Promoting the Construction of Knowledge during practical work

Suzanne Gatt*
University of Malta

Introduction

Practical work is an essential component of doing science. It is present as part of science across many countries, reflection national and international commitment to promoting scientific literacy for all and public understanding of science (Jenkins, 1999). Even from an early age, teachers get children to experience phenomena, try things out, to tinker with apparatus. Many times this process involves students in asking questions and making observations in order to find answers to their questions. This approach can be summarised to be that of hands on science. The assumption, in many cases is that if children are carrying out experiments, then they are learning scientific concepts too. This premise, in fact was that used by the Nuffield series developed during the 1960s and who based their approach on the belief that children learn by doing. Research in science education has since recognised that carrying out experiments does not necessarily equate to the understanding of concepts. Many times traditional practical work results in the mere following of instructions, the gathering and processing of data without really stopping to think about the how and why of such activities. This is why they have been aptly termed recipe-type experiments, where students simply follow instructions, as in the case of a recipe when cooking, without the need to know why or reflect on what they are doing. Experiments can also be reduced into a simple guessing game where students would be more interested in figuring out what they should notice rather than really be actively involved in the experiment itself (Driver, 1975).

This paper is not about abolishing practical work in science. It is about how practical work is to be organised such that it is used effectively to help students understand scientific concepts. This can be achieved through the constructivist approach whereby students are presented with situations, in this case, experiments, which provoke reflection and consequently the construction and understanding of concepts. It provides examples of such circumstances from research findings of a teaching scheme carried out with secondary level students in the area of Newton's Laws of Motion where cognitive conflict was used as the main vehicle to promote the construction of knowledge.

Theoretical Background

The constructivist approach to learning has been written about by many educators and given a number of different interpretations. It has also been applied widely in many teaching schemes. Basic to the theory of constructivism advocated by these numerous educators and researchers is the belief of the necessity for every human being to put together thoughts, interpretations and explanations that are personal to themselves in making sense of his/her experiences and situations. Windscith & Andre (1989) consider constructivism to take place when *students construct their knowledge from individual and/or interpersonal experience and from reasoning about these experiences'* (p.147).

* email: suzanne.gatt@um.edu.mt

On the same lines Watts (1994) states that '*constructivist learning is always an interpretative process involving individual's constructions of meaning relating to specific occurrences and phenomena. New constructions are built through their relation to prior knowledge."* (p.32). Constructivism considers that all individuals construct for themselves a unique picture of the world. In other terms, constructivism refers to learning in the form of 'making *sense of*'. The person needs to go through a mental process in order to be able to interpret and make sense of his/her surroundings. When one applies this to learning and teaching, it is important for the individual to be capable of understanding, or construing, the concepts that the academic community accepts as being true. Construction does not give learners the licence to claim that their meaning is as good as that of accepted knowledge. It is important to keep in mind that some meanings are better than others, especially those constructed and agreed on by the community of academics of any subject area or knowledge

The debate regarding the constructivist approach to teaching concerns the extent to which it is possible for any teacher to intervene in the thinking of a learner. This highlights the purpose and value of an intervention and how this can be achieved, and how effective it may be (Watts & Jofili, 1998). Learners organise and manage experiences so that their actions maximise desirable results and minimise undesirable ones. A constructivist teacher works at the interface between learner and the curriculum, making understanding knowledge and concepts meaningful for the learner without in any way diminishing the importance of having a specified curriculum. Had it not been possible for teachers to be able to play a role in determining and promoting the construction of knowledge, then teacher capability would not have any influence on the amount and quality of learning (Gatt, 2003).

There are two aspects of constructivism: the personal and the social aspect of learning and constructing knowledge. Many of the leading theories such as that of Piaget and Kelly are personal in nature, referring to the individual's cognitive activity and the brain interacting with the material to be learnt. Learning, however, also occurs within a social context, as is the case with the classroom The social aspect of constructivism focuses on how knowledge is constructed within a group or community. Knowledge is considered to be created and legitimised, now not through personal conviction but by means of social interchange in its many forms. The objective of language is that of delineating the relations among members of a community, being social, geographical or academic, and to achieve coherence in the community of knowledge (Staver, 1998). Knowledge is thus built both within the individual and by the community.

Constructivism is not a theory of teaching but a way of looking at knowing and learning. Therefore it does not imply a single specific teaching method. The individual may construct and learn under a variety of circumstances (Welford, 1996). In developing teaching approaches, one must keep in mind that knowledge is actively constructed by learners rather than transmitted by teachers.

Constructivism has been widely adopted when developing teaching schemes aiming at improving students' learning. The main approaches included conceptual change (Posner *et* al, 1982; Strike & Posner, 1985) and Driver and Oldham's (1986) constructivist approach. Many other schemes like concept mapping (Hammer *et al.*, 1998) and mental models, (Gilbert, 1998), have also been developed by many researchers. Common features that emerge are the use of cognitive conflict, metacognition and the application of scaffolding in promoting students' active participation in learning.

These approaches emphasise the need for learning to be stimulating. This can be achieved through the use of challenge or cognitive conflict, reflection or what is known as metacognition, and the ability to build patterns (Adey, 1997). It is important to provide children with opportunities where they can work out their ideas in their own language.

Stofflet & Stoddart (1994) assert that conceptual change is a necessary prerequisite for the formation of any valid theory. Learning involves the development of a new conceptual perspective through which content can be personally mediated and understood. Conceptual change allows challenging prior knowledge, a conflict that leads to accommodation of the pre-existing knowledge structure. Strike and Posner (1985) are the main advocates of conceptual change. They list four main steps necessary. These include the following: the student must first experience dissatisfaction with an existing conception; the new conception must be intelligible; the new conception must be plausible; and the new conception must be fruitful in that it has the power to make predictions and to predict phenomena.

Rosalind Driver is one of the pioneers of constructivism and research on children's ideas in the area of science. She has in turn also developed a constructivist teaching approach that formed part of the Children Learning in Science Project (CLISP). The strategy involved first eliciting children's ideas about the topic concerned, then helping them discuss the different views held, testing them for viability, and eventually, hopefully, changing the incorrect ideas into scientifically correct reasoning. The scheme was divided into the steps: *Orientation,* where students are given the opportunity to develop a sense of purpose and motivation for learning; *Elicitation*, where students spell out their ideas about the scientific topic tackled; *Restructuring of Ideas* involving the clarification and exchange of ideas where ideas held are conflicted and followed by the construction of ideas in a variety of ways in considering different phenomena; *Application of Ideas*, involving the application of the learnt ideas to a variety of situations; and *Review*, the final stage where students reflect on their learning (Driver & Oldham, 1986).

Cognitive conflict is also a vehicle used to promote the construction of knowledge and has been described as being central to the achievement of conceptual change (Park & Pak, 1997). Shayer and Adey *(1994) define cognitive conflict as* 'the term used to describe an event or observation which the student finds puzzling and discordant with previous experience or understanding' *(p.62) Stavy and Berkovitz (1980) argue that cognitive conflict occurs in two different ways: either between a child's cognitive structure related to a certain physical reality and the actual reality, or between two cognitive structures related to the same reality. It is not easy to produce cognitive conflict if students do not perceive causal relationships between the variables. This implies that the skill of attending to evidence may have to be explicitly taught on its own at some point in the school curriculum.*

Cognitive conflict is not, however, without problems. One problem is that students may not even be aware of any of the anomalies present (Stavy & Berkovitz, 1980). As Fensham & Kass (1988) point out, not all surprising events fulfil the potential of cognitive conflict, and can be simply shrugged off as just being inexplicable. This may occur either because students do not posses the cognitive ability to realise that a contradiction is present, or do not manage to observe that different behaviour is taking place. If students do not realise that the predictions are in contrast with their observations, or that the other students' ideas differ from their own, then it is not possible to promote the desirable conceptual change. Problems may also arise even though students are aware of the discrepancies between observations and predictions. This may occur if students opt to disregard findings on the ground that they are irrelevant to the current conception being considered by them. They may also choose to reject the observed results by voluntarily or involuntarily manipulating evidence (Gauld, 1989). In addition, students may be able to accept two conflicting conceptions at the same time where they do not distinguish between everyday and scientific reasoning (Solomon, 1983). Another problem with cognitive conflict is that it may make the situation intimidating to students (Watts & Bentley, 1987). It is discouraging for a student to realise that his/her ideas do not agree with what is actually believed by scientists to happen or to the conceptions held by peers, especially if the situation repeats itself a number of times. The teacher must be careful to provide conflict that is of the appropriate level to promote learning without demoralising students.

Every learning situation should have an element of self-regulation and awareness of one's own learning process – what is known as metacognition. Wittrock (1994) describes metacognitive learning as the *'awareness and control over one's thought processes during learning'* (p.30) and argues that it should be included as part of teaching. The advantage of metacognition is that it increases transfer among students of different abilities and across different subject matters and facilitates conceptual change.

Aim of the Study

The research reported here involves a teaching scheme developed within a constructivist framework. The topic area chosen is Newton's Laws of Motion. This topic was chosen since it is a particularly problematic topic and it happens to be taught at the beginning of the fourth year of secondary education. This ensures that students have a minimum of one year background knowledge of Physics but are as yet far from their national school leaving examination. The research aims to promote the construction of knowledge and consequently better understanding of Newton's Laws of Motion. It aims to achieve this through the use of cognitive conflict, scaffolding and metacognition. This paper focuses on how cognitive conflict can be used to promote construction of knowledge during practical work.

Methodology

The scheme adopts particular methods in providing the environment and situations to promote construction of knowledge. The main tool used includes cognitive conflict, between the prediction of and actual outcomes of experiments, and that promoted through the social construction of knowledge through discussion and exchange of opinions.

The scheme incorporates two types of cognitive conflict. The first one involves comparing and contrasting of ideas expressed by different students, while the second one compares a prediction with the actual outcome of experiments carried out. The conflict situations have been chosen such that they are: within a context familiar to the students; and while making a cognitive demand on the students, are neither too easy nor too difficult that they are incomprehensible.

One way of promoting the type of conflict described above is the use of social interaction between students. Different individuals have different ways of looking at things. They will, therefore, often have discordant ideas. Such ideas provide the necessary conflict, leading students to insight and understanding. This type of conflict can be identified in a number of occasions. The main pattern is that students, when working in groups, are given opportunities to discuss and debate the outcomes and results of their observations. Discordant observations will promote the desired conflict whereby students would then be interested and motivated to understand the concepts being discussed in order to know whether their assertions are good or not and why.

Cognitive conflict can also be brought about directly through practical experiments. The students are introduced to the experiment to be carried out. They are asked to predict what outcome they expect to obtain and why. When the experiment is actually done, and a different result is obtained, students would want to know and understand why. Constructive learning thus takes place.

One situation of cognitive conflict was used in introducing the properties of Newton's third law pairs. Students were organised in groups of four and given a pair of spring balances. They were asked to predict what each spring balance would read in two situations:

- when both students are pulling at the same time; and
- when one student is pulling and the other is holding his/her hand stiff.

Many of the students are expected to predict that the readings will be the same in the first case but different in the second. It is envisaged that students will expect the person pulling to exert a greater force than the one who is holding the spring balance. A common misconception is to believe that the more active one would exert the greater force. When the situations are eventually tried out and the same reading is obtained in both situations, conflict will arise. This will motivate students to try and make sense of the situation, providing fertile ground for active learning.

Another example of cognitive conflict was used when introducing Newton's First Law. The students were presented with a trolley on a friction-compensated runway. They were then asked to identify the forces acting on the trolley and to predict the resulting motion when released. Many are expected to predict acceleration. This would provide the first instance of cognitive conflict when constant velocity is obtained. Students are expected to realise more easily that a resultant force of zero gives constant velocity. The argument is further developed by considering two other situations. In the first case an additional forward force is added whereas in the second instance a resistive force is introduced. In these cases, a resultant force is present which produces acceleration and deceleration respectively.

The scheme consists of ten lessons, each three quarters of an hour long. The first five lessons focus on the properties of forces and Newton's third law. Lessons 6-8 focus on the effect of a net resultant force, while the last two lessons introduce the concept of momentum and Newton's second law. A teacher, teaching fourth form students in one of the Junior Lyceum schools (local state grammar type schools) was willing to try out the scheme. The teacher was a female education graduate and had five years teaching experience.

A total of 42 students in two fourth form classes in a girls' Junior Lyceum School were taught according to the scheme developed by the researcher. One class consisted of 25 students, and were considered to be of average ability. The other class had 17 students and were the weakest students in the whole form. Although there were disruptions in lessons due to class outings and other extra curricular activities, the scheme was eventually done within four weeks of work.

Data was collected in different ways and from different sources to ensure a degree of triangulation (Hammersley,1983). Quantitative and qualitative methods were used together in order to obtain as clear a picture as possible. The data collected included: Field notes through non-participant observation of the researcher; audio-taping all the lessons; and personal diary filled by students at the end of each lesson.

Results

The activities aimed at provoking cognitive conflict mainly included situations requiring students to make predictions about outcomes of experiments. This occurred basically in two situations: during the activity requiring students to arrive at the properties of the Newton's third law pairs of forces and when learning that a resultant force causes an object to accelerate.

The students' dialogues provide insight into the students' reasoning in any one of the situations identified. The transcript below shows the dialogue between the students and the teacher before trying out the experiment where they had to pull two spring balances connected to each other. The students predicted that the balances would give different readings depending on how much the person at each end was pulling. The role of the teacher here was crucial. The students had only considered the possible size of the force exerted and did not really think much about their logic. The teacher's questions not only helped the students to become aware of their own hypothesis, but also to reflect on how they arrived at their conclusion.

S_1 **The first experiment…one pulls from one side and another from the other**

T **Yes, and what is going to happen?**

S_2 **They are going to extend**

T **Yes, what do you think…what did you write that will happen?**
S_1 **I wrote that the one pulling more will have a greater force.**
T **What do you think, will the forces be the same or different?**
S_1 **No, different**
T **Why different?**
S_1 **Because they are going to pull with a different force.**
S_2 **It depends on his force**
T **What do you mean by 'depends on his force'?**
S_2 **The force of gravity and the force he exerts.**
T **Who is making the force?**
S_1& S_2 **We are**
T **Do you want to try it? You are saying that they are different**

The following excerpt, which occurred just afterwards, sheds light on the students' reaction on trying out the experiment in practice and noticing that the two balances gave the same reading. On reading the result together, the students experienced surprise on noting how much their predictions differed from what actually happened.

T **Do you want to try it out?**
S_1 **It moves on its own.**
Chorus **They have the same reading!**
T **Read the values**
S_2 **The force is being distributed.**
T **What do you mean by the force is distributed?**
S_2 **Because they are connected to each other**
T **What do you mean?**
S_2 **Because they are connected by the hooks in the middle.**
T **By the way, do you know what the spring balance does?**
S_1 **It depends on how much you pull.**
S_2 **It gives the force present……**
T **How much force you are making. What can you say about the force you are making?**
S_2 **That they are equal.**
T **So is it the same as what you thought before?**
S_1 **No**

Cognitive conflict alone, however, does not ensure that correct understanding will follow. The teacher's role in guiding the students thinking is again observed to be crucial in promoting the desired learning. As the transcript shows, the reason put forward by the students just after the observation does provide a logical and plausible explanation for the observation made. The reasoning manifested, however, is wrong, in that it is not the case that the force is distributed equally between the two, but rather that the two students were pulling with the same force.

The effectiveness of cognitive conflict arising from obtaining a different result to that expected transpires also from the students' diaries. The students realised the educational benefit of thinking about an experiment before actually trying it out. The '*unexpected outcome*', as one student described the discrepancy, helped the students to gain greater insight of the situation and to consider it in more detail than just at face value. Some comments made by students include;

'I enjoyed the lesson as it gave us time to think about the experiment before we made it.'

'I liked the lesson because things that are obvious to me, when doing them in an experiment, you find out that they are completely different than you imagined.'

'I liked the lesson because we did experiments in the lab to determine what was right and wrong about what we said and thought.'

Cognitive conflict was also designed to take place when introducing the effect of a net resultant force. The situation involved studying the motion of a trolley going down a runway. Having shown students that a trolley moves down the friction-compensated runway at constant velocity, an additional forward force was introduced through a falling weight attached to a string. At this point, the teacher, asked the students to predict the motion they expected to see. As had been expected, some of the students predicted a larger constant velocity whereas others mentioned acceleration. Cognitive conflict thus also occurred in this situation. It also motivated the students to want to know what actually results.

T **What type of motion do you expect?**
S_1 **It will go faster.**
T **It is going faster, but is it going to be constant velocity?**
S_1 **No**
T **Will I have constant velocity?**
S_2 **I think that the space between the dots will be larger, but the same**
S_1 **No, not equal, the space will increase with time.**
T **So what do you think? Will I have constant velocity but greater, or will the trolley increase its velocity with time?**
S_1 **As time passes, the trolley will go faster, gain velocity.**
T **We have different opinions. Let's then try it out.**
S_2 **I think that the space between the dots will be larger, but the same**

The teacher has a crucial role and must help students in trying to make sense of the situations encountered when doing experiments. The excerpt below shows students realising the effect of a net resultant force and making generalisations from the situation considered. The teacher's contribution not only can be seen to direct the students' thinking but also to the language that is typically used in Physics when expressing their reasoning.

S_1 **In the first situation the forces were equal, in the second case…**
S_2 **We had acceleration.**
T **Yes in the first case …**

S_1 **We did not have any weight (referring to the weight which provided the extra force forward)**
T **We did not have the weight, and we had constant velocity, and the forces…**
S_3 **Were equal**
T **Equal, with equal forces we had constant velocity, then what did we have?**
S_1 **Acceleration**
T **Acceleration, and the forces?**
S_2 **Not equal**
S_3 **They are not the same.**
S_1 **Equal forces, constant velocity, not equal forces make acceleration**
T **Yes you can say that, but instead of equal what can you say?**
S_2 **Different**
T **Or unbalanced forces because we do not have balance…**

Evidence that some form of knowledge construction did actually occur during these experiments can be gleaned from a number of the students' entries in their diaries. There are instances where the students are capable of stating the new knowledge constructed.

'I enjoyed the lesson because we learned about interesting forces that we didn't notice'

'I liked the lesson because we looked at knowledge about things we see everyday and which we find difficult to understand. So we can maybe learn the scientific reason'

Metacognition forms an essential step in learning and should follow cognitive conflict. It is not enough for students to discuss and resolve conflict when doing experiments, they also need to become aware of their own reasoning. Such examples can be identified in the teaching scheme. In one particular circumstance, in promoting metacognition, the students were not only asked to reflect on their own thinking, but also to learn how to label the situation, the thinking process.

T **When you had a weight similar to this, what type of motion did you get?**
S_1 **The weight was greater than the frictional force**
T **So, when you have one force greater than the other, what do we say that we have? If you look up your notes, you will know? Look it up.**
S_2 **Net resultant force**
T **Yes, I will have a net resultant force. Now, what type of motion do you expect to get in the situation you are considering?**
Ss **Acceleration (Chorus)**
T **Why are we going to get acceleration?**
S_1 **Because the force due to the weight is greater than the friction**
T **But what can you say overall?**
S_2 **The frictional force is smaller.**
T **So, I have one force greater than the other. What can I say?**

S_1 A net resultant force

T And when I have a net resultant force, what type of motion will we have?

S Acceleration (chorus)

The teacher's questions and probing is essential. Rather than giving the answer, the teacher directed the students to previous work and asked them to go through their notes to identify the language they had used to talk about that specific situation. Not only did the students realise that there was a net resultant force forward, but also that one usually discusses the situation in terms of the presence of a net resultant force.

Some of the student diary entries show their realisation of their own previous thoughts and ideas, and how they changed as a result of the activities done in the class.

'We learned the different properties of forces working in pairs. The most important thing was that we concluded what the properties are ourselves and how we can understand'

' was interesting because I learnt things which are easy but not so easy at first sight'

'I liked the lesson as it was very interesting. I did sometimes ask the same question to myself when I came across them, for example of magnets or that of having two forces'

It can be seen that although the activities involved mainly practical work, the students' focus is on their learning process – the construction of knowledge.

Discussion

If there is anything that comes out from this research it is that organizing practical work for effective learning takes much more thought than the preparation of equipment. Teachers need to think and plan about how to get their students to think and reflect on the activities and experiments that they are carrying out. What has been shown is that cognitive conflict is one approach that can promote such reflection. When presented with observations that conflict with predictions made, students are motivated into finding the reason to why such a discrepancy is present. The learning process has been activated.

It is important to consider a number of factors when evaluating the effectiveness of practical work. Miller et al. (1999), in drawing up a model for measuring effectiveness of practical work, include the teacher's objectives, the design features, what the students do and what the students actually learn as the four key factors. These are in turn influenced by the teacher's view of science, learning and the institutional context in which the practical is to take place, as well as the students' view of science, learning and institutional context. Within this framework, in order for constructivist activities to be effective, it is necessary for teachers to endorse fully constructivism and believe in its effectiveness in enhancing learning. If teachers are not convinced of the efficacy of the teaching methodology that they are using, then it would be difficult to promote the construction on knowledge. Likewise, students need to learn to appreciate that practical work goes beyond the mere following of instructions but that they need to reflect on both the experiments they are performing as well as their learning processes in grappling with the various scientific concepts they are learning.

Practical work should be the basis for active learning and the context for providing learning environments promoting it. Practical work should also be a vehicle to help students become independent learners. As Bentley and Watts (1989) state, active learners need to initiate their own activities and take responsibility for their own learning. This implies that they have to make decisions and solve problems, know how to transfer skills and learning from one context to other different contexts. Students therefore need to learn how to organize themselves and how to evaluate their own and their peers' work. Experiments form a very good context within which such skills can be developed. Finally they also help to make students feel good about themselves as learners, particularly in science. Practical activity thus goes beyond the scope of covering specific topics. It leads to a greater emphasis on learning how to learn than how to learn specific topics and areas in science or in any other subject.

Active learning can only be achieved within a particular framework. From an affective point of view, it is essential for active learning to take place within a non-threatening learning environment, as students need to work within a supportive environment if they are to discuss and test out their ideas (Bentley & Watts, 1989). Students need also to become involved in the organization of the learning process. Obviously, students need to have opportunities to take decisions about the content of their learning. This does not come alone, they need to learn the skills of learning, of evaluating and assessing their own work and of giving relevance to the work they are doing.

Conclusion

Practical work should be considered more as a vehicle through which students' learning can be enhanced than simply as a means of introducing students to the process of doing science. While one cannot diminish the importance of laboratory work to that of simply introducing students to the skills of observation, hypothesizing, data collection and evaluation etc. on which scientific methodology is based. The understanding of concepts should still keep centre stage in such activities. If one can manage to capture the development of skills concurrently with effective learning then practical work can be considered to be the central driving component in learning science.

References

Adey, P., S., (1997), It all Depends on Context, Doesn't it?, Searching for General Educable Dragons, *Studies in Science Education,* 29, 45-92.

Bentley, D., & Watts, M., (1989), **Learning and Teaching in School Science,** Milton Keynes: Open University Press.

Driver, R., (1975), The Name of the Game, *School Sci. Review*, 56, 800-805.

Fensham, P., Gunstone, R., & White R., (1994), **The Content of Science: A Constructivist Approach to its Teaching and Learning,** London : The Falmer Press.

Gatt, S., (2003) Constructivism – An effective Theory of Learning in Gatt, S., & Vella Y., (eds.), **Constructivist teaching in Primary School Social Studies, Mathematics, Science, ICT, Design and Technology,** Malta: Agenda Publishers.

Gauld, C., (1989), a Study of Pupils' Responses to Empirical Evidence, in Millar R., (Ed.), **Doing Science: Images of Science in Science Education,** London: The Falmer Press.
Gilbert J., (1998), Explaining with Models in Ratcliffe M., (ed.), **ASE Guide to Secondary Science Education,** Cheltenham : Stanley Thornes
Hammer, P., Allmark, B., Chapman, J., & Jackson, J., (1998), Mapping Concepts in Science, in Ratcliffe, M., (ed.), **ASE Guide to Secondary Science Education,** Cheltenham : Stanley Thornes.
Jenkins, E.W. (1999), Practical work in School Science –some questions to be answered, in Leach J., & Paulsen A.C. (1999), **Practical Work in Science Education – Recent Research Studies**, Roskilde University Press: Kluwer Academic Publishers.
Johnson, J.K., & Howe A., (1978), The use of Cognitive Conflict to Promote Conservation Acquisition, *Journal of Research in Science Education,* Vol. 15, No.4, 239-247.
Miller, R.H., Le Marechal Jean-Francois & Tiberghein A., (1999), "Mapping" the domain – varieties of practical work, in Leach J., & Paulsen A.C. (1999), **Practical Work in Science Education – Recent Research Studies**, Roskilde University Press: Kluwer Academic Publishers.
Park, J., & Pak, S., (1997), Students' Responses to Experiential Evidence based on Preconceptions of Causality and Availability of Evidence, *Journal of Research in Science teaching ,* Vol. 34, No.1, 57-67.
Posner, G., Strike, K., Hewson, P. & Gertog, W., (1982), Accommodation of a Scientific Conception: Towards a Theory of Conceptual Change, *Science Education,* 66, 211-227.
Shayer, M., & Adey, P., (1994), **Really Raising Standards,** London: Routledge
Solomon, J., (1993), Four Frames of Mind, in Black, P. & Lucas A.M., (eds.), **Children's Informal Ideas in Science,** London : Routledge.
Staver, J., (1998), Constructivism : Sound Theory from Explicating the Practice of Science and Science Teaching, Vol. 35, No. 5, 501-520.
Stavy R. & Berkovitz, B., (1980), Cognitive Conflict as a basis for Teaching Quantitative Aspects of the concept of Temperature, *Science Education,* 10(1), 99-110.
Stofflet, R., & Stoddart, T., (1994), The Ability to Understand and use Conceptual Change Pedagogies as a Function of Prior Content Learning Experience, *Journal of Research in Science Teaching,* Vol. 31, No. 1, 31-51.
Strike K., & Posner, G., (1985), A Conceptual Change View of Learning and Understanding, in West L.H.T., & Pines, A.L., (eds.), **Cognitive Structure and Conceptual Change**, London : Academic Press
Watts, D. M., & Bentley D., (1987), Constructivism in the Classroom, Enabling Conceptual Change by Words and Deeds, *British Educational Research Journal,* Vol. 13, No.2, 121-135.
Watts, D.M., & Jofili, J., (1998), Towards Critical Constructivist Teaching, *International Journal of Science Education,* Vol. 20, No.2, 173-185.
Watts, D.M., (1994), Constructivism, Re-Constructivism & Task- oriented Problem-Solving, in Fensham P., Gunstone, R. & White, R., (eds.) **The Content of Science : A Constructivist Approach to Teaching and Learning,** London : The Falmer Press.
Welford, G., (1996) Introduction, in Welford G, Osborne J. & Scott, P.,(eds.), **Research in Science Education in Europe**, London : The Falmer Press.