Developing a Model that addresses "Science for All" using a Constructivist methodology

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Introduction

This paper, for all intents and purposes, is my attempt to put into words the philosophy that I espouse for use in, not only my classroom, but also in classrooms which are directed by my colleagues. For the past three or four years, I have been involved in curriculum review, development, implementation and evaluation. This activity has centred on developing a new, constructivistically based, method of science teaching for high school (Grades 9 through OAC) classes. The paper will focus on what this new methodology is attempting to do, that is, to reform science education to make it more accessible for all students. Constructivism, the philosophical basis for the methodology, will be discussed as to its applicability in bringing about a more equitable science programme. A few features, both beneficial and problematic, of a constructivist science programme will also be presented. Although this paper could be viewed as being self indulgent, it is primarily intended to help put many of my thoughts regarding these subjects into some semblance of order.

Science for all!

One of the common themes that is heard frequently in circles which deal with educational issues is that of a focus on all students. This is especially true in the case of science education. *The Common Curriculum* (Ontario Ministry of Education and Training, 1995, pg. 9) speaks of programs which "must reflect the abilities, needs, interests, and learning styles of students of other genders and all racial, linguistic, and ethnocultural groups." The document, *Science for All Americans*, (American Association for the Advancement of Science, 1990) is a list of recommendations that the AAAS feels are needed for all citizens. A rationale is given for this broad application of its recommendations. The report states, "science education-meaning education in science, mathematics, and technology-should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. America's future-its ability to create a truly just society, to sustain its economic vitality, and to remain secure in a world torn by hostilities-depends more than ever on the character and quality of the education that the nation provides for all of its children." (American Association for the Advancement of Science, 1990, pg. xiii). Documents from Britain echo a similar theme. "Everyone needs some understanding of science, its accomplishments and its limitations, whether or not they are themselves scientists or engineers. Improving that understanding is not a luxury; it is a vital investment in future well-being of our society." (The Royal Society quoted in Hodson and Reid, 1988, pg. 653)

Hodson and Reid (1988) discuss at least two different interpretations of what 'Science for All' would mean. The first meaning implies that all students will be exposed to some science while attending school. This conveys the idea that science education would be compulsory to all students. The second interpretation that is possible, according to Hodson and Reid, is that the same science education will be provided for all students. This may be translated to mean that an identical curriculum regardless of location, class or any other discriminating factor will be presented to all students.

Why science for all?

The reasons for this rallying cry are numerous. One of the most telling though is pointed to by Hodson and Reid. "There are large numbers of children, of both high ability and low ability, who opt out of science in school at the earliest opportunity and large numbers of children who leave school ignorant of, or even hostile to science." (Hodson and Reid, 1988, pg. 653) Much of this ignorance and hostility can be attributed to the methodology which is used to present science in school.

David Layton and his colleagues (Layton et al., 1993) carried out a series of case studies designed to address the question of the relevance of science education to groups of individuals who might have benefitted from scientific information. The people who participated in the study were chosen on the basis of a perceived need, determined by the research group, for scientific input into a problem area in their lives. These groups included the parents of Down syndrome children, councillors on a waste management sub-committee, and elderly people dealing with energy conservation in their homes. Layton et al. came to the conclusion that "the representation of science as a coherent, objective and unproblematic entity characterized by certainty and direct applicability to everyday life received little support from the case studies." Much of the science offered to these groups was perceived to be "inappropriate, untimely, and irrelevant" to the needs of the people in the groups studied. (Layton et al., 1993, pg. 118) Unfortunately much of the science that is present in schools can be characterized in the same way as described by Layton and his colleagues.

Hodson and Reid (1988) suggest that schools, in the British tradition, have attempted to offer science education on the basis of curriculum differentiation. This allows for a two-tiered scientific educational system. High status 'academic' science, with an emphasis on cognitive aims, is offered to students who are deemed to be of high ability. Low status 'non-academic' science, with an emphasis on topics of relevance and interest to the students, is presented to students of lower ability. The same type of differentiation may be seen in the curriculum guides offered by the Ontario Ministry of Education (Ontario Ministry of Education, 1987), especially when curriculum guidelines of comparable levels are examined (for example see the Curriculum Guidelines for Grade 10 Advanced, General, and Basic levels) Course curricula that differentiate in this manner may lead to undesirable ends. The opportunities available for those that are viewed to be of a lower ability level may be greatly restricted while those that are viewed to be more able experience science material that may be of no relevance or interest to them at the time of the schooling or even in the future.

A more detailed discussion of the type of science programmes which have been developed and implemented based on this two tiered system would be appropriate here, however keeping the scope of this paper in mind, it is probably sufficient to note a number of references which explore this area. A number of writers have been researching this crucial aspect of science education and most of these have been discussed by Derek Hodson in a series of papers found in a variety of educational journals. (Hodson (1992a&b), Hodson, (1990), Hodson (1993), Hodson (1986)). Hodson relies upon ideas which have been developed and presented by prominent and respected workers in this field. His reference lists include the names of G. Aikenhead, R. Driver, P. Fensham, P.K. Feyerabend, and T.S. Kuhn, among others. It becomes clear that science education as it has been presented in schools around the world it should be apparent that it is in need of drastic revision. This renewal should not be in methodology only but also in terms of the philosophical basis on which science is viewed.

What is constructivism?

Having established a need for a change in science education, a major question becomes evident. Which direction should be pursued? Essentially there are probably four approaches to teaching and learning science that have been proposed and followed over the past few decades. The material discussed in this section is derived from course lectures delivered by D. Hodson (1994). The approaches discussed include the transmission approach, the discovery approach, the process approach, and the interactive approach.

One approach, transmission, involves providing students with versions, delivered at age appropriate levels of sophistication, of scientific theories. The students are expected to understand the theories and also to believe (accept) these theories as the definitive ways to think about the properties of the materials studied. Science, in this approach, is viewed as being definitive, that is, science delivers the right answer to problems presented to it. Student learning is "based on the idea that the scientist's knowledge will be accepted by learners if it is presented at an appropriate level by someone who is considered by them to be credible and reliable." (Hodson, 1994)

The discovery approach proceeds with providing the students with a series of selected experiences. The students are expected to determine patterns that exist between the experiences and to note discrete specific scientific occurrences. This approach views science as existing as a body of knowledge that is, to a large extent, independent of human activity and that can be 'discovered' by students. Students will learn, according to this approach, when they reach the right stage of intellectual development (Piagetian), and that their learning occurs as a result of interaction with, observation of, and manipulation of the physical environment.

In the process approach, students "are provided with carefully selected activities for the purpose of developing specific process skills (e.g. measuring, observing, hypothesising) and (students) are expected to develop skills that they can apply to a wide range of problem situations." (Hodson, 1994) The process approach includes the view that scientific methodology should take precedence over scientific content. This perspective suggests that students will be able to develop these scientific skills if provided the appropriate opportunities. These skills, then, would be transferable to other situations and can be used to develop scientific principles that are applicable to these new circumstances.

While these three approaches do have some validity, it would be wrong to develop entire programmes on each of them separately. Some of the problems that become apparent could include the following issues. The transmission approach easily turns into a cueing and guessing game. The teacher 'holds all of the cards (cues)' and it is up to the students to guess at appropriate responses. Science becomes a series of statements, terms and phrases, for which the students have no real understanding. Science is also, to a large extent, viewed by students as something that occurs in school and is not related to their real lives. The discovery approach suffers because there are many aspects of science that are not discoverable. This is most apparent if transmission of terminology is also expected along with discovery. Where is the term 'gravity' found in the dropping of a pencil to the floor? Students also tend to interpret phenomena in terms of their present view of the world. There is little need for students to reinterpret events that do not fit their schema. These events can be dismissed as magic or accidents. Similarly, the process approach suffers since there is very little, if any, evidence that skills learned in one context are transferrable to another context especially if the student's view the situations as being totally dissimilar. Process skills, such as observation skills, can only be developed in the context of the student's theoretical understanding. As a result when students are asked to use observational skills while viewing cells under microscopes, they are frequently unable to observe cells or cell inclusions. Frequently, they will even confuse air bubbles as a new form of cell structure.

Science education needs to incorporate all of these approaches in contexts that are appropriate to the student, to the phenomena used and to the concept being studied. Hodson (1994) terms this as the interactive approach. He describes the approach in this way.

> "Children are provided with experiences for the purpose of generating children's questions and eliciting their present ideas, and children are expected to work towards clarifying their ideas and resolving their questions with help and guidance. This approach is based, in part, on,
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> 1. a view of science as an individual and collective activity to make better sense of the world, and
> 2. a view of learning based on the idea that, using their present knowledge, each learner must construct all knowledge for him or herself and that learning is something for which the learner must take responsibility."
>
> (Hodson, 1994, pg. 4)

What Hodson is describing in his interaction approach is more formally referred to as constructivism. Constructivism has been defined in several ways, all of which have a central set of commonalities. J.G. Brooks (1990) describes constructivism as the result of individual constructions of reality. She states that constructivists view learning as that which "occurs through the continual creation of rules and hypotheses to explain what is observed. The need to create new rules and formulate new hypotheses occurs when the student's present conceptions of reality are thrown out of balance by disparities between those conceptions and new observations.” (Brooks, in *The Constructivist Model of Learning*, pg. 1) W.L. Saunders defines constructivism “as that philosophical position which holds that any so-called reality, is, in the most immediate and concrete sense, the mental constriction of those who believe they have discovered and investigated it." (Saunders, in *The Constructivist Model of Learning*, pg. 5) Peter Fensham and his colleagues extend these ideas in the statement “that people construct their own meaning for experiences and for anything told them. The constructed meaning depends on the person’s existing knowledge, and since it is inevitable that people have had different experiences and have heard or read different things, all have different (though often similar) meanings for any concept.” (Fensham, et al., 1994, pg. 5) Dennis Cheek quotes Von Glasersfeld when he states that:

> “constructivism involves two principles:
> 1. Knowledge is not passively received but actively built up by the cognizing subject.
> 2. The function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality.
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> The first principle has long been recognized within philosophy and education. Von Glasersfeld terms holding to this principle alone as ‘trivial constructivism.’ The second principle involves acceptance of the view that knowledge of objective reality is not possible by human reasoning.” (Cheek, 1992)

The central concepts that should be apparent through all of these definitions are that constructivists believe that each person builds for him/herself an individual perspective of reality based on their experiences and frame of reference, and that learning can only occur if students are given opportunity to construct their own meanings out of the experiences.

This type of learning theory has implications for the way in which science is perceived and also for the way in which science must be presented in schools. As Larry Bencze states, “when it comes to establishing ‘truth’ in science, it can only be done by argument, and eventual consensus among scientists. Science is a democratic process in which each participant has his/her say, and then the group’s decision prevails. The decision may be good or bad, but it will be defended by the group.” (Bencze, 1993)

A Sample Constructivist Model

The following sections deal with a model that was designed by Larry Bencze and has been modified with input from myself and several other inservice teachers. This model has served as the basis for a constructivist conception of how units in Grade 9 science class may be developed and implemented. There will be a brief description of the model (which is included). This will be followed by a discussion of some of the weaknesses and strengths of the model. For perusal of specific classroom materials based on this material see the Science and Invention chapter and the Skills Handbook section of the Nelson Science 9 textbook (Ritter et al., 1995) and Students’ Science & Invention. (Bencze, et al., 1995)

Larry Bencze describes the model as constructivist in nature, in that there are three main elements:

1. Exposing students' prior conceptions. Students are asked to record their personal hypotheses and practical problems regarding certain 'practical experiences';
2. Providing Alternatives. The teacher arranges for students to come to understand the viewpoints of others, including those of their classmates and those of scientists and technologists. This is intended to challenge the students' prior conceptions;
3. Testing Alternatives The teacher insists that the student carries out scientific tests of various alternative hypotheses and/or solutions to practical problems. The teacher also ensures that students have a working knowledge of methods of science and technology. (Bencze, 1993)

In the Exposing Prior Conceptions section, a variety of situations in a variety of formats are arrange for the students to experience. Based on these experiences, the students express their scientific (and otherwise) understanding of the phenomena. Students communicate their perspectives in a variety of ways including concept maps, stories, and poems. In addition to these other forms of response, students are also directed to form causal questions, hypotheses, practical problems and possible solutions.

Providing Alternatives is the section of the model where alternative (to the students) understandings of the phenomena are presented. Generally, this is done in a way that is unambiguous in that there is no component of this section where the students are left to 'discover' understandings that other scientists have determined or agreed upon. The information in this section is presented using a variety of methods including: worksheets, demonstrations, notes, readings, research, and group learning activities. It is important to note that the teacher is not to present the information in this section as 'the only' way to understand it, but rather as what most scientists have agreed upon. Another important note that should be made at this point is that this is the information that most teachers, parents and students would identify as 'what needs to be known' (ie. content). This becomes a difficult task to make this discrimination, requiring appropriate teacher preparation in that many teachers could have difficulty with this type of presentation of the material. This section of the model also calls for the students to return to their causal question/practical problems/hypotheses/possible solutions and to modify them based on the additional information to which they have been exposed. This modification may be indicative of the amount of 'cognitive dissonance' that the students are experiencing.

The final section of the model, Testing Alternatives, allows the students to put their ideas to the test. Theoretically, the students are directed at this point to determine which of the explanations for the phenomena that they have experienced are the most relevant to themselves. This is done through the use of three methodologies: experiments, correlational studies, and innovations. When the testing procedures are complete the students should have a better understanding about which of the conceptions of reality is best for themselves. This is to lead to a further modification of the cognitive structures that each student has. The results of the testing procedures must be shared with other so that, just as scientists share the conclusions of their studies, the students can come to a consensus with respect to the topic under discussion. The conclusions that students make must be acceptable to the decision making body, the peers within the class.

Weaknesses of the Model

There are several difficulties that need to be addressed within the model and the entire programme that sprang from it. Some of these complications can be dealt with by appropriate and on-going teacher professional development. However, some strategies for solving there problems are yet to be determined. A brief description of some the difficulties that have been noted and addressed will be provided.

One negative factor that has been identified with the program as it is presented here is that the students must work on a variety of levels simultaneously. Originally the programme required students to learn (become familiar with) the methodologies of science while attempting to determine their responses to scientific phenomena all within the space of one unit. All of the elements of the program, from causal questions through to innovations, must be introduced, taught, tested and evaluated within the context of one unit. This necessitates spending several weeks, if not months, on one area of content. It is conceivable that students might not be motivated to continue with the programme if there was not much variety in the topics studied. This would also result in much of the instructional class time, in a semestered school particularly, being used for only one unit. The simple solution to this difficulty is to introduce the program elements in the context of different units. For example, experiments could be introduced in one unit while correlational studies and innovations were left for other units.

Additional problems arise with the programme when teachers are unfamiliar with constructivist theory. This is complicated by the change in emphasis from learning science (that is, the accepted laws and theories of science) to the broader scope of the course when it includes leaning about science (the values and attitudes of scientists, as well as the nature of the scientific endeavour) and leaning to do science as well. Many teachers perceive this as a 'throwing out all of the content.' In addition to this some teachers have also noted what they perceive as a 'lack of structure' within classes that are following this model. While this may be only a perception, there seems to be a tendency on the part of some teachers to become resistant to this change in classroom practice on account of this perception.

There seems to be only one practical way of treating the above situation. Teachers must be exposed to classes that are run following this type of format and the teachers must become part of a team that is working at the development of this type of programme in their home schools. This raises the possibility of a new style of professional development involving both the teachers and an outside facilitator who will take on the role of the 'teacher' for the group just as the teachers do for their own classes. The groups would cooperatively develop curricular materials based on this or a similar model. The groups would meet on a regular basis with the school for an extended period of time (several weeks or months).

One final obstacle that will be discussed is that of assessment and evaluation. Parental expectations in the present atmosphere of ‘back-to-basics’ are typically numerically and objectively oriented. The programme that is outlined here is not of this nature. Parents may also expect that the science that is taught to their children will be similar in many respects to that which they experienced in their own high school days. The programme and the model discussed here relies on having the students solve the cognitive dilemmas that are created within their minds. This is not something that can be evaluated, reported on or assessed with traditional pencil and paper tests, quizzes and exams, nor are there endless lab reports that are structured in exactly the same way. Other methodologies must be employed in order for the teacher to be able to determine the progress that each students is making and then report that progress to the parents in a way that they can understand.

Parents must be made aware of what is occurring within the classroom. From personal experience, parents who asked about the programme are fairly supportive once they have been informed as to the nature of the aims, the classroom practices and the nature of the assessment and evaluation. It is still not clear if parents fully understand what is entailed in the programme. More contact must be made with the parents to brief them on the nature of the programme.

A second solution might be suggested. Assessment tools may be changed significantly to reflect the nature of the program that is being offered. These tools may be radically different from those that have preceded them. Some of these tools might include concept maps, prediction-observation-explanation tasks, interviews about instances and events, fortune lines, relational diagrams, question production, as well as portfolios. (White and Gunstone, 1992) There must be an educational programme instituted in this event so that parents, students, and teachers will know what the limits and advantages of the new strategies are.

Strengths of the Model

There are several advantages to curricular materials that are arranged in a way that acknowledges constructivism and follows the kind of model described here. Most of the positive attributes of the program are in the area of having the students attempting to understand science in a much broader scope than that found in the traditional science courses. These is also room in this programme for the students to design their own science programme to a much greater degree and to work at the their own ability levels than is possible in other types of programs. While this makes teaching a greater challenge in terms of planning, logistics, classroom control and assessment, it also provides for greater participation by the students since the programme attempts to meet them at their own level of understanding and interest, at least initially. This also promises a greater degree of students motivation for all students since in it students address their own ideas and thoughts.

Conclusion

This paper touches on many different aspects of science teaching, as it presently exists and as it might exist in the future. It over reaches itself in that it does not address any of these areas to any great degree. Each of the topics addressed need further study and research. However, it is the hope of this author that in placing these ideas together, I have been able to clarify some of my thinking (it has been very much of a reflective type activity) regarding science for all. The role of constructivism in the preparation of this type of programme and in the learning of students within the programme seems to hold great promise, not in the assurance of which ideas will be learned, but in that some ideas of lasting value are bound to be learned.

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