes water; what happens to water when it has been polluted; why pollution should be controlled; and how pollution can be controlled. Students will make their own contributions using their own backgrounds and apply the knowledge gained from the lesson in their everyday life to help the society understand the effects of water pollution on their health. Each group will report its contribution to the class and this will be evaluated by other students with the guidance of the teacher. After all group presentations have been made, students and the teacher will review their findings. This is an example and some of the ways in which students could learn using the constructivist approach in the classroom.

The misconceptions students bring to science classes are remarkably resistant to instruction as established by Kaput and Clement (1979) in Bodner (1986). Kuhn (1970) argued that, each of us constructs knowledge that "fits" our experiences, and simply being told that we are wrong is not enough to make us change our (mis) conceptions. The only way to replace a misconception is by constructing a new concept that more appropriately explains our experiences. The constructivist model requires a subtle shift in perspective for the teacher, a shift from someone who "teaches" to someone who tries to facilitate learning; a shift from teaching by imposition to teaching by negotiating (Herron 1984).

Thus, the constructivist model emphasizes the importance of a two–dimensional flow of information between teachers and their students. Traditionally, teachers tended to focus almost exclusively on their information output devices and neglect the development of information input devices. As Confrey and Upchurch (1985:510) have noted, "…...*one of the things that happen as students learn to relate to teachers is that they come close and teachers fill in the blanks*". A constructivist teacher, instead, questions students' answers whether they are right or wrong, insists that students explain their answers, focuses the students' attention on the language they are using, does not allow the students to use words or eqations without explaining them, and encourages the student to reflect on his or her knowledge, which is part of the learning process.

CONCLUSION

In conclusion, the above discussion clearly demonstrates that constructivism benefits both students and teachers during the teaching–learning process. The types of alternative learning strategies it offers, and has since generated, have made an important contribution to our understanding of the learner and learning. The main aim of this concept paper was to review and critique constructivism as epistemology and as learning theory; reviews learning theories, constructivist teaching methods and cognitive developmental theories; concepts and percepts formation; learning theories; constructivist teaching approaches; conceptual change model; and constructivist teaching–learning and teachers' concerns. Therefore, in the constructivist approach, knowledge is not passively received by learners but rather is built up actively by the individual during the teaching–learning process. In other words, learners are at the forefront or in the driver's seat' and in charge of their own learning whilst the teacher acts as a facilitator during the teaching–learning process.

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