Helping Young Children understand Science Concepts

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Central to constructivism is the idea that children construct their own knowledge (Driver, Asoko *et al.*, 1994). They do this both formally, within a classroom context, and informally, when they try to make sense of the everyday phenomena that they come across. Consequently, children construct ideas about scientific concepts before they encounter them at school. Teachers, then, need to take these ideas in consideration when teaching science to children.

Research (Driver, Squires *et al*, 1994; Osborne *et al*, 1990; Driver, Guense *et al*, 1985 are just a few examples) has shown that often children's constructions are different from the correct scientific concepts as accepted by the scientific community (Driver, 1983). Various labels have been given to these ideas, often referred to 'thoughts', 'beliefs', 'notions', 'concepts', 'intuitions', 'opinions', 'interpretations', 'meanings' and 'schemata' (Gauld, 1987). Other common labels include: preconceptions (Ausubel, 1968), children's science (Bell & Gilbert, 1996; Gunstone, 1990), misconceptions (Lawson, 1989) and alternative frameworks (Driver, 1983). The term 'alternative frameworks' will be used to refer to these ideas in this case. In explaining the nature of students' ideas, Driver and Easley (1978) argue that pupils develop '*autonomous frameworks for conceptualising their experience of the physical world'* (p.62). Hence the term 'alternative frameworks'. Even this term has, however, been criticised (Wandersee *et al.*, 1994) as a framework designates a stable pattern of knowledge held by learners. This has been shown, however, not always to be the case (Driver, 1985).

During the 80's, researchers in science education have probed children's ideas in a number of areas in science. Topics ranged from light (Goldberg & McDermott, 1986; Guense, 1985; La Rosa *et al.*, 1984; Osborne *et al*, 1990; Stead & Osborne, 1980); electricity (Black & Solomon., 1987; Duit *et al.*, 1985; Johsua, 1984; Osborne & Freyberg, 1985; Shipstone, 1984, 1984a; Solomon *et al.*, 1985); heat (Engel Clough & Driver, 1985; Erickson & Tiberghein, 1985; Hewson & Hamlyn, 1984; Stavy & Berkovitz, 1980), to motion (Bliss *et al.*, 1988; Bliss *et al.*, 1989; Clement, Brown *et al.*, 1989; Gilbert & Zylbersztajn, 1985; Kilmister,1982; McLelland, 1984; McDermott, 1984; Slojberg & Lie, 1981) in Physics; living things (Braund, 1991; Bell & Barker, 1982;Brumby, 1982; Sedgwick *et al,1978*); nutrition (Barker & Carr, 1989; Lucas, 1987; Bell, 1985); reproduction and inheritance (Engel Clough &Wood-Robinson,1985; Brumby 1984) in Biology, and solids, liquids and gases (Osborne & Cosgrove, 1983; Comber 1983), chemical change (Andersson, 1991; Bouma & Brandt, 1990) and water (Russel *et* al, 1989; Russel & Watt, 1989; Beveridge, 1985) in Chemistry. The topics mentioned are not exhaustive. In fact research was so extensive that books containing just reviews and lists of references of the numerous studies conducted have been published (Driver *et al*., 1994,1985; Pfundt & Duit, 1994).

Most of the research in alternative frameworks was, however, conducted mainly with students at secondary and tertiary level and very little attention was given to younger children The major project focusing on primary level children was carried out in the late 80's (1987-90). The project 'Science Processes and Concept Exploration' (SPACE) project was a class-based project that aimed to establish:

- the ideas which primary school children have in particular science areas;
- the possibility of children modifying their ideas as a result of relevant experiences (Russel *et al.*, 1991).

The research was divided in two phases. The first phase, the elicitation phase, involved identifying the ideas that children develop and what experiences might have led children to hold these ideas. The topic areas were many, and the first session (1987-89) covered concepts about electricity, evaporation and condensation, everyday changes in non-living materials, forces and their effect on movement, and sound. In the second part of this phases a further ten concept areas were studied: earth; earth and space; energy; genetics and evolution; human influences on the earth; processes of life; and weather (Russel *et al*, 1991). The second phase of the research, the intervention phase, studied whether it was possible to encourage a change in children's ideas that will help them develop a more scientific understanding of the topic taught (Russel *et al.* 1991). A particular feature of this project was that it was a collaborative exercise between university researchers and practising teachers.

Access to Children's ideas

Researchers have used various methods to elicit children's ideas. Sutton (1980) identifies four main different approaches: the clinical interview as developed by Piaget; the use of word-associations where a word is presented and the child is requested to respond with the first word which comes to mind, selecting a word or definition; and identifying and using bipolar dimensions where students' ideas can be placed within a ready-structured continuum. Other techniques used include, for example, the interview about instances approach developed by Osborne and Freyberg (1985). In this method children are presented with drawings depicting situations related to the concepts under study and then asked to comment about these concepts. Another common method used to elicit children's ideas is through the use of questionnaires (Millar & Kragh, 1994). This approach involves presenting children with particular situations and asking them to provide explanations, many times by choosing from a number of options provided. Sometimes, open-ended questions are also set. Such a method, unlike the previous methods that are more time consuming, allows the collection of data from a large number of respondents.

There is no best method for probing children's ideas. The various methods described serve to gather different types of data. On the one hand, quantitative methods such as questionnaires provide width in that we can get a snapshot of the range and frequency of alternative frameworks held across ages and cultures. Qualitative methodologies, on the other hand, provide an in-depth analysis of the thought processes involved in the ideas held.

Common feature of alternative frameworks

The massive research on alternative frameworks has allowed educators to identify features and patterns of the ideas held. Driver (1985), lists the following common features:

- ***The frameworks are coherent on their own terms.*** Although the reasoning is scientifically wrong it is not irrational but reflects a degree of logical reasoning. For example, it makes sense for a child to think that no force is present on an object when it is not moving, even though such an idea is scientifically incorrect. After all, we have all seen things move as a result of being pushed or pulled.

- ***Children are imprecise in the language they use to express their ideas***, reflecting a degree of confusion in their understanding of scientific concepts. For example, children use labels such as animals and mammals without realising the differences between them. In other instances they talk about a force being used up when a ball is thrown in air when they should be referring to its energy instead.

- ***Similar ideas are found among children of different ages and backgrounds***. Research across the world, ranging from Europe, America to Australia shows that children across the world have similar ideas about scientific concepts. For example, similar ideas have been identified in what children consider as living, an animal or a plant, or what happens to food once we eat it.

In addition, other researchers have added on to this list and identified other common features:

- ***Children's alternative frameworks are persistent*** (Dawson, 1992; Solomon,1983; Tasker,1992; Smith *et al*, 1993), or as defined by Ausubel (1968), '*amazingly tenacious and resistant to extinction*' (p372). Research has shown that children tend to stick to their original ideas even just after carrying out investigations that disprove them directly. One particular case in point is a study done by Gauld (1989) who targeted current flow in a circuit. On showing children through by means of ammeters that the value of the current in a circuit is the same at any point in the circuit, even after passing through a resistor, they still held on to their original idea that current decreases. A particular feature in this study was that three months after carrying out the investigations, children recalled being shown evidence that the current actually decreases. Their original alternative framework was so embedded in their belief system that they imposed it on their recollection of what took place during instruction.

- ***These alternative frameworks are personal in nature.*** Children interpret information in their own way in terms of already existing knowledge. The ideas that children hold about any area in science are then only their personal construction (Driver *et al*,1985). It is very difficult to get to know what meaning children give to concepts taught. The only way to gain insight to their thinking is by letting them talk about these concepts.

- ***Children may use different reasoning in explaining different situations*** without being aware of the difference or even contradiction between the ideas used (Driver,1985). In some cases, children do not feel the necessity to be consistent in their reasoning. So you may get a child explaining that a large log of wood floats because it is large, and yet giving the same reason to explain why a large metal rod sinks straight to the bottom.

- ***Children hold alternative frameworks about a range of phenomena before any formal instruction in the topic*** (Arnold & Miller, 1996; Dawson, 1992; Duit & Glynn, 1996; Tasker, 1992). There is no need for children to learn about scientific concepts in order to build up constructions about scientific phenomena they come across. As they try to make sense of things happening around them, they construct knowledge that is scientifically inaccurate or as often occurs, wrong. This is problematic to teachers as then these ideas interfere with learning in science.

What causes children to construct these alternative frameworks?

The reason as to why children hold such ideas has been a topic of discussion and debate among researchers for some time now. A number of possible factors involved have been identified and arguments in favour of their influence have been put forward. Some researchers identify the influence of personal experience in everyday life (Claxton, 1993; Russel, 1993; Solomon, 1983). Others emphasise the effect of language and culture on patterns of reasoning (Claxton, 1993; Russel, 1993). Children's level of cognitive development has also been cited (Monk 1991, 1990).

Personal experience

Personal experience is considered as one major factor that may influence students' ideas about physical phenomena. Whether such experience is called 'gut dynamics' (Claxton, 1993) or life world knowledge (Solomon, 1983), the argument is more or less the same. Children try to make sense of the world around them as they grow. As a consequence, they develop ideas about the mechanics of things. Claxton (1993) argues that such ideas tend to be unarticulated and not necessarily conscious. However, they provide the individual with the ability to interact physically with the world.

Likewise, Russel (1993) talks about the representations of the real world which result from the direct interaction of the individual with the environment and which often lead to physical changes of the nervous system. Various representations have varying degrees of 'goodness of fit' and serve as long as their predictive and explanatory utility is still useful to the child.

Dawson (1992) speaks about what he calls the everyday frame. He argues that most of our everyday knowledge is tied to experiences which we share with the different groups around us. Gunstone (1990) identifies a type of reasoning which he calls children's science. However, likewise, he also argues that ideas result from a common interpretation of everyday observations. This implies that each individual constructs personal meanings of experiences, that these understandings vary from one individual to another and that much of the construction that occurs involves linking with the individual's already existing knowledge and beliefs (Gunstone, 1990).

Language and cultural influence

Personal experience is not the only source of information available to children. In describing the role of 'lay dynamics', Claxton (1993) argues that children grow up to speak and hear about images of experience, this being through media, books or other sources. This situation provides a mixture of fact, fantasy and beliefs all of which influence thought. Such knowledge gives the individual practical advice and intrinsically interesting things to talk about (Claxton, 1993), but may confuse understanding when learning science. As Russel (1993) argues, the social milieu offers a range of ready-made templates for classifying the multiplicity of sense impressions. Various modes of communication, including spoken and written language as well as other forms of abstract notation have their own rules and conventions. These all allow information transfer that may not always be congruent with reasoning in science.

Personal and social influences cannot be separated as they occur at one and the same time (Russel, 1993). They can be at times independent of each other or overlap depending on the situation and the individual. Representations of the same phenomena from different sources may have the potential to combine or to separate, but may in any case be the source of the ideas which children hold. Confusion tends to occur when formal instruction, direct experience and culture represent the same phenomena in a different way and from a different perspective.

Dawson (1992) talks about everyday knowledge and how this is tied to experiences that are shared among different groups. These experiences are shared through the use of language that allows communication, but at the same time constrains the meanings created. The scientific frame, on the other hand, is different in that it demands scepticism and questioning. The scientist attempts to create a deep and coherent explanatory framework, removing the 'self' from the investigation.

Likewise, Duit and Glynn (1996) argue that during the pre-school years, children construct mental models of phenomena such as digestion, rain, fire, gravity etc. They construct these ideas from stories and fairy tales they have been told, television programmes they have watched and come across during play activities with other children. These models are not phenomena observed personally but are constructed in different contexts like the home, church, sport centres etc. Language contributes to the formation of these ideas owing to the number of metaphors used.

The difference between everyday and scientific knowledge demands that children are able to distinguish between the two modes of thinking, scientific and everyday meanings, in different contexts. They need to realise that everyday ways of talking about objects have different purposes from scientific explanations (Scott & Leach, 1998). It is therefore, the teacher's task to help children learn how to recognise when there is a need to think and talk about concepts in a scientific way as opposed to everyday talking. Children need to be formally introduced to the scientific way of thinking and talking (Dawson, 1992). They need to be shown when it is appropriate to use the scientific frame and when it is not needed, that is, which is the appropriate frame to adopt. Teachers, therefore have the task of teaching children how to talk and think about the world using scientific concepts, with their specific purposes and limitations (Scott & Leach, 1998).

Cognitive development
Cognitive development has also been linked, even if not directly, to the types of ideas which children hold about scientific phenomena. Monk (1990 &1991) has considered the topics of optics and electricity in putting forward his argument. He considered the ideas identified by Ramadas and Driver (1989) and Osborne (1983) for optics and Stead and Osborne (1980) and Shipstone (1984 & 1984a) in the case of electricity. Monk grouped the different patterns of ideas expressed in terms of Piaget's stages of cognitive development and identified two main points, these being that:

1) pupils' cognitive processes are limited by the stage of their genetic epistemological or cognitive development, that is on whether they are at the pre-operational, concrete operational or formal operational stage of development; and

2) pupils do benefit from instruction in topic areas where their stage of cognitive development enables them to develop the required operational schema, (Monk, 1990, p.13). This means that children at the concrete operational stage will only be able to understand concrete aspects of science, things that can be observed directly and relationships that preferably do not involve more than two factors as they as yet do not have the ability to deal with complex abstract concepts.

In view of these findings, Monk (1991) argues that although it is his belief that schemata must be constructed as a result of personal experience, *"the stage of genetic epistemological development marks out a maximum performance and not a necessary performance. Students who may have the epistemological tools to operate successfully with certain problems will not perform at that level unless they have experience of the content in context"* (p.263)

Monk's argument is that having the mental ability to understand certain scientific concepts does not automatically mean that children actually do learn these concepts correctly. They may still hold alternative frameworks just the same. Research carried out by Gatt (2002) substantiates Monk's argument as better understanding of specific concepts was found with increase in the children's level of cognitive development. However, abstract thinkers were still found to hold alternative frameworks.

Since we are now considering only children at primary level, the argument would then apply only to children at the pre-operational and concrete operational stage. One would then understand that children's understanding of scientific models and concepts would be very limited.

So what are the implications of these ideas to a Constructivist teacher?

No teacher can just tackle a topic in science as if the children know nothing about it. As has been outline in the chapter on constructivism, every learning outcome depends both on the learning environment and the learner's prior knowledge (Driver & Oldham, 1986). Teachers, therefore need to take into consideration the ideas which children already hold. In a way, one has to follow Ausubel's (1968) advice to '*find out what the learner already knows and teach him accordingly*' (p.337).

This approach to learning has been adopted by Rosalind Driver, a science educator who has made a significant contribution to constructivism in science education. Together with her team of researchers, she has developed a constructivist scheme that takes children's alternative frameworks in consideration. Her approach involved a number of pedagogical steps: orientation; elicitation; restructuring of ideas; application; and review. This framework was also adopted by the SPACE research team in their intervention stage. The steps included in the scheme involve the following aspects:

Orientation Phase.
The pupils are given the opportunity to develop a sense of purpose and motivation for learning about the topic. Practical problems, teacher demonstrations, film clips, videos and newspaper cuttings about an aspect of the topic can be used at this stage. So one can, for example, get a newspaper cutting about a man who was electrocuted if tackling electricity, or else use a documentary about how dolphins communicate in introducing mammals. What is essential at this point is that children are allowed to think about their ideas and the teacher is careful not to express any opinion. The teacher must remain neutral to the children's comments during the whole phase.

Elicitation Phase
At this stage pupils have the opportunity to spell out their ideas and beliefs about the scientific topic tackled. This can be done through discussions, poster designing or writing. It is important to get the children to spell out what they think such that they can become aware of their own ideas about the phenomena discussed. It also serves to inform the teacher about the range of ideas that the children hold, and which need to be tackled at the restructuring phase.

Restructuring of Ideas
This phase is the heart of the constructivist scheme and involves the clarification and exchange of ideas where ideas held are conflicted. It is only through resolving conflict that construction of ideas takes place. Children need to see that there are a variety of ways in which to consider the phenomenon under study. This realisation then leads to the evaluation of the effectiveness of the different ideas put forward. Construction of knowledge takes place once students are dissatisfied with their existing conceptions. The teacher must act as a diagnostician, being careful to avoid giving the correct answer, but somehow getting the children to think and reflect on the concept being discussed. The children should be allowed to arrive at conclusions themselves such that reconstruction of their old ideas occurs.

Application of Ideas
Once construction of knowledge has occurred, children need to practise using the concept. This is achieved through applying their newly constructed ideas to a variety of situations. This exercise allows reinforcement of the concepts constructed and

promotes the assimilation of the ideas learnt. If children are capable of applying the newly acquired ideas to a variety of situations, it would then be easier to make the reasoning their own.

Review

This is the final stage. At this point, children need to reflect on their learning process. They must first review their own previous ideas and opinions and compare them to their newly acquired views. If children are aware of their own change of conception, it is more likely that it will be held permanently (Driver & Oldham, 1986). Metacognition, as described in chapter 1, is used at this stage. It empowers the children not only to become aware of their learning process but also to be in control of it.

Practical suggestions

The main constructivist framework developed by Driver in the Children Learning in Science Project (CLISP) and adapted by the SPACE project, have included these aspects in a scheme spanning over a number of weeks. The approach so far has been that of tackling a topic as one single block. So, the first few lessons would serve as orientation phase. The next set of lessons then elicit children's ideas. The bulk of the remaining lessons then include the restructuring process, application of ideas and review. The whole topic would take a number of weeks to complete.

One main but significant criticism has been that such a scheme is often too time consuming and that it would be difficult to cover all the topics in a typical school syllabus using the constructivist model throughout. In addition, at primary level, topics tend to run across years rather than being covered as a single unit within one year. Should one then give up adopting a constructivist approach when teaching science? The answer is definitely a no. A teacher should always take a model of could practice and try and utilise it as part of his/her teaching approach. The constructivist model described is an example of quality learning. It provides a good methodology that promotes the construction of knowledge. There is surely much to be benefited in adapting features of this model to classroom practice.

The constructivist model being advocated is similar to Driver's scheme. It, however, takes time constraints in consideration and offers a possibility of adapting her approach to separate single science sessions. The term sessions, rather than lessons is being used as the model being proposed would require more than the traditional 45 minute lesson. It is envisaged that sessions running up to about one and half hours long can be organised.

The steps involved in the science sessions involve the following:

Introduction: Orientation and elicitation

The introduction to the session is to be characterised with a main activity engaging the children. A traditional introduction usually serves to tell children about the scientific concepts that are to be tackled in that particular lesson. The activity in this case, serves rather to get the children thinking about a particular aspect of the concept being covered. Such activities may take different forms. They may, for example involve the children in carrying out some practical experiments or some other form of group work which involves brainstorming ideas. In either case, if the activity is to serve both to introduce a concept and to elicit the children's ideas about that concept, it is essential to plan activities that provide ample opportunities for the children to express their ideas and opinions in a friendly atmosphere.

Examples of such activities may include asking children to take a piece of plasticine and make it first in the form of a sphere and then in the form of boat. Each time they are to see whether it floats or sinks in water. Such activity introduces the concept of floating and elicits children's ideas as to what makes some objects float and others sink. In another instance children can be asked to brainstorm in groups. In introducing the concepts of evaporation and condensation in the water cycle, children can be given questions such as 'what do you think happens when puddles dry up? Where do you think rain falling in the street ends up? Where does the water which we extract from the ground come from?' All these activities get the children to reflect on the mechanisms behind scientific phenomena that they experience.

Restructuring Phase

At this stage, the children tackle the scientific concept directly. Having expressed their ideas in the first phase, the children are now challenged. So, if a group of children believe that the water in dried puddles simply disappeared, then investigations on water can be organised. Heating some water and collecting the steam produced shows that the water had evaporated and was contained in air. A similar activity using a boiling kettle placed beneath a cold tile also shows children what air can hold. The differences of such an approach from the traditional one is that the experiments, rather than being used to illustrate a concept, serve to promote the construction of knowledge. The children need to be provided with situations where observations made help them to reflect on what is happening and why.

The teacher's role at this stage is that of promoting learning. The teacher needs to provide a cognitive platform. So rather than explaining and telling children that the water droplets obtained on the tile are condensed water, s/he needs to get the children thinking about how that water was formed. The teacher needs to ask questions like 'From where do you think that the water came from? Why did it form on the tile and not on another surface? What can you say about the tile?' These questions are the cognitive platform on which understanding and learning can take place.

Cognitive conflict is one type of platform for constructivist learning. As discussed in Chapter 1, asking children to predict outcomes of experiments can create conflict in Science. So instead of just trying out different materials to see which ones float and which sink, children can be asked to discuss the materials in groups and predict what would happen on dropping them in water. In the case of biological concepts such as living and non-living, children can carry out classification in groups. Conflict between group members and with the information eventually looked up in order to establish what classification there should have been also provide the necessary conflict to promote learning. These examples help to get children cognitively active, wanting to know whether their ideas are correct and in the process construct knowledge.

Application of Ideas and Review
Children can be considered to have fully understood a concept when they are able to apply it to different contexts. It is therefore important for teachers to provide instances where children can practise applying these newly constructed concepts. As many different examples and aspects of concepts should be tackled. So, on doing the concept of floating, children can look at different materials to see how they are used in practice. The examples of ships, where one has to consider the mixture of metal and air to understand why they float can be tackled. The significance of the painted bottom that delineates the limit of how much a ship can be loaded is also an application of the concept of floating. Such examples serve to consolidate learning, embedding the construction of knowledge within the child's cognitive structure.

The review serves to further consolidate the construction of knowledge taking place during the session. Children should be guided in their reflection on how the ides that they held at the beginning of the session were changed or consolidated as a result of the investigation that they carried out. This review process promotes metacognition when children become aware of their learning process. This awareness of one's own learning can be achieved by making children talk through their learning process to the rest of the class. Another method may be that of asking children to represent their learning journey on a poster.

In describing the various steps of these sessions, examples have been provided. One, however, may still at this point in time find difficulty in visualising what a typical complete science session may involve. The rest of the chapter is dedicated to describing two examples of such science sessions that have been developed and tried in the primary classroom.

Two particular examples :

How stable is it?
In the elicitation stage children were given a number of objects and asked to try and balance them on their different sides. One object used was an empty plastic bottle. The children were asked to try and balance it on its top, bottom and side. They had to do the same exercise with a small teddy bear soft toy. This activity made the children look closely at the dimensions of the object, whether it was flat or rounded, wide or narrow and reflect on how these aspects affected the object's stability. They were asked to explain why at times it was easy to balance the object in certain positions but not in others. What factors were determining how easily the objects could be balanced and how could they make an object more stable? Children expressed their ideas about their observations. In the investigation, the children were then given a flat square made of cardboard. They were first asked to see on which side it could be balanced without toppling over. They were then asked to balance it in the tip of a biro. Having done this simple experiment, the children were then made to carry out an investigation to determine the balance point for the square and for an irregular object. This standard

experiment involved making a number of holes at different points and hanging the objects and tracing the vertical line produced by a weighted string hung from the same point. Children were then asked to note why the two points obtained coincided. Children could then conclude that objects have a point at which they balance. If this point is on the side of the point at which one tries to balance it, the object topples. The children then presented their results to the rest of the class. In the review stage the children were asked to consider again the objects given at the beginning and to discuss where they believe that the point of balance is and how this determined the stability of the object. A number of practical examples were considered. As a conclusion, children in groups were asked to summarise what they had learnt in the lesson by representing their thought process on a chart.

Organs in our body

In the elicitation stage, the children were given an outline of a body and asked to draw the organs which they think make up our body. The drawings provide insight to the variety of organs which children are familiar with and their relative size. In the stage involving the restructuring of ideas, the children were divided into groups. Each group was assigned a different organ and asked to write down a number of questions about what they would like to know about an organ assigned to the group. They were then given books and other resources from where they could look up the information. A number of resources including facts about the different organs were produced by the teachers. These were given to the children to search for the answers to their questions. At the end of the activity, each group was to make a presentation to the rest of the class. Since each group had a different organ, then a considerable amount of knowledge was covered. In the application stage, the children were allowed to further their knowledge by considering other issues that relate to the organs involved. Again, the session was concluded with a presentation by the children who traced their learning over the session on a poster, although other activities such a written paragraph, or a concept map could be used.

Conclusion

Science sessions require a lot of preparation, both in thought, and in preparation of working and finding the appropriate resources. However, when one considers the richness of the learning experience, the whole exercise would be definitely worthwhile. It is of much greater educational significance to provide children with fewer science experiences promoting quality learning than numerous lessons involving the simple transmission of knowledge. In the long term, the gain acquired through science sessions would definitely outweigh the baggage of knowledge delivered through traditional methods.

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