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Factors Influencing Curriculum Development in Higher Education Physics

A Physical Sciences Practice Guide

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Report of a Literature Review.
Factors Influencing Curriculum Development in Higher Education Physics

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Introduction

This report presents a summary of the main findings from the science education research literature relating to physics education. These findings are used to offer guidance in developing a curriculum in physics at higher education levels.

The overall evidence from the research literature is brought together under four headings:

Physics for Whom?
What Physics?
How to be Taught?
How to be Assessed?

From this, an attempt is made to develop a set of specific guidelines. These are offered as a set of **landmarks** which will define the territory of curriculum design as applied to physics in higher education.

Curricula constructed following these guidelines are likely to match the needs of learners, their aspirations and requirements. For undergraduates, an important aspect will be the need to develop the skills required for a very wide range of career opportunities involving skills specific to physics as well as a range of wider skills.

The bibliography shows the range of papers consulted in developing this analysis. We have looked at the aims of physics education and the nature of physics, problem solving, laboratory work, assessment in physics, students' attitudes related to physics, theories of science/physics learning and psychological theoretical underpinnings as well as a possible framework for understanding and evaluating higher education physics.

The aim throughout has been to base all recommendations on the ***clear evidence offered in the research literature***.

Appendices offer an annotated bibliography and details of the journals consulted.

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Executive Summary

The aim has been to bring together the evidence from empirical research and to use this evidence to define a set of clear guidelines to inform future curriculum planning. Thus, the recommendations are ***not*** based on opinion or experience but attempt to reflect what is clearly demonstrated empirically.

The physics curriculum should:

1. Meet needs of all learners	Be designed to meet the needs of all students: those taking a single course as part of another degree; those likely to pursue a career outside formal physics; as well as those who will become practising physicists: education *through* physics as well as education *in* physics; reflect attempts to answer questions like: what are the questions that physics asks? How does physics obtain its answers? How does this physics relate to life?
2. Build on school physics and the way learning takes place	Take into account school physics: what is taught, how it is taught as well as the wider experiences and aspirations of those who have undertaken school courses. Higher education must build on what has already been achieved not only in terms of knowledge and understanding but also in terms of the way processes of thinking and learning have developed;
3. Aim at conceptual understanding	Aim at allowing students to understand and not merely memorise, to appreciate the way understandings have arisen, the way physics knowledge develops as well as acquiring the key skills associated with understanding physics: this will require significant content reduction, focusing on the essential skills and understandings which are required; offer opportunities for students to apply ideas, to develop critical thinking and to be able to weigh evidence;
4. Reveal the role of physics in society	Be built in the context of applications (or, better, around applications), which are appropriate to the interests, needs and aspirations of students;
5. Take into account the way students learn	Be developed using the research findings about the way learners process information: avoid developing topics with high information demand before the underpinning ideas are adequately established to avoid overload and confusion; use pre-lecture activities to reduce information load;
6. Offer genuine problem solving experience	Offer students opportunities to develop problem solving skills, to be seen not only in terms of applying knowledge in a routine way but also in highly open-ended situations where physics ideas relate to life situations and decision-taking;
7. Use labwork appropriately	Be designed with laboratory work which has clear explicitly stated aims, where experiments are used to illustrate, to develop and challenge ideas, where the whole experience is seen as integral to the very nature of learning physics (involving pre-labs as well as meaningful post-lab exercises);
8. Take account of language and communication	Be designed with opportunities for students to gain experience in communicating the ideas of physics both orally and in writing as well as opportunities for students to work collaboratively in teams;
9. Develop intellectual growth	Be organised in such a way that students develop intellectually, moving from the passive acceptance of knowledge to a more mature appreciation of the nature of knowledge, their role as learners and, ultimately, towards the ownership of knowledge and personal autonomy;
10. Involve appropriate assessment	Employ assessment that is integrated into the curriculum and reflects curriculum purpose, is diagnostic and formative, and aims to give credit for a wide range of skills including conceptual understanding, critical and analytical thought, communication and the application of ideas in new situations.

Main Conclusions from Research

Aims of Physics Education at the Higher Education Level

Although the aims of higher education are articulated in many documents, concerted efforts are needed to enable these goals to be achieved. Thus, over a degree in physics, the student should:

1. Develop the basic skills and understandings over the general area of physics;
2. Learn to apply physics ideas to new situations appropriately;
3. Look critically at understandings derived from physics;
4. Learn to weigh evidence and take decisions;
5. Be able to work in a team to achieve a common goal;
6. Be able to communicate some ideas of physics cogently and clearly.

There is an underlying dilemma with such goals. Some students undertake courses in physics because their commitment lies in physics and to a career in physics. Others will not have such specific career goals. A degree in physics may be seen as a means to enter a wide range of other career options. There will also be some who undertake a specific course in physics as part of a degree in a cognate or, even perhaps, unrelated subject area.

The physics knowledge and experience can be an end in itself but it is better to see it as a means to achieve many goals which will bring benefit to the student in a wider context. Therefore, a student who undertakes one course in physics as part of another degree programme might develop some of these skills but the emphasis might be less on the physics knowledge and experience skills and more on the wider skills, including skills related to learning in general.

The Nature of Physics

Physics, like the other science disciplines, operates at three thought levels: the macro, the micro and the symbolic (See Figure 1). The macro refers to the phenomenological: what can be perceived by the senses without the aid of instruments. This is usually concrete. The micro refers to that which can only be perceived with the aid of instruments or that which is abstracted by inference from physics enquiry. This is often abstract. The symbolic refers to symbols, models and equations and these are often representational. The micro and the symbolic often interpret the macro. These three interact and have to be manipulated skilfully for understanding to take place. The novice learner has great difficulty in working at all three levels at the same time, almost certainly because of information overload.

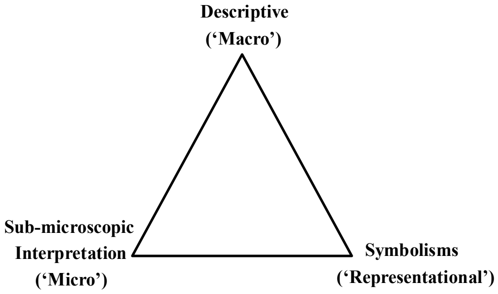

Figure 1: Three levels of science concept representation (Source: Johnstone, 1991)

At school level, working at all three levels too soon brings about rapid information overload. Understanding becomes virtually impossible and students resort to memorisation to pass examinations. There is clear evidence that this also happens at university: understanding is the casualty while attitudes towards the physics taught tend to become more negative. Thus, it is important to allow school students time to experience the macro before launching into the interpretation and representational aspects and this will still be true at early levels in higher education courses.

At school level the nature of physics, as with any other science discipline, emphasises its three levels of thought and operation. However, at the higher level, emphasis should also include its epistemology. For example, there are observable facts (like gravity). The interpretation of such facts is open to adjustment in the light of new evidence. There are two aspects of epistemology: whether an interpretation of evidence is true (ontological aspects) and the place of the individual in the construction of understandings (relational aspects). The approach adopted by a university teacher will strongly affect the way the students understand the nature of physics knowledge.

Many students even at the higher education level interpret the facts of physics using wrong ontological categories contrary to what experts do. They also use intuitive knowledge as a resource in their interpretations. Higher education physics should be constructed taking these into consideration. Otherwise students maintain their alternative conceptions as well as misconceptions. In addition, many continue to find this domain difficult. Students must be allowed to see themselves as important in physics knowledge construction and should be given opportunity to consider the development of physics inventions, the result of the interpretation of physical facts.

Language and Structure of Physics

The language of physics is another important aspect of its nature. This can be considered from different perspectives. One perspective is its discursive characteristics. Whereas social discourses are characterised by being personal, theory constitutive, anthropomorphic, speculative and animistic, the language of physics is often impersonal, descriptive, transmissive, objective and labelling.

A major problem is the way that physics uses English words from every day language in very precise and specific ways (eg energy, work, equilibrium, power). There can be a ‘carry over’ of everyday language use into physics resulting in considerable confusion.

Physics language has high information density. This implies that the language is often of the content type. It is claimed that, while every day discourses have about 2-3 content words per clause, physics often has between 10-13. We have also noted that the micro level, where physics is often focused, involves processes of abstraction. This has an effect on the language of physics. Abstraction often demands the use of models and analogies.

There is a real danger in the model being seen as the reality and the analogy being used not only to illustrate but to prove points. There is also the danger that too many models may exist and that some models may over-simplify. Models and analogies may introduce added complications in generating information overload. Thus, while models and analogies may be very useful in making abstract ideas more accessible, there are some dangers that such approaches may lead to greater confusion

Alternative Conceptions in Higher Education Physics

Alternative conceptions (or intuitive knowledge) exist even among undergraduate students. Research, however, reveals that students progress along a path from naïve knowledge to more authentic knowledge. Thus, students at the higher education level will be at various points of progression. Contrary to the belief that these alternative conceptions lack structure, it has been demonstrated that they indeed possess structure imposed by the students. They are robust, phenomenological and driven by surface features.

Alternative conceptions interact with authentic physics knowledge. They can form resources with which students interpret incoming information in physics. This interaction may be fruitful or may be a set back. It can be fruitful when they are adequately related to the concepts being taught. In that case they form anchoring material. On the other hand, if they are wrongly related (eg while dealing with the same concept the naïve conception may be placed in wrong ontological category), then it will form an impediment to correct conceptions.

Numerous alternative conceptions are identified in the literature. The curriculum must take these into account in the selection of topics. The curriculum must be structured in such a way that the topics progress from the phenomenological to the micro. It must also be born in mind that the micro, which is readily used by the expert, is not often understood nor used by the students easily.

In all of this, there is a real place for dialogue, where students perhaps work in groups as they tackle a series of more open-ended problems. This allows ideas to interact and misconceptions to be exposed in an acceptable fashion. The tutorial offers considerable opportunities for this. However, learning will need to be re-thought in terms of groups of students interacting with physics situations, the lecturer's role changing from the central controller of information to be manager of learning. The use of the tutorial needs re-thought.

Problem Solving in Higher Education Physics

Problem solving is intrinsic to all scientific activity. However, the literature reveals that the conception of problem solving as a generic skill that can be taught is in question. In other words, a student may be able to solve problems in physics but that is no guarantee that the student can solve problems as well in other areas of life. In addition, there are major issues about the extent to which problem solving skills in physics can be taught. Here, it is likely that experience and increasing confidence may be two major factors. Both of these demand that students have increased opportunities on their own or in groups to solve problems, especially the more open-ended problems.

Research has unequivocally demonstrated that the difference between expert and novice problem solving ability is greatly dependent on the extent of domain knowledge they possess. Thus, experts are better problem solvers because they have acquired a great deal of domain specific knowledge. The presence of extensive domain specific knowledge enables an expert to group information into manageable units as well as to pick out important information while ignoring redundant material. The domain knowledge has other benefits: novices use sensorial or surface features in analysis whereas experts use other features or criteria such as causal relations, functional relations, internal consistency across objects or problems etc. This has led to the emphasis on formation of background knowledge and formation of schema rather than the teaching of problem solving skills.

Deriving directly from the above is the use of the different types of problem solving. These have been organised into a scheme of eight as shown in Table 1.

Type	Data	Method	Goals	Skills Bonus
1	Given	Familiar	Given	Recall of algorithms.
2	Given	Unfamiliar	Given	Looking for parallels to known methods.
3	Incomplete	Familiar	Given	Analysis of problem to decide what further data are required. Data seeking.
4	Incomplete	Unfamiliar	Given	Weighing up possible methods and then deciding on data required.
5	Given	Familiar	Open	Decision making about appropriate goals. Exploration of knowledge networks.
6	Given	Unfamiliar	Open	Decisions about goals and choices of appropriate methods. Exploration of knowledge and technique networks.
7	Incomplete	Familiar	Open	Once goals have been specified by the student the data are seen to be incomplete.
8	Incomplete	Unfamiliar	Open	Suggestion of goal and methods to get there; consequent need for additional data. All of the above skills.

Table 1: Eight Scheme Categorisation of Problem Types (Johnstone, 1993)

At university level, although the more algorithmic problems have an important place, there is a need to use many more extended open-ended problems to enable the students to develop the wider skills and insights relevant to their future careers. It is important to recognise that real-world problems tend to be very open and not easily solved simply by applying appropriate algorithms. Thus, there needs to be greater experience offered to students of more open-ended problems. Many such problems exist in the literature.

‘Problem-based learning’ is a phrase which has appeared, especially in relation to higher education. It is important to recognise that the phrase is often used loosely. Problem-based learning is *not* simply the use of problems in laboratories and tutorials although this is, of course, desirable. Problem-based learning is a *total paradigm shift* in teaching and learning when all learning is built around real-world problem scenarios. There is evidence, from the field of medicine, that it does generate very different learning outcomes.

It has been suggested by empirical evidence that higher education students’ problem solving approaches are to a large extent determined by what they perceive to be the values and expectations of assessment policies in a department. Sometimes, the policies of a department and those of lecturers conflict while both may conflict with what the student actually requires and desires. Again the level of intellectual development of these students provides a framework for the understanding of this trend. Too often problem solving is reduced to an algorithmic process by which students learn to apply procedures correctly. While important, this is too limiting a process for the genuine intellectual development of students. Evidence shows that students wish much more and, indeed, are capable of much more.

The Laboratory in Higher Education Physics

Physics gains its understandings of the world around primarily through experimentation (including computer-based experimentation and simulation). At the moment, frequently laboratory activities are conceived as appendages to theory classes. However, the literature identifies the importance of the laboratory in enhancing conceptual understanding. Seen in this way laboratory practices ought to change from a place of strict adherence to already prepared laboratory manuals with specified instructions, procedures and outcomes to a place where *genuine enquiry* can take place. The laboratory can be used for problem solving and development of concepts. This will lead to a major revision in the way labwork is conducted. Manuals will be seen not as procedural guides but as guides to conceptual development. There is clear evidence of the power and effectiveness of laboratory experiences in offering opportunities for genuine problem solving. This does not necessarily mean changing the experiments to be undertaken. It does mean changing what we do with these experiments in terms of learning.

It is possible to set goals for laboratory instruction under three broad headings:

1. *Practical skills* (including safety, hazards, risk assessment, procedures, instruments, observation of methods);
2. *Transferable skills* (including team working, organisation, time management, communication, presentation, information retrieval, data processing, numeracy, designing strategies);
3. *Intellectual stimulation*: explanation of phenomena, developing conceptual knowledge, making connections with the ‘real world’, raising enthusiasm for physics, seeing physics at work.

In designing a labwork experience for any curriculum, it is essential to specify the purpose of that labwork. The organisation of labwork is therefore dependent on the goal set out for each session. To assist in this process, four laboratory styles can be distinguished with three descriptors (Table 2).

Style	**Description**		
	Outcome	**Approach**	**Procedure**
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student generated
Discovery	Predetermined	Inductive	Given
Problem-Based	Predetermined	Deductive	Student generated

Table 2: Laboratory Instructional Styles (Domin, 1999)

As can be seen from the description of the laboratory styles, the effectiveness and appropriateness of each style is dependent on the goal set out for the activity. Again the use of each style is also influenced by the stage of education. For the purposes of further emphasis, whatever the style, labwork should ***NOT*** be seen as a means of *concretising* conceptual learning but as a means of *developing* conceptual learning.

Care has to be taken in not over-emphasising the skills associated with the experimental. For some students, many specific experimental skills will be irrelevant as they move into non-physics careers. For many, specific skills taught in an undergraduate laboratory will not be relevant when they work as physicists: for most graduates employed as physicists after graduation, the specific skills are often very limited and can be developed as needed. It may well be thinking skills, confidence, the grasp of how experimentation can be used, and an understanding of how data can be interpreted which are much more important in both the short run and the long run. There are excellent reviews of the purposes of labwork and there is clear evidence in the literature that labs can be modified easily to generate better outcomes.

Assessment

Assessment in higher education should reflect the aims of higher education. Specifically, assessment in physics must reflect the aims of physics education. Too much has tended to emphasise the recall of information or procedures. Much that seeks to test applications of knowledge merely tests student skills in applying memorised procedures, with new data. Fundamentally, the aim in physics education is to develop understanding so that students can interpret and make sense of the physical world.

Although there are many different types of assessment in the literature, it is important to employ the right style of assessment for a particular purpose. In particular, it is important not to de-skill students by using objective testing like multiple choice which can frustrate the able as well as devalue open-mindedness and critical thought. The literature makes it clear that it is a very flawed way to assess. Structural communication grids offer a much more versatile form of objective testing, with greater emphasis on understanding although, again, overuse can de-skill. Concept mapping has also been found to be very helpful in understanding the process and stages of concept development of the learner. It is very useful as a diagnostic tool as well as for formative purposes.

Other forms of assessment relevant for higher education include portfolios, performance assessment, journal writing, open-ended short essays, verbal presentations. It is important to be clear about what skills are to be assessed (these need an agreed specification list) and then to select the best procedures. Thus, performance assessment provides insight into a student's level of conceptual and procedural knowledge while journal writing and portfolios give indications of the students' level of progress in their thinking, learning patterns and performance. Structural communication grids are easier to set than multiple choice, and are machine markable, while giving very useful diagnostic insights. Fundamentally, they give useful evidence on understanding physics concepts.

Attitudes Relating to Physics

Attitudes have been described as involving cognitive, affective and behavioural components. Once an attitude has been established, it tends to be stable over time. Technically, there is a difference between attitude and other affective concepts such as interest and motivation, but only attitudes are considered here. Attitudes have been demonstrated to influence and be influenced by achievement and by cognition.

Researchers demonstrate that there is a link between the cognitive and the affective and that physics education goals should embrace the two and not treat them as mutually exclusive domains. The implication is that attitudes can be developed and much of the study in the literature indicates that the approach to presentation and organisation of the curriculum goes a long way to determining the development of desired attitudes in students.

There are four areas where attitudes are important:

a. Attitudes towards physics;
b. Attitudes towards topics and themes in physics;
c. Attitudes towards the learning of physics;
d. Scientific attitudes.

Much research has shown clearly that a negative attitude towards physics is the dominant factor affecting student willingness to study further physics. Based on social psychological models, it has been shown that attitudes towards topics and themes in physics are developed by means of interactive teaching materials (teaching materials where the learners have cognitively to relate new input to previously held attitudes by means of specific teaching strategies of which the most common is role play).

There is little evidence relating to the latter two attitude targets. However, scientific attitudes are better regarded as scientific ways of thinking. The evidence available suggests that success in this is very heavily dependent on cognitive development.

It is very clear that a negative attitude towards physics gained quite early in life is the main reason why physics is not attracting potential undergraduates into physics courses. These attitudes tend to be well formed at early stages of secondary education and well-meant interventions by higher education physics departments (like school visits, open days etc) have minimal impact in modifying such attitudes. Some recent work suggests that, when physics is made inaccessible to school students (almost always through information overload), they tend to resort to memorisation to pass examinations and this, in itself, seems to generate negative attitudes towards physics.

At school level, the way the curriculum is presented is critical in attracting students towards physics or repelling them from the subject. One major factor is the perceived future relevance of physics to the student. An applications-led approach has been found to be very effective. By 'applications-led' is meant that actual topics to be studied are determined by the applications. Relevance to the lifestyle of the learners at their stage of development becomes of utmost importance. The same physics is covered but the order, context and presentation are all very different. In two countries where such an approach has been adopted, the impact on school students is remarkable in attracting and retaining students in their studies. In turn, this generates many more applicants for higher education in physics. Research with university physics students suggests that this approach would be *very attractive* at higher education levels.

It is too easy to dismiss such an approach as removing the rigour. The evidence shows clearly that the rigour is ***not*** removed and, in one country where this has been studied, the standards at the end of school were found to be unexpectedly high (higher when compared to another country where the traditional approach was used).

Science Learning and Teaching Theories

Science education has come of age and a number of learning/teaching theories have been propounded as a guide to practice. It must be remembered that the word 'theory' is used to mean a working summary of understandings derived from empirical evidence. We have distilled those relevant to this report and categorised them under the cognitive acceleration theory, cognitive load theory, the information processing theory, the conceptual change theory and the alternative conceptions agenda. The presentation is in no particular order.

The cognitive acceleration theory (Shayer and Adey) is based on the assumption that there is a mismatch between the cognitive capacity of school students and curricula demands. It therefore seeks to handle the problem by proposing an acceleration of the cognitive development of the students through intermittent activities. Research results, however, show that the impact on performance is mediated by a number of other factors and that cognitive capacity does not have a deterministic effect on performance. Most of the suggestions from the literature are to integrate the intervention packages into the curriculum.

Cognitive load theory (Sweller) is interested in the problems that arise from the interaction between task complexity and cognitive architecture. It engineered a number of instructional strategies that address the issues of the worked example effect, the completion effect, the redundancy effect, the expertise reversal effect, the modality effect, the split attention effect, the imagination effect, the isolated interacting element effect, the element interactivity effect, the guidance fading effect, and the goal-free effect. This is an evolving area for research and holds promises of directing teaching in physics. However, this theory is limited in its focus when a consideration is given to all the variables involved in the teaching/learning process.

The information processing theory (Johnstone) is premised on the fact that manipulating the teaching/learning situation in the light of the way students process information will lead to a better performance. Research has shown unequivocal results that authenticate this claim. The major message is the need to organise learning to reduce the demand on the working memory, to prepare the learner by prelectures or prelabs and to reduce 'noise' or redundant material while making the 'signal' or important material explicit. A predictive model was developed for science learning taking into account other strategies in the learning process. However, much of the research under this agenda has focused on the working memory section of this process, that is, on actual processing, to the neglect of other aspects of the information processing system (eg perception and representation). However, recent work is offering some insights into the way information is stored in, and accessed from, long term memory. The theory offers a clear prediction guide in making learning more successful and the evidence from numerous studies support the predictions well.

The conceptual change theory (Posner and Strike) is the practical implementation of the alternative conception agenda and takes its cue from the accommodation and equilibration principles of Piaget's work. Its assumption is that learning is a rational process and that information can be made to be rational and therefore acceptable or understandable to the learner given the learners' prior conceptions. It therefore prescribes the conditions for conceptual change to include dissatisfaction with existing conceptions (presence of anomalous data), intelligibility, plausibility and fruitfulness of a new conception. Research reveals that these are not always positive in bringing about conceptual change as individuals process information in idiosyncratic ways; and that the socio/affective perspectives are important in bringing about conceptual change.

The alternative conception agenda has its roots in the work of Ausubel but was granted impetus by Driver in science education. Its major tenet is that children develop alternative explanatory frameworks and conceptions prior to formal science education. The agenda tries therefore to explore and unravel these frameworks and to apply the knowledge to science education. Subsumed under this is the generative learning model that takes this further to examine how appropriate links can be fostered between prior conceptions and science conceptions. The latter has not received adequate attention from the science education community. Recently, however, a number of studies have tried to concentrate on the representation of science knowledge and to understand these representations and the reorganisation of semantic science categories. The alternative conception agenda holds promises for influencing the conceptual sequencing of the science curriculum; as research results have indicated a progression of students toward adequate conceptualisations and personalisation of science knowledge.

Understanding and Evaluating Higher Education Curricula: A Possible Framework

The work of Perry offers a framework to guide the construction and evaluation of curriculum at the higher level. Perry demonstrated that beyond formal education the emphasis shifts from cognitive to affective issues. An individual is no longer influenced by what he knows to be true, but by what he perceives as important to him and perhaps others. The student at the higher level therefore negotiates his position in the learning process. Perry identifies nine positions of increasing complexity. For the purposes of this work we will present Johnstone's simplification and their descriptors (Table 3).

	Student A	**Student B**	**Student C**
Student Role	Passive receiver. Acceptor of what the teachers say.	Realises that some responsibility rests with the student. But what? And how?	See student as source of knowledge or is confident of finding it. Debater. Making own decisions.
Teacher's Role	Authority giving of facts and know-how.	Authority. Where there are controversies, wants guidance as to which the lecturer favours.	Authority among authorities. Values views of peers. Teacher as facilitator.
View of Knowledge	Factual; black and white. Clear objectives ; non-controversial; Exceptions unwelcome.	Admits 'black-and-white' approach not always appropriate. Feels insecure in the uncertainties this creates.	Wants to explore context. Seeks interconnections. Enjoys creativity and scholarly work.
View of Exams	Regurgitation of 'facts'. Exams are objective. Hard work will be rewarded.	Quantity is more important than quality. Wants to demonstrate maximum knowledge.	Quality is more important than quantity. Wants room to express own ideas and views.

Table 3: Johnstone's Simplification of Perry's Scheme

From the descriptors four variables emerge: the place of divergent opinions, authority and structure, interaction and experiences with peers. These will determine the extent to which the goals specified for physics education above are achieved. At the beginning of higher education the student is seen as embedded, that is requires a higher level of structure, while being gently introduced to cooperative experiences and appreciation of divergent views. At the end, the expectation is for the students to be able to think critically, weigh evidence, appreciate the views of others while being committed to their own view with justification and to contribute to a team to achieve a common goal. That is actualisation of the whole person using physics content knowledge.

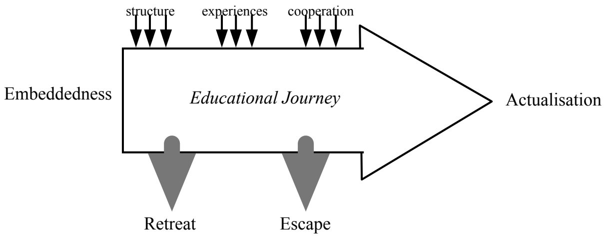

Figure 2: Continuum of intellectual and ethical development (adapted from Perry, 1970)

All the sections above are therefore to be interpreted based on how much structure they provide, what experiences are provided and how much cooperation and collaboration is provided. This should be along a continuum, eg from strict structure to liberalism. If we take the lab for instance, from expository to problem-based; for problem solving, from algorithmic to open-ended; for assessment, from objectives to concept mapping, from performance assessment to portfolios or journal writing; etc: this is illustrated in figure 2. It must be pointed out that along the way some students retreat or look for ways of escape. They remain parochial.

Bringing the Evidence Together

The suggestions we make here will guide the recommendations at the end of the report. It is obvious from the summary above, that a number of theories have been propounded for science/physics teaching/learning. These theories taken in isolation cannot predict performance nor describe an overall positive effect on the learning process. Each has a contributing role in the understanding of physics learning. If we take physics learning to involve the presentation of physics knowledge in a learning environment, the perception of the presented knowledge, the processing of the knowledge and the representation of the knowledge, we will begin to appreciate the relationship and interaction of the different theories and the Perry framework.

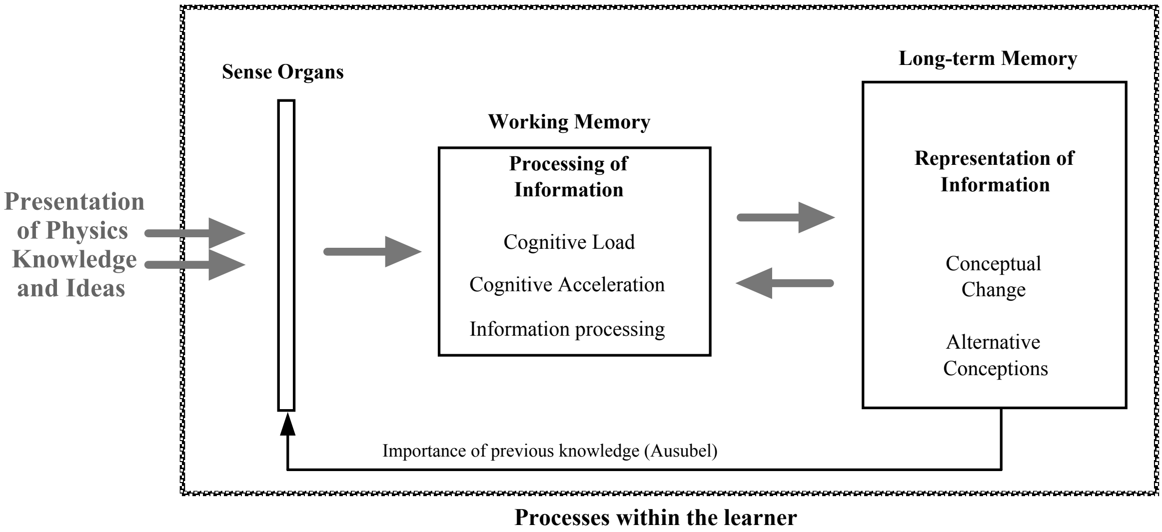

Figure 3: A way to look at learning (bringing many theories together)

Figure 3 represents a systems approach in considering science teaching and curriculum design. The different theories and the stage at which they make their contributions are schematically represented. The nature and structure of physics should be addressed as well as the approach to be adopted in the sequencing and selection. Presentation should be concerned with amount of structure, experience and collaboration provided. This will consider peer relationship, authority and institutional structures, and physical environment. These two variables (nature and structure of physics and presentation) will to a large extent determine the effectiveness of the processes within the learner. The explanations derived from each of the theories can therefore be applied in the two processes outside of the learner.

The above should not be taken to be as simplistic as it appears with a clear-cut line of demarcation between the different theories and their loci of operation. Rather, they interact and in actual fact traverse the boundaries, having some similarities and some differences. However, for clarity and the purpose at hand we make them as simple as possible.

Towards a New Approach at Higher Education Level

Aim: to summarise the evidence which can offer guidelines in the development of the curriculum in physics beyond school.

The aim of any higher education physics curriculum is not only to educate *in* physics but also to educate *through* physics. However, the emphasis on the development of a graduate group who can demonstrate *competency in their understanding* of physics and its applications is of great importance. The emphasis on understanding is important in terms of developing a genuine competency.

The outcomes from the research evidence are now interpreted against that background.

Physics for whom?

Physics is in a powerful position as a science, with a strong quantitative edge, which underpins so much understanding in the world of materials, medicine, biology and medicine. Those with a mature understanding of physics phenomena have, therefore, much to contribute beyond the confines of physics itself.

The physics to be included in the curriculum must reflect this context. It is impossible to cover all areas of physics in a degree. The rate of growth of knowledge will make the selection process increasingly more and more critical. The degree must simply offer the student an insight into the key fundamental ideas which underpin the subject along with knowledge of how to use the information and where to find what they need when faced with unfamiliar physics situations. The key question to ask is what physics is the *essential* basis for *every* student?

As with school physics, the physics curriculum can be constructed by exploring three themes:

1. *What are the questions that physics asks*?
2. *How does physics obtain its answers*?
3. *How do these answers offer insights into physics problems*?

Such an approach will meet the needs of the whole student group but will provide the essential critical basis for those who will offer leadership in the development of physics by means of research.

What Physics?

When faced with the question, *what physics*?, the temptation is to list the topics and themes to be included in a syllabus. These are usually defined by the logic of the subject as well as the needs of later stages of learning. There is also the temptation for the curriculum to include those lecture courses which reflect the specialist research interest of the staff members available. *All of this must be resisted.*

There needs to be a massive paradigm shift in thinking and the willingness to jettison much traditional physics. The criterion must simply be: what is *essential* for all so that they can make sense of relevant phenomena? This will require a study of what former graduates actually have found essential in their future careers. There needs to be time to allow students to understand and not simply memorise. Students need time to consider how the evidence was gained and to sort out misconceptions, to discuss ideas and to think like a physicist. Content reduction would allow such time. There is clear evidence that adding more to a curriculum actually brings about *less* learning.

On grounds of information overload, it is essential not to introduce physics at all three levels (macro, micro, symbolic) at the same time when introducing a new topic. The macro approach can be related to previous knowledge and experience, thus rooting physics in real life rather than allowing it to become a subject dominated by abstraction and symbolic complexity.

Information processing offers specific guidelines for curriculum development as well as teaching itself. Physics is both abstract and highly representational, the use of models (mental and physical) being common. By its very nature, many themes in physics are high in information in the sense that the learners have to manipulate many pieces of information *at the same time* to gain understanding. Such themes may well be important but they need to be presented in such a way that information overload is minimised.

Attitudes are often presented as important in curriculum specifications and then largely ignored in both curriculum construction and assessment. At school level, it is well established that a curriculum which is 'applications-led' rather than designed by the logic of the discipline generates *very* positive attitudes towards a subject. In an applications-led approach, students are introduced to the physics that is needed to make sense of the world around as they know it, giving insights into the perspectives and methods of physics enquiry as well as its outcomes. There is considerable evidence of how to develop such teaching approaches and the very powerful benefits it brings to an undergraduate population. Social attitudes relating to physics need emphasis. The approaches to develop these have been well established by means of mental interactivity. Teaching units need to be built into the curriculum with this aim in mind and several such units already exist.

How Physics should be Taught?

Inevitably, students will come to the degree courses with pre-conceived ideas. Many of these have been pinpointed. It is essential that time and appropriate opportunity is allowed for these to be explored so that, in as natural a way as far as possible, such misconceptions and alternative conceptions are modified and altered.

Many physics courses place much emphasis on algorithmic problems. Although these have their place in offering learner confidence in routine procedures and providing techniques and approaches which work, more open-ended problems (especially group based) have been shown to be highly effective in developing attitudes, generating enjoyment and addressing issues where physics can be applied in real-life situations. They also offer great opportunities for genuine understanding to develop. It has to be recognised that problem solving skills are highly context dependent. Therefore, problem solving cannot be essentially a generic skill and presented as a curriculum aim in this way.

Higher education tends to revolve around lecture courses. There is clear evidence of the value of pre-lecture experiences where underlying ideas are revised and there is an attempt to ensure that students approach new material with minds prepared so that they can make a serious attempt at understanding. The role of lectures needs to be reviewed. These can be offered merely to give students the essential landmarks of a topic, the students being expected to develop their ideas from that. However, usually, lectures transmit knowledge. Major studies have demonstrated that students record in their notes only about 10% of what is said and the basis by which they select what to record is quite idiosyncratic. Students need to be given a clear picture of the purpose of lectures and to be offered direction during the lecture so that they can see what are the key points.

The place of labwork is not really contested. However, its purpose is often unclear and poorly specified. The aims cannot simply be centred around the development of practical skills (for many of these are irrelevant to most students) nor should labwork be used to 'confirm theory'. Labwork in the curriculum should be devised to develop:

> *Outcomes relating to the Learning of physics*: To make physics real, tangible, related to actual materials and their behaviour; to illustrate ideas and concepts, to expose theoretical ideas to empirical testing.
>
> *Practical Outcomes*: Most specific skills are irrelevant but more generic skills are important: careful observation, safe experimentation, being accurate where appropriate.
>
> *Scientific Outcomes*: Skills of deduction and interpretation; an opportunity to see the place of the empirical as a source of evidence in enquiry; opportunities to devise experimental approaches which can offer genuine insights into physical phenomena.
>
> *General Outcomes*: team working, presenting data, discussing, time management, developing ways to solve problems, appreciating diversity, and understanding the place of self in knowledge construction.

Great care will have to be taken so that assessment does not skew these aims. The use of prelab experiences is well documented and their effectiveness is very clear.

How Physics is to be assessed?

Too much assessment relies on knowledge recall or recognition. The curriculum should seek to develop higher order thinking skills and the assessment must reflect this. The aim of the proposed curriculum should be to educate *through* physics as well as *in* physics. Assessment must take into account skills like data handling, analysis of experimental data, drawing appropriate conclusions, understanding the implications of physical situations, as well as the assessment of how well the students actually *understand* the ideas of physics. All of these are very different from recall and recognition which often underpin much assessment. Great emphasis should be placed on the interpretation of physics situations rather than on the recall of the outcomes. There is a large literature on assessment in physics at higher education level, offering much useful research-based insight.

Landmarks for Successful Curriculum Construction in Higher Education Physics

We attempt here to give a set of guidelines from the research evidence that will guide curriculum construction in physics at the higher education level. The aim is to have a generation of students who have not just gone through an education in physics but who have been *educated through physics*. These would be students who are fully actualised intellectually and ready to contribute meaningfully to society as well as being equipped for life-long learning and development. The following has therefore been suggested for the physics curriculum at the higher level - which should:

1. Be designed to meet the needs of all students: those taking a single course as part of another degree; those likely to pursue a career outside formal physics; as well as those who will become practicing physicists: education *through* physics as well as education *in* physics; reflect attempts to answer questions like: what are the questions that physics asks? How does physics obtain its answers? How does this physics relate to life?
2. Take into account school physics: what is taught, how it is taught as well as the wider experiences and aspirations of those who have undertaken school courses. Higher education must build on what has already been achieved not only in terms of knowledge and understanding but also in terms of the way processes of thinking and learning have developed;
3. Aim at allowing students to understand and not merely memorise, to appreciate the way understandings have arisen, the way physics knowledge develops as well as acquiring the key skills associated with understanding physics: this will require significant content reduction, focusing on the essential skills and understandings which are required; offering opportunities for students to apply ideas, to develop critical thinking and to be able to weigh evidence;
4. Be built in the context of applications (or, better, around applications), which are appropriate to the interests, needs and aspirations of students;
5. Be developed using the research findings about the way learners process information: avoiding developing topics with high information demand before the underpinning ideas are adequately established to avoid overload and confusion; use pre-lecture activities to reduce information load;
6. Offer students opportunities to develop problem solving skills, to be seen not only in terms of applying knowledge in a routine way but also in highly open-ended situations where physics ideas relate to life situations and decision-taking;
7. Be designed with laboratory work which has clear explicitly stated aims, where experiments are used to illustrate, to develop and challenge ideas, where the whole experience is seen as integral to the very nature of learning physics (involving pre-labs as well as meaningful post-lab exercises);
8. Be designed with opportunities for students to gain experience in communicating the ideas of physics both orally and in writing as well as opportunities for students to work collaboratively in teams;
9. Be organised in such a way that students develop intellectually, moving from the passive acceptance of knowledge to a more mature appreciation of the nature of knowledge, their role as learners and, ultimately, towards the ownership of knowledge and personal autonomy;
10. Employ assessment that is integrated into the curriculum and reflects curriculum purpose, is diagnostic and formative, and aims to give credit for a wide range of skills including conceptual understanding, critical and analytical thought, communication and the application of ideas in new situations.

Appendix 1: Annotated Bibliography

(Arranged thematically)

1. Aims of Physics Education at the Higher Education Level (General)

Barnett, J. & Hodson, D. (2001). Pedagogical context knowledge: toward a fuller understanding of what good science teachers know. Science Education, 85, 426-453.
The authors propose a model called *pedagogical context knowledge* with which they examined the manner in which science teachers deliver science knowledge. This revealed that good science teachers make use of four kinds of knowledge when discussing their classroom practices. These include academic and research knowledge, pedagogical content knowledge, professional knowledge and classroom knowledge. The paper describes transition from novice to expert and used the framework to interpret data collected from semi-structured interview of some exceptional teachers. They concluded that the model was effective in examining and categorising teachers' views and knowledge on which they draw when they teach or talk about their teaching.

Boyer, R & Tiberghien, A. (1989). Goals in physics and chemistry education as seen by teachers and high school students. International Journal of Science Education, 11(3), 297-308.
The authors used two questionnaires to elicit responses from 1249 sixteen-year old students and 284 teachers on their perceptions about goals in physics and chemistry. They found that gaps existed between the views of teachers and their students. Whereas teachers preferred goals related to the logic of the subjects, students preferred goals of a social kind, that is, an instrumentalist perspective.

Viennot, L., Chauvet, F., Colin, P., & Rebmann, G. (2005). Designing Strategies and tools for teacher training: The role of critical details, examples in Optics. Science Education, 89, 13-27.
The gap usually felt between research and practice influenced the authors to investigate the transformations of innovations and how the understanding of this can inform teacher training. The characteristics of the teachers' transforming actions were highlighted, and examples of critical details were given in the area of physics. They suggested a possible structure for teacher-training materials. They made a final remark upholding the notion that research in education should not seek at delineating detailed and specific modes of teaching but should seek at substantiating principles that pervade thinking about teaching and learning.

Elby, A. (1999). Another reason that physics students learn by rote. American Journal of Physics, 67(7), S52-S57.
The author analyzed the responses of 106 introductory college physics students on questionnaire items seeking to find out how they study and how they would advise a hypothetical student to study. Results indicate most students' study differently from how they would without grade pressures. There was no difference between high and low achieving students. The author identified two divides in the study of students epistemologies namely, the nature of physics knowledge and approaches to studying physics. He concluded that students perceive studying for deep conceptual understanding as a different activity from studying to make good grades. He drew implications for this.

Hammer, D. (1994). Epistemological beliefs in introductory physics. Cognition and Instruction, 12(2), 151-183.
Students' epistemological views about what constitutes physics knowledge and how the knowledge is developed were explored. These were determined through interviews of six undergraduate students throughout a semester. An analytic framework comprising of three dimensions was used to characterise students thinking. The paper addressed three major alternative explanations including content-level knowledge, general cognitive resources, and goals in the course. The results indicate that indeed students can be characterised by their epistemological beliefs and that these have a direct causal effect on students' learning of physics contents.

Kinchin, I. M. (2004). Investigating students' beliefs about their preferred role as learners. Educational Research, 46(3), 301-312.
A total of 349 secondary school students were asked to respond to concept cartoons about the objectivist and constructivist teaching styles. They were to relate this to their preferred roles as learners. Understanding of students' views was furthered by the use of Focus Group Discussions. It was found that students preferred to a large extent the constructivist learning environment. The author sounds a note of warning that failure to transit to a more constructivist epistemology may contribute to an epistemological gap that will ultimately hinder meaningful learning.

Linder, C. J. (1992). Is teacher-reflected epistemology a source of conceptual difficulty in physics? *International Journal of Science Education, 14(1),* 111-121.
The author argues that the epistemological overtones reflected in physics classroom practices forms a source of conceptual difficulty for students. A group of physics graduates were interviewed and it was found that teachers often reflected metaphysical realism in their classroom practices and that this encourages students to learn physics by rote and discouraged them from coherent understanding. It also leads to the association of conceptual understanding with an ability to solve stereotypical tutorial problems as well as a tendency to teach rapidly in order to cover large amounts of curricula material.

Lising, L. & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics, 73(4),* 372-382.
This builds on recent emphasis by the physics education research community on the link between student epistemology and learning. It presents results from an in-depth case study of a student in an introductory college physics course. The aim was to determine the causal function of epistemology. They used videotapes and interview to explore the subject's reasoning.. The videotaped classroom data was reviewed. They found that the subject's learning behaviour was strongly influenced by her epistemology. The subject placed reasoning in physics into two categories, formal, technical reasoning and everyday intuitive reasoning. She placed a strong barrier between the two. The investigation examined alternative explanations about the subject's difficulties in tutorial classes and concluded that her epistemology has a direct causal effect on her learning. They addressed the implications for curriculum developers and teachers. Specifically, they suggested curriculum developers take up the challenge of helping students associate their productive epistemological resources with the lecture activities, courses and the discipline.

McDermott, L. C. (2001). Oersted Medal Lecture 2001: "Physics Education Research—The Key to Student Learning". *American Journal of Physics,, 69(11),* 1127-1137.
Adopting the stance that teaching is an art as well as a science the author showed how research into the teaching and learning of physics can provide a veritable and effective improvement on physics instruction. She drew insights from research in teaching and learning in non-standard physics classes, and from standard introductory courses. She drew generalisations from these instances. The article then showed how these can be applied to the construction of curricula.

McDermott, L. C. & Redish, E. F. (1999). Resource Letter: PER-1: Physics Education Research. *American Journal of Physics, 67(9),* 755-767.
This is a resource material documenting the bibliography of articles that will help to guide college physicists on where to find materials for improvement of their teaching. The target is physics education researchers and instructors. Altogether 224 articles were cited.

McDermott, L. C. and Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity Part I: Investigation of student understanding. *American Journal of Physics, 60(11),* 994-1003.
The Physics Education Group of the University of Washington, Seattle in this article documents the effort to build a research base that can be used to guide curriculum development. In this article the work from investigation of students in introductory electricity class. They used demonstration interviews and descriptive methods undertaken during class periods to obtain data. Identification and in depth exploration was made of nature of students difficulties. These were used to develop curricula. The researchers concluded that curricula that would foster active participation of students should be based on what students know and can do rather than on the assumption about what they should know and should be able to do.

Oh, P. S. (2005). Discursive roles of the teacher during class sessions for students presenting their science investigations. *International Journal of Science Education, 27(15),* 1825-1851.
Based on the fact that the discursive practices of the teacher plays a vital role in directing the learning of students, the paper sets off to investigate the discursive practices of a Korean science teacher. The investigation was done through an action research approach. The aims of the teacher for the science lessons were analyzed. In line with the aim identified, a modified Group Investigation was implemented in four classrooms over a period of two years. The teacher served as a practitioner and reflector. The classroom interactions of the students were videotaped and these were transcribed and used in a qualitative analysis. The analysis revealed three major and nine subordinate roles of the teacher geared towards helping students to learn. He asserted that there are more to teacher discourse supporting student learning than simply telling them scientific information with little chance to participate.

Roth, W-M., & Lucas, K. B. (1997). From "truth" to "invented reality": A discourse analysis of high school students' talk about scientific knowledge. ***Journal of Research in Science Teaching, 34(2),*** **145-179.**
This is an action research into students' views about the nature of science and its progress from the intuitive stage to an authentic view. This study is by a teacher with 23 students over a period of 15months. The discourses of the students were analyzed to explore their ontological, epistemological and sociological beliefs. The results indicate that students drew on nine types of discursive resources and that the number increased as instruction progressed. Students experienced situations of collaboration, negotiation and critiquing knowledge claims much like what obtained in real science. The authors claim that the domain of physics provides an ideal context for reflecting on the nature of knowledge and suggested curricula should be constructed to incorporate experiences of 'inventing knowledge.

Sunal, D. W., Hodges, J., Sunal, C. S., Whitaker, K. W., Freeman, L. M., Edwards, L., Johnson, R. A. & Odell, M. (2001). Teaching science in higher education: faculty professional development and barriers to change. ***School Science and Mathematics, 101(5),*** **246-258.**
Based on the assumption that traditional pedagogical approaches in undergraduate introductory science courses do not work effectively with most of today's students, the authors sought to better understand the change processes necessary for university science teaching reform to be successful. Thirty universities that participated in a country-wide professional development programme were involved in the study. Members of faculty in these universities formed the subjects of the study. The study adopted both the ethnographic and case study approaches. It was found that all faculty members had conceptions of effective teaching and learning of science in undergraduate courses that guided their actions. However, many were found to have conceptions of the change process that inhibited successful actions.

Taber, K. S. (2006). Physics and pupil thinking – poles apart. ***Physics Education, 41(1),*** **10-11.**
The author argues that the way physics is taught, conceptualised and thought of at the university level is different from what goes on at school level. The latter entails the learners making sense of physics in terms of their prior knowledge, familiar experiences and demonstrable models in the classrooms. He therefore emphasises the need for teachers especially beginning teachers to be aware of the various intuitive physics or alternative conceptions students bring into the classroom and suggest the use of diagnostic assessment techniques to unravel these at the beginning of the lesson. The author contends that practical work often do not trigger conceptual change because cognitive conflict is not induced, rather students see the outcomes they expect. He then analyzed the classroom teaching of a beginning teacher who made use of the principles of learning demand, i.e. the differences between learners' current thinking and the curriculum requirement (target knowledge). He concludes from the observations made that teachers need to plan learning routes informed by the essential concepts of physics, students' current ideas and the target knowledge.

Thacker, B A. (2003). Recent advances in classroom physics. ***Report on Progress in Physics, 66,*** **1833-1864.**
The paper reviewed studies and identified factors that have influenced the teaching of physics in recent years. These were grouped under four categories, 1) results from physics education research, 2) the technology media, 2) decline in the number of students opting for physics and 4) concerns about physics content knowledge possessed by different groups of students. The review looked at the different levels of education and showed how these four areas have influenced each level. This article referenced 392 articles and is a useful material for curriculum developers in physics.

Tobin, K., McRobbie, C. & Anderson, D. (1997). Dialectical constraints to the discursive practices of a high school physics community. ***Journal of Research in Science Teaching, 34(5),*** **491-507.**
This study is set in a physics classroom that explored four belief sets embedded and guided discursive practices of the teacher and students. Specifically, this study explored the relationships between power (as represented by the discursive practices) and knowledge (relativity). This study couched in the hermeneutic interpretive framework, incorporating two broad views of social phenomena: the actor-oriented and structure-oriented perspectives. Using participant observation, the authors monitored the discursive practices of the physics classroom for a two-year period. Classroom transactions were videotaped, and interviews conducted. It was observed that the classroom interactions were shaped by the teacher's beliefs on autonomy, but these were largely constrained by technical interests that directed the conversations towards pursuance of correct answers rather than on elucidation of concepts. What counted as physics was accepted by faith in the authoritative voice of science as represented by the teacher. It was clear that the four belief sets held sway in determining the classroom transactions and warrants for viability were acceptance of the authority of science rather than coherence with the students' schemata or with empirical results.

Viennot, L., Chauvet, F., Colin, P., & Rebmann, G. (2005). Designing Strategies and tools for teacher training: The role of critical details, examples in Optics. ***Science Education, 89,*** **13-27.**
The gap usually felt between research and practice influenced the authors to investigate the transformations of innovations and how the understanding of this can inform teacher training. The characteristics of the teachers' transforming actions were highlighted, and examples of critical details were given in the area of physics. They suggested a possible structure for teacher-training materials. They made a final remark upholding the notion that research in education should not seek at delineating detailed and specific modes of teaching but should seek at substantiating principles that pervade thinking about teaching and learning.

Volkmann, M. J. & Zgagacz, M. (2004). Learning to teach physics through inquiry: the lived experience of a graduate teaching assistant. ***Journal of Research in Science Teaching, 41(6),*** **584-602.**
Using two frameworks, teaching orientation and identity, the work tried to articulate shifting patterns of teaching of a graduate teaching assistant in a physics undergraduate classroom. The perspective adopted in the interpretation of the lived experiences of the assistant is the hermeneutic phenomenology. Data was collected by audiotapes, the assistant's journal, and an independent study where she reflected on current research in science education in comparison to her teaching. Analysis was by the hermeneutic interpretation. They found that the subject constructed her identity in relation to other people in her life. The result also illustrates that approach to teaching is constructed at a deep level and changing one's approach involves examining beliefs and being open to new identity as a teacher and as a learner. Suggestions for improvement of the university teaching staff were made.

2. The Nature of Physics

Beyer, A. D., Koesters, M., Libbrecht, K. G., & Black, E. D. (2005). Macroscopic coherence effects in a mesocopic system: Weak localization of thin silver films. ***American Journal of Physics, 73(11),*** **1014-1019.**
The basis of this work was to provide a laboratory environment that will help students transit from performing pre-packaged experiments to more independent experiments. An experiment was therefore designed for students to observe weak localisation. The students made their own samples, made electrical contacts to them, cooled them and then made measurements. The results indicate students were able to observe the macroscopic expressions of weak localisation and that the effect is observable at easily accessible temperature.

Borges, A. T., & Gilbert, J. K. (1999). Mental models of electricity. ***International Journal Science Education, 21(1),*** **95-117.**
The paper defines and discusses the meaning of mental models emphasising their roles in knowledge acquisition for the individual. It discusses previous research into students' ideas about electricity and asserts that irrespective of their ages, they attempted to connect the bulb to the battery according to one of a specified number of ways. They also believe there is a cause located in the battery. The authors listed the different models employed by students and gave their characteristics as well as how they differ. Using four groups involving students and professionals, the authors proceeded to investigate the models used by the sample to think about the nature of electric current. Data were obtained by means of semi-structured interview that probed the subjects in experimental situations involving prediction-observation-explanation. It was found that even among a heterogeneous group as the sample of this study, a limited number (four) of models were found. These models attempted to capture the progression in individuals' models along a dimension. Individuals start with a general model of electricity as flow, then to electricity as opposing current, electricity as moving charges and electricity as on field phenomena. They conclude that model progression is a general trend in science conceptions depicting the evolution of a learner's sense of how things work and how they behave in the way they do.

Chi, M. T. H. & Slotta, J. D. (1993). The ontological coherence of intuitive physics. ***Cognition and Instruction, 10(2&3),*** **249-260.**
They discuss diSessa's theory of intuitive physics knowledge agreeing with most of the points and emphasising their points of departure. They propose a theory of ontological categories to account for the structure of intuitive physics. They explained the difficulty in learning some physics concepts in terms of three suppositions: epistemological, metaphysical and psychological aspects. They assert that students' intuitive physics is incompatible with veridical ontology of the associated physics concepts. This is seen as the major cause of lack of understanding. The paper then discusses some empirical support for the coherence of children's intuitive knowledge. The implication for instruction is that there has to be substantial structural change in knowledge in order for it to succeed.

diSessa, A. A. (1993). Toward an epistemology of physics. ***Cognition and Instruction, 10(2 & 3),*** **105-225.**
This paper considers the sense of mechanism that characterises intuitive physics and how it develops toward an expert scientific understanding of physics. That is, how intuitive physics contribute to and develop into school physics. The view is pursued by considering the capabilities that a sense of mechanism bequeaths the individual, and the meaning of the sense of mechanism was fully articulated. The paper advances by explaining the meaning of intuitive physics and tracing the origin of efforts toward understanding this by physicists. The theory of knowledge as presented here is advanced by highlighting the elements of knowledge (knowledge structure), the systematicity that exists, and the cognitive mechanisms responsible for the operation of the system. The empirical base for this theorising is based on interviews conducted over a three ear period with 20 undergraduate physics students. The theoretical claims of this theory were elucidated and the educational implications were drawn.

Galili, I. & Lehavi, Y. (2006). Definitions of physical concepts: a study of physics teachers' knowledge and view. ***International Journal of Science Education,28(5),*** **521-541.**
Reflecting on definitions of physical terms and the process of their constitution, the authors argue that operational definitions of these terms are too heavily loaded with theory. Hence they submit these cannot be practically realised nor can they provide satisfactory descriptions of physical concepts. Definitions are perceived as necessary for the coherent presentation of and organisation of a subject. The authors implicate faulty concept definitions in some students' misconceptions. With a sample of 75 practicing teachers the investigators explored the definitions of teachers in 11 basic concepts of physics as well as their perception of the importance of definition in physics teaching. They responded to an open-ended questionnaire and had a discussion that aided the interpretation of their responses. Two types of definition were identified: theoretical statements relating the concepts to other concepts and epistemic definitions, relating the concepts to measurement. It was found that the definitions were heterogeneous. Teachers gave several reasons for the importance of definitions for the purposes of teaching. They also found that most of the definitions were of the theoretical type in contrast to present science education understanding of the necessity to provide each physical concept with a pair of complementary nominal and operational definitions.

Hecht, E. (2004). Energy and Work. ***The Physics Teacher, 42(L2),*** **L1-L3.**
Considering energy and mass, the author contends that students and physicist deserve clear definitions of fundamental physics concepts such as this. This contrasts sharply with what is observed, that is, that such definitions are framed in terms of less fundamental concepts. This to the author leads to difficulty in understanding such concepts as well as inability to formulate them satisfactorily. He however insists that students especially novice students deserve clear definitions. He suggests ways this can be done satisfactorily.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. ***Journal of Computer Assisted Learning, 7,*** **75-83.**
The paper relates the difficulty students experience in the learning of science to the nature of science with particular reference to its multilevel thought requirement, its language and the disparity between expectations of the teachers in the laboratory and the actual perceptual field. Of particular emphasis was the way science is taught. The interaction of these and the learners' learning processes are discussed. The author proposes the information processing system to guide teaching and research in science learning processes.

Kantz, C. H., Heron, P. R. L., Loverude, M. E., & McDermott, L. C. (2005). Students; understanding of the ideal gas law, Part I: A macroscopic perspective. ***American Journal of Physics, 73(11),*** **1055-1063.**
This is a report of a long-term project to improve students' learning in thermal physics by a physics education group at the University of Washington. The aim was to explore the macroscopic variables of pressure, volume and temperature and their relationship to one another through the ideal gas law. The subjects comprised of 1000introductory physics students from four universities. They began by interviewing 45 students and found that these students could make right predictions although their microscopic arguments were incorrect. The second stage involved designing problems to probe students' understanding of these three factors. They found that after standard instructions, many students in the introductory physics lecture had serious difficulties in interpreting and applying the ideal gas law. They categorised the difficulties into three, conceptual, reasoning and mathematical categories. From these they designed a research-based instruction to explicitly address the difficulties. It was found that the intervention increased considerably students' understanding and did not increase the period of the lectures although breadth of coverage and illustrations of problem solving was warranted.

Kantz, C. H., Heron, P. R. L., Shaffer, P. S., & McDermott, L. C. (2005). Students; understanding of the ideal gas law, Part II: A microscopic perspective. ***American Journal of Physics, 73(11),*** **1064-1071.**
This built on the Part I of this study that investigated the macroscopic variables. The methods were the same. It was found that students had flawed microscopic models for pressure and temperature in the ideal gas law. These were identified and an intervention designed to handle them explicitly. The understandings of students were substantially improved. These findings were used to construct a set of tutorials and laboratory experiments to help deepen students' understanding. They conclude that the result of the study has strong implications for curriculum designers and developers for the development of instructional materials for K-12 students.

Thacker, B. A, (2006). A study of the nature of students' models of microscopic processes in the context of modern physics experiments. http://www.phys.ttu.edu/~batcam/Publications/AmJPhysnd.DOC (accessed: 02/06/06)
The author was concerned with students understanding of macroscopic phenomena as underpinned by microscopic processes. Twelve undergraduates were interviewed in order to understand the nature of the models of microscopic processes they use in the explanation of macroscopic phenomena. The is to find out whether these are in the schemata of students as memorised facts or whether the students have mental models that could be consistently used in the explanation of phenomena. Another cohort (high school physics students) of students' understandings were probed by the use of interactive demonstrations. It was found that students have preconceived mental models of microscopic processes, however, these come from memorised facts. Students are aware of the need for models of microscopic processes and look out for these during instruction. They emphasised that this implies that curricula should be structured around building models of microscopic processes grounded in macroscopic observations.

3. Language and Structure of Physics

Cassels, J. R. T. & Johnstone, A. H. (1985). ***Words that matter in science.*** **London: Royal Society of Chemistry.**
Using a sample of 30,000 pupils from 200 secondary schools, the investigators explored students' understanding of a selection of ninety common words. The tests were administered to the different years from first to sixth form. Each word was cast in four formats. The items were compared for inter group stability and the performance of words in different formats. The results showed a strong stability indicating that the sampling has been substantially random. They found that performance improved with age, and very few words were satisfactory in all their formats. It was also found that many words are not readily accessible to students, the context in which a word appears influences the understanding by students. Implications of these to concept formation and problem solving were drawn. They recommend that science teachers take time to explain the words used in science lessons.

Fang, Z. (2005). Scientific literacy: a systemic functional linguistics perspectives. ***Science Education, 89,*** **335-347.**
This paper analyses the language of scientific discourses and argues that they contain unique linguistic features. It contends that an understanding of these features is critical to the construction of scientific knowledge by students. It discusses these special features including the informational density, abstractness, technicality, and authoritativeness. It draws the educational implications.

Sutton, C. (1996). Beliefs about science and beliefs about language. ***International Journal of Science Education, 18(1),*** **1-18.**
Sutton claims that tacit beliefs in scientific language influences the beliefs about the nature of science held by teachers and students. The paper explores the assumptions of scientific language and reveals a tension between scientific language, identified as labelling, and the learner's experience of language as interpretive. He suggests that science textbooks and classrooms should incorporate the interpretive voice of the scientists in the activities. Suggestions for future research were made.

4. Alternative/Prior Conceptions in Physics

Alvermann, D. E. & Hynd, C. R. (2001). Effects of prior knowledge activation modes and text structure on nonscience majors' comprehension of physics. *Journal of Educational Research, 83,* 97-102.
A sample of 62 non-science majors was involved in the study. Eligibility for inclusion in the study depended on the subject demonstrating a naïve conception of how forces affect a projectile's motion. Subjects were assigned to six groups in a two by three factorial design. The treatment involved three levels of prior knowledge activation and tow levels of text. Results showed that better readers depend less on the text to cue them about conflicting information than do poorer readers. It also revealed that dispelling inaccurate information depends on how explicitly such activated naïve conceptions are exposed to materials that differ from theirs. These results were discussed in the light of earlier findings.

Brown, D. E. (1989). Students' concept of force: the importance of understanding Newton's third law. *Physics Education, 24,* 353-358.
Using interviews involving oral tutoring, tutoring with written materials and multiple-choice diagnostic test, the author collected data from the interview of a sample of five high-school students who were yet to take formal instructions in physics. The multiple-choice test was administered to 78 students. Results indicate students have naïve views about forces as innate property of objects.

Budde, M., Niedderer, H., Scott, P. & Leach, J. (2003). 'Electronium': a quantum atomic teaching model. *Physics Education, 37(3),* 197- 203.
This article focuses on the descriptive atomic model, 'electronium'. This was developed to facilitate students' learning of quantum atomic physics. The author contends that the use of the spatial and/or energetic shell models as well as the Bohr model to teach quantum atomic physics in the UK is limited and results in students' retaining the classical planetary model. They propose the explicit teaching with quantum atomic models in order to overcome the limited classical atomic conceptions. They analyzed previous research and identified common misconceptions in this area. The paper thus identified learning difficulties associated with the quantum atomic 'probability' model, compared the different atomic models mentioned in the article, and gave an explanation of the learning difficulties in terms of the students' preconceptions. They, thus, formulated teaching hypotheses about teaching approaches that might support or inhibit students' learning taking into consideration the preconceptions in this area.

Cahyadi, M. V. & Butler, P. H. (2004). Undergraduate students' understanding of falling bodies in idealized and real-world situations. *Journal of Research in Science Teaching, 41(6),* 569-583.
This article is an effort at understanding the preconceptions of students and how these affect their ability to answer questions. On the whole, 18 undergraduates in a first year physics course were involved in the study. They worked individually on written tests consisting of a number of qualitative mechanics problems about motions in idealised and real world situations. Data from this test was analyzed qualitatively while data from interviews of the subjects were transcribed. Results showed that students gave more correct answers for the idealised cases than for the cases with air resistance and that they understand the impact of air resistance on differing object size better than on differing mass. Results also indicate that presenting different situations of the same principle aids students to understand that principle. Implications of these were highlighted.

Corni, F (2006). Water tank experiment clears up some refraction misconceptions. *Physics Education, March 2006,* 103-104.
The author proposes one method of introducing light refraction; the major point being to show the various roles refraction plays in what we see. He contrast the conventional pictures used in textbooks (image of a straw partially immersed in water) to the ones he proposed showing the advantage of the latter over the former. The conventional pictures are perceived to be reinforcing students' misconceptions about the refraction of light. This, the author posits, is critical given that refraction is a general everyday phenomenon and that students need to apply their knowledge in various contexts and from different perspectives.

Driver, R. (1983). *Pupil as Scientists?* Milton Keynes: Open University Press.
The book faulted the curriculum of its time that based its approach on induction, the heuristic method and presentation of scientific inventions as a catalogue of objective facts. It argues that children come to the science classroom with already formed ideas about the world and natural phenomena. It posits that these preconceptions influence how each student conceives a scientific facts even in the face of 'objective knowledge. With many examples this is driven home and claims that some of these ideas are resistant to change. The book expounds Piaget's theory, not so much the stage theory as his idea of the process of learning, and esteemed teaching for conceptual change over teaching for cognitive skill development. Finally, it raises the question of classroom practice and curriculum inclusions and organisation.

Driver, R. (1989). Students' conceptions and the learning of science. ***International Journal of Science Education, 11(Special Issue),*** **481-490.**
Driver writes an introduction to this special issue by reviewing work done in the area of children's ideas in science and the conceptual change literature. She ends by raising an agenda for future research in the area.

Driver, R. & Easley, J. (1978). Pupils and paradigms: a review of literature related to concept development in adolescent science students. ***Studies in Science Education, 5,*** **61-84.**
The authors made a distinction between misconceptions and alternative frameworks and show how these are related to two kinds of studies, nomothetic studies, with four particular questions; and the ideographic studies. The authors then review nomothetic studies under grade placement studies, studies of psychological ordering of sub-concepts within a conceptual area, studies relating concept development to Piagetian stages and studies of misconceptions. Ideographic studies were reviewed under, Piagetian early studies on children's interpretations of natural phenomena, Piaget's epistemological perspectives, Piagetian studies on causality, naturalistic studies of pupils' alternative frameworks and conceptual frameworks (the effect of experience and instructions). They called for Piaget's work to be placed in the correct perspectives and for curricula to be versatile taking into consideration the individuality of learning while taking cognisance of patterns and trends in pupils' conceptual development.

Driver, R., Guesne, E. & Tiberghien, A. (1985a). Children's ideas and the learning of science. In R. Driver, E. Guesne, & A. Tiberghien, (Eds.) ***Children's ideas in Science*** **(pp. 1-9). Milton Keynes: Open University Press.**
The article introduces the idea of alternative frameworks by considering an episode involving two students doing an experiment and the process and discursive activities of their coming to know. The authors assert that children have built up explanatory frameworks before formal science lessons. These ideas are characterised as personal, incoherent and stable. They proffered a model of the interaction between these prior ideas and science learning by making reference to the psychological theories of Ausubel, Piaget and Wallon. The model incorporates the ideas of schemes and knowledge structures in the memory. Knowledge structures imply organisation of some form, which may need reorganisation for assimilation to take place. The authors give three purposes of this understanding.

Driver, R., Guesne, E. & Tiberghien, A. (1985b). Some features of children's ideas and their implications for teaching. In R. Driver, E. Guesne, & A. Tiberghien, (Eds.) ***Children's ideas in Science*** **(pp. 193-201). Milton Keynes: Open University Press.**
The article discussed the characteristics of children's ideas under the following headings: perceptually dominated thinking, limited focus, focus on change rather than steady-state situations, linear causal reasoning, undifferentiated concepts, context dependency, and predominant conceptions. The authors contend that in some areas the history of the development of conceptions parallel those in science itself and draw the conclusion that conceptual change is a long term process. Curriculum planning according to this article must therefore take into consideration the learners' prior knowledge, provide opportunities for pupils to make their own ideas explicit, introduce discrepant events, encourage the generation of a range of conceptual schemes, provide a range of situations for practice in using ideas.

Engelhardt, P. V., Gray, K. E. & Rebello, N. S. (2004). How many students does it take before we see the light? ***The Physics Teacher, 42(4),*** **216-221.**
This research report was premised on results of prior research that suggest that some students are not able to reason correctly about complete circuits. Using undergraduate students they demonstrated that students' understanding is faulty because they believe that wires from the filament are connected to the base of the bulb at the bottom. The presence of this misconception as indicated by the results of the study related to the type of introductory physics lessons received by the students. The authors therefore devised activities aimed at aiding the students develop the correct concept of a complete circuit and how a light bulb can be wired.

Galili, I. & Bar, V. (1992). Motion implies force: where to expect vestiges of the misconceptions. ***International journal of Science Education, 14(1),*** **63-81.**
This paper investigated the progression of students in the understanding of the force-motion relationship. They used different levels of students ranging from 10th grade students to introductory physics undergraduate students and pre-service physics teachers. From their findings they recommended the inclusion of more qualitative problems addressing known misconceptions in physics; the use of more diagnostic assessment strategies; that inertial forces should be taught to prepare students to reconcile their views and that of veridical science.

Hammer, D. & Elby, A. (2003). Tapping epistemological resources for learning physics. *Journal of the Learning Sciences, 12(1),* 53-90.
Reviewing literature in this area the author asserts that research has demonstrated that students' epistemological stance influence the outcome of their learning efforts. The authors supported the view of intuitive knowledge as fine-grained context-sensitive resources called into use by students during learning. They acknowledge that familiar strategies and curricula ascribe ontological resources to students. They therefore criticised conceptual change strategies that elicit and confront alternative frameworks. In its place, they suggest the use of strategies that help students find and activate intuitive knowledge productive for their learning. The paper proceeded to present the work of the authors that sought to help students study physics by teaching them how to learn physics, developing an awareness and learning to refine everyday thinking, and an understanding the goal of principled consistency. They applied these principles in two laboratory experiences. Two implications were particularly stressed for curricula, reduced use of textbooks and to encourage fluid lesson plans.

Harrison, A. G., Grayson, J. A. & Treagust, D. F. (1999). Investigating a Grade 11 student's evolving conception of heat and temperature. *Journal of Research in Science Teaching, 36(1),* 55-87.
This was a longitudinal case study aimed at describing the learning process that favoured a change from intuitive student conceptions to the desired scientific view of heat and temperature. The students were allowed to proceed in the learning process at their own pace and to negotiate their understandings. Students were pretested, and tested again midway through the treatment period and at the end. Data was collected using portfolios, written answers, and recorded discussions. Students were also asked to write concept maps of their conceptions of heat and temperature. Initially it was found that the subject could not differentiate between heat and temperature. He gradually added scientific concepts such as thermal interactions and thermal equilibrium by conceptual capture. The subject was found to have progressed to the point of the scientific conceptions being fruitful incrementally. The social context of the learning was judged a scaffold as he struggled to accommodate the new and counterintuitive conception.

Hellingman, C. (1989). Do forces have twin brothers? *Physics Education, 24,* 36-40.
This article set out to explore how intrinsically difficult the concept of force is. The author declared that the concept is difficult for both students and teachers alike. Even textbook authors according to this article have wrong notions about the concept. He traces this difficulty to the description of force given by Newton about three hundred years ago. He proposes a 'more efficient' description. This was defended for the case of classical mechanics. The error that arises from the use of the terms *action, reaction* and *interaction* were discussed. And force as a unilateral or bilateral phenomenon is considered. The paper proposes a new definition of the concept.

Hellingman, C. (1992). Newton's third law revisited. *Physics Education, 27,* 112-115.
Following his earlier paper the author deliberates more on the concept of force in accordance with Newton's third law. He reported a study done with professional physicists that indicated they also share common misconceptions with students.

Helm, H. (1980). Misconceptions in physics amongst South African Students. *Physics Education, 15,* 92-98.
A misconception test was administered to first year university students. The aim was to identify common misconceptions in physics and their origin. This served as the trial testing group. The test was eventually administered to 460 secondary school students and 65 teachers. The author found certain misconceptions common to the students. He identified major source as the triumvirate of teachers, textbooks and examinations. Two major areas were highlighted by the result of the test, 'force exerting agents' and 'potential difference' and the interaction of correct understanding with 'Aristotelian notions'. The second cause of difficulty identified was the level of cognitive development of the students. Ways forward were suggested.

Lynch, P. P. (1995). Students alternative frameworks: towards a linguistic and cultural interpretation. *International Journal of Science Education, 17(1),* 107-118.
Using students from three language groups, this paper demonstrated the explication of students' alternative frameworks in chemistry in terms of language and culture. It revealed the distinct influences of the two by two strategies, triangulation and comparison of science vocabularies of the three languages investigated. They made the case for different subcultures implying subcultures within the western world e.g. pop-culture, influencing science learning and conceptions differently. A number of questions for school science instructions were raised.

Oliva, J. M. (2003). The structural coherence of students' conceptions in mechanics and conceptual change. *International Journal of Science Education, 25(5),* 539-561.
His paper examines the relationship between the degree of coherence of students' conceptions and the probability of conceptual change. The author used 155 15-16year olds as the sample of the study. They responded to two instruments. It was found that students with high level of formal reasoning have preconceptions that are more structured and also tend to change with ease. It was also found that the level of formal reasoning interacted with the level of structure of the preconceptions in effecting change in conception.

Thus higher level of formal reasoning and well structured preconceptions induced better conceptual change as well as low level formal reasoning with less well organised preconceptions. The educational implications of these findings were discussed.

Savinainen, A., Scott, P. & Viiri, J. (2005). Using a bridging representation and social interactions to foster conceptual change: Designing and evaluating an instructional sequence for Newton's First Law. ***Science Education, 89,*** **175-195.**
This study explores the use of a conceptual change strategy in the design of an instructional sequence as well as the role of the teacher in staging the activities in the actual classroom situation. The authors made a review of literature of Newtonian concept of force and concluded that Newton's Laws are both difficult to teach and learn. They identified a limited number of alternative conceptions on the concept of force. However, the alternative conception arising from the 'impetus' concept and the dominance principle prove to be the most difficult and the last to be relinquished. They also identify four contextual features that students use in reasoning about forces as velocity, mass, pushing and acceleration. Using the principles of bridging analogy and bridging representation, the authors designed and taught 23 Finnish students. The results demonstrate that the instructional approach enhanced contextual coherence, increased the students learning gains in comparison to an equivalent group taught with a more traditional approach. They concluded that big conceptual changes come from evolutionary changes rather than revolutionary changes.

Saxena, A. B. (1992). An attempt to remove misconceptions related to electricity. ***International Journal of Science Education, 14(2),*** **157-162.**
In a three phase instructional model, the author used a strategy to attempt to deal with students' misconceptions on the concept of electricity. Altogether 25 B.Sc, B.Ed Part III students were involved in the study. The strategy involved the students in experimentation and verification of their predictions. There was limited success in the progress of the students toward correct scientific conceptions. Several reasons were put forward including the fact that the open-ended method adopted was novel to the students, the short duration of the experiment and the stability of the misconceptions.

Taber, K. S. (2000b). Finding the ultimate level of simplification: the case of teaching about heat and temperature. ***Physics Education, 35(5),*** **320-325.**
The author recognises the validity of simplifying the curriculum content in order to bring curriculum materials to the cognitive level of the students but argues that this has reached a point where the logical structure of the subject has been compromised, at least in the area of heat and temperature. The author therefore considered the differences between children's ideas, teachers' ideas and curriculum ideas. He considers what cases a shift from alternative conceptions to correct scientific conceptions. He analyzed Carlton's (2000) recommendations for teaching introductory thermal physics. The paper then discussed what degree of simplification is useful.

Taber, K. S. (2001a). Shifting sands: a case study of conceptual development as competition between alternative conceptions. ***International Journal of Science Education, 23(7),*** **731-753.**
This paper reports an in-depth case study employing a longitudinal interview of students for two years. It traces the shifts in the cognitive structure of the students as well as the differential weighting in their conceptual profiles. It showed how students can hold more than one explanatory framework for an area of study. Implications of the result were unfortunately not elaborated upon.

5. Problem Solving in Higher Education Physics

Blosser, P. E. (1988). Teaching problem solving – secondary school science. . ***ERIC/SMEAC Science Education Digest, 2*** **(ERIC Identifier: ED309040).**
Reviews research and literature dealing with problem solving in the areas of biology, chemistry and physics. The meaning and importance of problem solving in science education were analyzed. The author claims that problem solving in chemistry was characterised by the use of algorithms in solving quantitative problems. The implications of this and the trend in the other sciences were drawn.

Case, R. (1974). Structures and strictures: some functional limitations on the course of cognitive growth. ***Cognitive Psychology, 6,*** **544-573.**
The article extends Pascual-Leone's theory by proposing a functional theory of intellectual development. Arguing that this would achieve a greater predictive power for developmental psychology, it was expected to compliment Piaget's theory, which to the author is an entirely structural theory. Using a sample of 52 7- and 8-year olds, the author demonstrated that this could be used to generate performance models for some Piagetian tasks. The primary focus was the control of variables task. They concluded that the acquisition of any item of knowledge depends on the match between the pragmatic structure of the situation in which the child first has a

chance to construct that particular item of knowledge and the functional limitations of his thought processes at the stage in his life when he first encounters the situation.

Chi, M. T. H. & VanLehn, K. A. (1991).The content of physics self-explanations. ***Journal of the Learning Sciences, 1(1),*** **69-105.**
Ten undergraduate students were involved in the study. The design involved a five-phase treatment, pretest, reading of text, studying examples, solving problems and posttest. They found that students have partial knowledge of the principles of physics involved in the concepts. However, these were made more understandable as they engaged in self-explanations. They also found that students who were good problem solvers generated more self-explanations than the weak problem solvers. The self-explanations of the good problem solvers contained a greater number of distinct pieces of constituent knowledge than the poor problem solvers.

Garrett, R. M. (1986). Problem solving in science education. ***Studies in Science Education, 13,*** **70-95.**
Written in the mid-eighties, the author gives two frameworks that have influenced problem solving (gestalt and associationist traditions). The author reviews the literature along the lines of the methods or design used in problem solving including the control/experimental group design, individual interviews, protocols and case studies. Other issues addressed are the purpose of the problem solving investigations in literature, the type of tasks, the subject variables. The author tried to present the differences between problem solving literature in the USA and the UK and suggested research being concentrated on particular issues rather than being diffused.

Gil-Perez, D, Dumas-Carre, A, Cailot, M. and Martinez-Torregrosa, J. (1990). Paper and pencil problem solving in the physical sciences as a research activity. ***Studies in Science Education, 18,*** **137-151.**
The review began by asserting the results of many studies that show that students have serious difficulties in doing paper and pencil problem solving, often not knowing where to begin or how to go. It presents the two theoretical foundations (expert and novice tradition versus the algorithmic tradition) underpinning most problem solving literature, and the meaning of the term problem from literature. The paper addresses problem solving as a research activity and proffered several ways in which problem solving can be approached in the classroom. Finally, problem solving is related to the constructivist paradigm where students can apply their preconceptions and experience cognitive conflicts.

Heller, J. I. & Reif, F. (1984). Prescribing effective problem solving processes: problem prescription in physics. ***Cognition and Instruction, 1(2),*** **177-216.**
The authors formulate a prescriptive model for understanding problem solving. They contend that since it is prescriptive and not descriptive, it serves a general purpose. The paper summarises the general approach used in the study to formulate and to test the model. They tested this by means human agents (24 undergraduates) as against computer simulations often used for such purposes. The model specifies an explicit procedure for generating a theoretical description from a basic description of any problem in a specified domain. They applied this to the domain of mechanics. The implications of this model were drawn. The authors claim that the model is sufficient to generate excellent problem descriptions, markedly improve subsequent problem solutions and that the major components of the model are necessary for good performance. It also prevented the subjects from making common mistakes. They conclude that this model is highly relevant in the design of instruction for teaching students improved problem solving skills.

Henderson, C., Yerushalmi, E., Kuo, V. H., Heller, P. & Heller, K. (2004). Grading student problem solutions: The challenge of sending a consistent message. ***American Journal of Physics, 72(2),*** **164-169.**
The authors contend that gap between teaching practices and instructor values in grading of problem solutions can be explained by another set of values that conflict with those expressed. They examined the grading practices of a sample of 30 physics faculty from an interview. Four areas of what the instructors know form the rationale for the study. They posit that most instructors know that there are three advantages for students to show their reasoning in problem solutions. However, the results revealed 40% of the instructors gave students incentives for their reasoning, 43% could be viewed by students as penalising demonstrated reasoning and that generally instructors have internal conflicts while grading student solutions.

Henderson, C., Yerushalmi, E., Yerushalmi, E., Heller, K., Heller, P. & Kuo, V. (2006). Physics faculty beliefs and values about teaching and learning of problem solving. Part I: Mapping the common core.
http://www.sci.ccny.cuny.edu/~rstein/percpaps/sharma.pdf (accessed: 02/06/06)
This paper is a continuation of an earlier paper that sought to construct a model that could be used to characterise the beliefs of college professors.(see Yerushalmi et al, 2006)

Hollabaugh, M. (2006). Physics problem solving strategy.
http://faculty.normandale.edu/~physics/Hollabaugh/probsolv.htm. (accessed, 31/05/06).
The article identifies two variables that can make an individual a better physics problem solver. These include understanding the principles of physics and having strategies for applying these principles to novel situations. He asserts that physics problem solving can be learned, a claim empirically disproved. He enumerated and detailed the steps to be followed in physics problem solving processes.

Huffman, D. (1997). Effect of explicit problem solving instruction on high school students' problem solving performance and conceptual understanding of physics. *Journal of Research in Science Teaching, 34(6),* 551-570.
This study employed a two-sample, pretest/posttest quasi-experimental design. The purpose of the study was to determine the comparative effects of an explicit-problem solving strategy and a textbook problem solving approach on problem solving performance and conceptual understanding of physics. Eight physics classes with a total of 145 students were involved in the study, assigned to either an experimental or the comparative group. The problem solving aspect was assessed using traditional textbook and context-rich problems. Multiple-choice and open-ended written tests were used to assess students' conceptual understanding. Results indicated that students in the explicit problem-solving group performed better than those in the traditional textbook group especially in the area of physics representation. There were no significant differences in the areas of mathematical executions and organisation of the solutions. There was no significant difference on the conceptual understanding of the two groups. Gender interacted with the methods to effect a difference among the males and females.

Lee, Y., Baylor, A. L. & Nelson, D. W. (2005). Supporting problem solving performance through the construction of knowledge maps. *Journal of Interactive Learning Research, 16(2),* 117-132.
The paper employs cognitive theory of knowledge representation in its entire outlook. It contends that the use of external representations to illustrate a learner's knowledge and structure of the knowledge enhances complex cognitive processing during problem solving. It thus considered knowledge representations and the limitations of conventional tools on problem solving performance. Given these limitations and their effect on problem solving performance the authors suggest five design principles in order to support problem solving. These include combinational representation principles, contextual enhancement principle, spatial flexibility principle, the property association principle and the multiple representation principle. Finally, the paper presented the application of these principles in a new knowledge map construction.

Martinez, M. E. (1998). What is problem solving? *Phi Delta Kappan, 00317217.* Database: Professional Development Collection (accessed, 31/05/06).
The article starts with a definition of problem solving, and refers to it as the cognitive passport to the future. It addressed the heuristics of problem solving and contrasts this with algorithms. The paper stressed the fact that what constitutes problem solving varies from person to person being dependent on the interaction between a person's experience and the demand of the task. The author discussed the power of heuristics and different kinds of heuristics. A distinction was made between general and specific heuristics, the former content-free and the latter content-specific. The role of metacognition in the problem solving process was discussed. Finally, the paper addressed a number of issues in proposing a new mindset for the education community.

Taconis, R., Ferguson-Hessler, M. G. M. & Broekkamp, H. (2001). Teaching problem solving: an overview of experimental work. *Journal of Research in Science Teaching, 38(4),* 442-468.
The major aim of this study is to synthesise a systematic description of types of instructional approaches demonstrated to be successful in teaching science problem solving to students as well as describe critical differences between successful methods and other less successful ones. They adopted the theoretical perspective of cognitive theory. To do this they analyzed the articles published between 1985 and 1995. They identify 22 articles describing 40 experiments judged to meet the criteria for a meta-analysis. Criteria for selection of articles and journals were explicitly specified. Three variables were considered in the problem solving processes considered, variables describing the cognitive activities involved in the intervention; variables characterising the intervention in terms of the type of knowledge they require to be used; and variables describing the conditions for performing the learning task. The analyses revealed a consistent pattern of variables describing aspects of interventions that facilitate mastery of science problem solving; evoking the schemata had a positive effect as against evoking use of problem solving heuristics; immediate feedback also had a positive effect on science problem solving; small group work does not improve science problem solving except when combined with other measures that have been shown to be effective. In fact, they found the use of group work to have shown significantly negative effect.

Tsaparlis, G. (1998). Dimensional analysis and predictive models in problem solving. *International Journal of Science Education, 20(3),* 335-350.
Using first year undergraduate students, the author investigated the validity of Johnstone-El Banna predictive model of problem solving. He employed the dimensional analysis to determine the task complexity of items in an organic synthesis test. He found that the model can only hold when some necessary conditions are applied. These conditions were enumerated and investigated in the investigation.

Watts, M. (1991). *The science of problem solving: A practical guide for science teachers.* Portsmouth: Heinemann.
This book is intended to be a guide for science teachers. It introduces the concept of problem solving by emphasising applicability of previously learned rules in new situations. The author makes a case for problem solving, discusses the types and dimensions of problem solving. The author then discusses approaches and skills required for problem solving. He details constructivism, group work and co-operative learning and their relationships; as well as ownership of learning and transfer of learning. He gives a guide on how to teach problem solving and manage the classroom for problem solving. Finally, the methods of assessment of problem solving as well as research done in this area were addressed with an examination of how problem solving can be managed in the curriculum.

Yerushalmi, E., Heller, K., Heller, P., Henderson, C. & Kuo, V. (2000). Why solve problems? – Interviewing college faculty about the learning and teaching of problem solving. Proceedings of Physics Teacher Education beyond 2000 international conference, Barcelona, Spain, August 27 to September 1, 2000.
This paper discusses the differences between the problem solving approaches adopted by two faculty. The motivation of the study is on the approach to the teaching of introductory physics classes in higher institutions. The study is based on the claim that designing curricula based on the understanding of the belief and knowledge of both instructors and students will enhance their adoption by faculty. The authors contend that although curricula based on conceptual understanding and problem solving skills develop conceptual understanding and expert-like problem solving skills respectively in students they are seldom adopted by faculty. They used an open-ended interview designed around comparisons of concrete curricula artifacts, to induce reflection on practice. They found that in many cases, instructors are not aware of holding competing models, and that the major differences in the problem solving approach adopted by faculty is in the details of their teaching models and the way they treat competing models of teaching. They also found that physics faculty held coherent models but sometimes competing models of teaching.

Yerushalmi, E., Henderson, C., Heller, K., Heller, P. & Kuo, V. (2006). Physics faculty beliefs and values about teaching and learning of problem solving. Part I: Mapping the common core.
http://www.sci.ccny.cuny.edu/~rstein/percpaps/sharma.pdf (accessed: 02/06/06)
This paper argues that even the most effective curricular materials, tools and pedagogies must be accepted by instructors in order to become routine practice. In line with this, physics professors from six faculties were interviewed in order to build a model to describe the beliefs (about teaching and learning) of physics faculty, which influence their choice of curricular materials and pedagogy. This is as related to problem solving in introductory physics. From the result of the analysis, an initial model was constructed that reveals a common structure in the beliefs of physics professors.

Yerushalmi, E. & Magen, E. (2006). Same old problem, new name? Alerting students to the nature of the problem solving process. *Physics Education, 41(2),* 161-167.
The authors presented students with two problem types that needed the same principles in physics to be solved. The aim was to foster the appreciation and realisation that problem solving is not a linear process involved in the solving of exercises but a convoluted search process involved in real life problem solving. One of the problem types was context-rich and the other context-poor. It was found that students were able to transform the context-rich problem into context-free problems and recognised the differences between the two. Although the students found the context-rich problem difficult to complete, they nonetheless were enthusiastic about coping with the challenges of the problem and developed analysis and planning skills in problem solving.

6. Laboratory in Higher Education Physics

Berg, C. A., Bergendahl, V. C. B. & Lundberg, B. K. S. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of an expository versus an open-ended version of the same experiment. *International Journal of Science Education, 25(3),* 351-372.
The investigator determined the outcomes of exposure to two types of laboratory exercises. One adopted the expository method and the second adopted an open-ended method. The students were also classified into high and low attitude positions. Data was collected using an attitude questionnaire at the onset of the experiment, and thereafter with students' self evaluation sheets, and by interviews. It was found that students with low attitude positions preferred the expository method to the open-ended form and conversely, those with high attitude positions preferred the open-ended form. It was also found that the open-ended form showed a more positive outcome in terms of logistics. However, the investigation reveals that in an open-ended form students investigate a wide range of phenomena and come up with different results. This raises a number of questions for example how can laboratory work be assessed and what goals should a given experiment seek to pursue?

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education, 76(4),* 543-547.
Presents a review of the different styles of laboratory instructions and identified four such styles, the expository, inquiry, discovery and problem-based. Each was analysed using three descriptors, outcome, approach and procedure. The author reflected on the constructivist paradigm and contended that the styles affect the environment in distinct ways, which in turn lead to different learning outcomes. He asserts that the comparative effectiveness of the styles was not certain since more research was needed. He therefore concluded by calling for more research in this area.

Donnelly, J. F. (1998). The place of the laboratory in secondary science teaching. *International Journal of Science Education, 20(5),* 585-596.
The author employed the observational technique and interview to determine the place of the laboratory in science teaching. Of particular interest to the author were the language of practice, the characteristics of the science lessons and the institutional and material aspects of laboratory work. The teachers were found to make a distinction between practical work and theory and this influenced their judgment and planning of a lesson as well as the relationship of the pupil to the lessons (e.g. interest and attention span). The science laboratory is viewed as a very important aspect of the science lessons and to this extent it influences the institutional and material situation of teachers. The paper analyses how this structures teachers work and relates to the teachers' own agency in undertaking this work.

Garrett, R. M. & Robberts, I. F. (1982). Demonstration versus small group practical work in science education. A critical review of studies since 1900. *Studies in Science Education, 9,* 109-146.
The authors define a number of terms and identified arguments in literature concerning demonstrations and small group work. He noted that the questions raised by earlier workers are still with us, questions of logistics, goals and procedure of laboratory work. A review of the works followed under the headings: the experimental design, the statistical techniques and conclusions produced, the investigational tools employed, and the purity and consistency of the strategies and tactics employed. They concluded that the way forward is to determine the function of the school laboratory and the development of instruments for measuring the outcomes of practical work as well as the laboratory environment. Demonstration and small group work were seen to have their relative places in practical work.

Hazari, Z., Key, A. W. & Pitre, J. (2003). Interactive and affective behaviours of teaching assistants in a first year physics laboratory. *Electronic Journal of Science Education, 7(3),* March 2003. (accessed: 9/05/2006).
The study involved physics students and their laboratory supervisors (teaching assistants) in a first year introductory physics class. One aim of the programme is to influence, positively, students' appreciation of the laboratory and of experimental physics. Two instruments were used to collect data, from participant observers (students). One that measured the nature of the interactions of the students with the teaching assistants; and the second, explored students' evaluations of the teaching assistants in terms of the assistance given by, influence and fairness of the teaching assistants.

Hodson, D. (2005). Towards research-based practice in the teaching laboratory. *Studies in Science Education, 41,* 167-176.
In reviewing the book *Teaching and Learning in the Science Laboratory* (edited by Psillos, D. and Nieggerer, H.), the author posits that in the past during the phase of inquiry learning the case for practical work was made in terms of cognitive, affective, skills-based and class management arguments. The change in the paradigmatic underpinning of science teaching notwithstanding, the author states the expectations of laboratory work, in terms of its goals, has not changed. Research findings indicate the effectiveness is questioned and reasons for this were proffered: (i) practical work is too gross a term, too large a category; (ii) teachers do not always (perhaps only rarely) do what they say they will do. In other words, there is significant mismatch between rhetoric and practice; (iii) students do not always do what the teacher intends or expects. They may misread instruction, fail to distinguish between what is significant and what is unimportant, lack the necessary skills to collect reliable data, or just get bored and fail to finish; and (iv) practical work frequently doesn't work, in the sense that it gives unexpected, inconsistent or inconclusive results, and sometimes no results at all. The review ended by analysing the different contributions to the book and extracting their strengths and weaknesses.

Johnstone, A. H. & Al-Shuaili, A. (2001). Learning in the laboratory: some thoughts from the literature. *University Chemistry Education, 5(2),* 42-51.
This review examined the purpose of laboratory work under skills and affective aims. It also reviewed literature on the types of laboratory work and came up with an abridged descriptor of the different types as well as the strategies employed in each type, relating these to the purposes identified. Finally, it addressed the assessment of laboratory outcomes.

Johnstone, A. H. & Letton, K. M. (1989). Is practical work practicable? *Journal of College Science Teaching, 18(3),* 190-192.
The authors assert that laboratory work in our age is not efficacious because it does not take into consideration the psychology of learning. They reflected on the processes of the information processing system and showed how the limitation in working memory interacts with the procedures and requirements of laboratory work to create an impossible learning situation for the students. They proposed that laboratory work should be seen as a freestanding teaching mode; where acquisition of manipulative skills will precede the use of the skills in problem solving situations, rather than tying it to any theoretical lecture course. Secondly the lab manuals can be written in a manner that will reduce redundant materials.

Kang, N. & Wallace, C. S. (2005). Secondary science teachers' use of laboratory activities: linking epistemological beliefs, goals, and practices. *Science Education, 89,* 140-165.
The authors posit that the laboratory plays a central part in knowledge construction. Hence it can be a veritable source for identifying epistemological beliefs underlying teaching actions. They therefore set out to identify teachers' epistemological beliefs about lab activities, why teachers use the lab and the interaction between these two factors and their teaching actions. The guiding principle of the work was the more sophisticated epistemological beliefs, i.e., the acknowledgement of multiple interpretations of the same phenomena and the active role of the knower in knowledge construction. Data was obtained from three teachers through formal and informal interviews, classroom observations, and teaching materials such as student worksheets and lab sheets. The results showed that teachers response to critical incidents neglect to take into consideration in the laboratory students' active negotiation processes in making sense of unexpected lab results. However, observation data revealed these do not agree with their epistemological stands. This confirmed the argument that beliefs activated into actions depending on the context. They concluded that teachers' sophisticated epistemological beliefs are not always applied to their teaching practices but rather interact with their instructional goals and teaching contexts to influence their teaching practices.

Kelly, G, Crawford, T. & Green, J. (2001). Common task and uncommon knowledge: dissenting voices in the discursive construction of physics across small laboratory groups. *Linguistics and Education, 12(2),* 135-174.
Drawing from sociolinguistics and ethnographic theoretical orientations, the authors explored the discursive process of meaning making by four groups of students in a physics laboratory in a participant-observer design. The aim was for the laboratory to serve as a review of basic concepts in mechanics and to provide opportunities for students to apply these concepts in oscillatory motion. Data was collected from videotape records, artifacts produced on the computer and laboratory notebooks. They used a micro-ethnographic perspective for the analysis from which transcripts and data tables were created. They discussed how students negotiated what counts as task, text and physics; what counts as talk or knowledge, and who is a member; how students negotiated talk, position and content; and when dissenting voices count. They also highlighted the place of dissenting voices in meaning making and how dissenting voices can be used to reopen discussions. They suggested that much of what gets accomplished and eventually counts as science occurs through discourse and interpretive processes.

Rijlaarsdam, G., Couzijn, M., Jansen, T., Braaksma, M. & Kieft, M. (2006). Writing Experiment Manuals in science education: the impact of writing, genre, and audience. *International Journal of Science Education, 28(2-3),* 203-233.
This paper conceives of the experimental manual as a genre that serves to enable peers perform an experiment without problems as well as understand the procedures, anticipate the observations and measurements of an experiment. It also should serve to explain the outcome of the experiments as evidence for scientific claims. Using an experiment that shows that air takes up space, 105 fifteen year olds were instructed to write an experimental manual. It was found that the pre-writing activities were less effective than the post-writing activities. There was no evidence for the weak forward search hypothesis, rather the strong forward search hypothesis was supported. They recommended the introduction of writing tasks in science classrooms as part of the enculturation process into the world of science.

Pekmez, E. S., Johnson, P. & Gott R. (2005). Teachers' understanding of the nature and purpose of practical work. *Research in Science and Technological Education, 23(1),* 3-23.
The investigation involved 24 teachers from eight participating schools. They responded to questions on a structured interview. The questions were to gain an understanding of the teachers' perception of the nature and purpose of practical work. It was found that teachers had the view that practical work is to support the substantive explanations of science and laboratory is a period of discovery of these ideas. A large majority saw practical work as investigation, that is, they held a process view of laboratory. Only a small minority held a procedural view of the laboratory. The authors argue that this is a limiting factor in achieving the aim of practical work.

Roth, W-M., McRobbie, C. J., Lucas, K. B. & Boutonne, S. (1997a). The logical production of order in traditional science laboratories: a phenomenological analysis. *Learning and Instruction, 7(2),* 107-136.
Over a six-week period, the investigators collected data from the observation of some physics students in actual laboratory situation. The techniques for data collection included videotapes, observation, interview, tests and examinations. The results indicated that students constructed phenomena from interaction of existing practices such as language, actions, worldview and social relations. An action is judged adequate by the interpretation of the outcome rather than a judgment of the action in itself. It was also found that even with elaborate instructions, students constructed phenomena different form the one the instructor expected because they bring different interpretive frameworks to bear upon the result of their actions. The authors proposed strategies for dealing with students' non-scientific interpretations (phenomena) during laboratory work.

Roth, W-M., McRobbie, C. J., Lucas, K. B. & Boutonne, L. S. (1997b). Why many students fail to learn from demonstrations? A social practice perspective on learning in physics. *Journal of Research in Science Teaching, 34(5),* 509-533.
Premised on the fact that seeing the world around us with specific objects and properties is not a self-evident process, the authors investigated the reasons why students fail to learn from demonstrations in physics classrooms. They used an interpretive framework to investigate an enacted curriculum on rotational motion based on the assumption that reasoning is observable in the form of socially structured and embodied activity. The subjects comprised 17 boys and 7girls together with their teacher in a Year 12 physics class. He collected data by means of process and paper and pencil tests. The classroom transactions were videotaped and observations were carried out and interviews conducted. They identified six factors as mediating the learning of rotational motion in a traditional physics classroom. Recommendations were made. They concluded that viewing knowing science as competent participation in science related discourses will aid teachers in resituating their demonstration practices as well as redirect their perceptions of indicators of successful science learning.

Séré, M-G, (2002). Towards renewed research questions from the outcomes of the European project *Labwork* in science education. *Science Education, 86,* 624-644.
This paper summarised and reported the outcomes of the Europe-wide research on labwork aimed at addressing the effectiveness of labwork in science education. The present article concentrated on articulating the objectives of labwork under the categories of conceptual, procedural and epistemological objectives. On the conceptual perspectives, they argue that the worlds of concepts and models are closely linked to the worlds of objects/events/observations. Therefore the laboratory should induce students to use theories and concepts through appropriate questions. That is the goal of laboratory work should not just be for practice to consolidate concepts but rather for theories to guide practice. On the epistemological front, they assert that what the students construe as what and how the scientist work influence what they do in the laboratory. On the other hand, what the students do also influence their understanding of the scientists' work. The laboratory is thus a good place to teach the epistemology of science. On the procedural front they posit that autonomy is enhanced by awareness of procedures, know-how and approaches.

Solomon, J. (1989). A study of behaviour in the teaching laboratory. ***International Journal of Science Education, 11(3),*** **317-326.**
Practicing science teachers were used to make sense of normal laboratory behaviour of adolescent students. The teachers wrote case records immediately after each session with students from the case data. Three case studies of this sort were reported. The author drawing from the result of the study posited that there are realistic ways of dealing with difficult behaviour by recognising group space and group honour. Limitations of teachers in controlling adolescent behaviour were also made visible.

Yang, M. J. & Atkinson, G. F. (1998). Designing new undergraduate experiments. ***Journal of Chemical Education, 75(7),*** **863-865.**
This paper describes a series of checklists that an instructor might use to develop a new experiment. The issues covered include selecting objectives, the period before the experiment, the actual experiment, the cost and designing the write-up. The authors reveal these tips were based on actual experience and observations.

7. Assessment

Aikenhead, G. S. & Ryan, A. G. (1992). The development of a new instrument: "Views on Science-Technology-Society" (VOSTS). ***Science Education, 76(5),*** **477-491.**
This paper reports the steps taken to develop an instrument that assesses students' views on science, technology and society. It addresses the rationale for the instrument, the general characteristics of the instrument, and the five-step development procedure. It makes clear the benefits that may be derived from the use of the instrument and the ways in which it can be used. Areas covered by the instrument includes: the meaning of science and technology, influence of society on science/technology, influence of science/technology on society, influence of school science on society, characteristics of scientists, social construction of scientific knowledge, social construction of technology and nature of scientific knowledge.

Aikenhead, G. S., Ryan, A. G. & Fleming, R. W. (1992). Views on Science-Technology-Society (VOSTS). College of Education, University of Saskatchewan, Saskatoon, Canada.
This instrument has a pool of 114 empirically derived items on some science, technology and society issues. The areas covered include, the meaning of science and technology, influence of society on science/technology, influence of science/technology on society, influence of school science on society, characteristics of scientists, social construction of scientific knowledge, social construction of technology and nature of scientific knowledge. Each area has a number of items, with an item stem and varying number of alternatives. The last three alternatives give an individual opportunity to reject all of the alternatives provided, at the same time yielding a diagnostic response. However, no scoring procedure was suggested

Austin, L. B. & Shore, B. M. (1993). Using concept mapping for assessment in physics. ***Physics Education, 30,*** **41-45.**
This paper is concerned with the knowledge involved in multi-step problem solving. It claims that ability to successfully solve such problems is an indication of meaningful learning. The understandings of twelve students enrolled in twelve weeks of instruction on elementary electricity were tested using concept maps. The aim was to assess the degree to which the concept maps can assess meaningful learning. The procedure for the evaluation took into account previous scoring methods and was fully articulated. Results showed that performance on multi-step problems calls on different qualities of knowledge than performance on single-step problems. It also demonstrated that concept maps serve useful purposes in measuring meaningful learning to the extent this can represent multi-step problem solving.

Berenson, S. B. & Carter, G. S. (1995). Changing assessment practices in science and mathematics. ***School Science and Mathematics, 95(4),*** **182-186.**
In this paper, the authors emphasise the need for a change in the way assessment is carried out in schools. They proffer five alternative assessment formats, journal writing, open-ended problems, portfolios, interviews and performance assessments. The strengths and weaknesses of each form of assessment were elaborated on and samples of these were included. Hints were also given on how to use these forms of assessments.

Botton, C. & Brown, C. (1998). The reliability of some VOSTS items when used with preservice secondary science teachers in England. *Journal of Research in Science Teaching, 35(1),* 53-71.
To assess the reliability of VOSTS as an assessment instrument, the authors selected two sections of the instrument, defining science and epistemology. These were administered to 29 postgraduate preservice science teachers. A retest was made after one month. A cross tabulation procedure and a Pearson chi-square were applied to the data to determine consistency and independence of choices. A cluster analysis of the responses was also undertaken to identify any differences between clusters and dendograms were obtained from the SPSS cluster procedure. From the results obtained, they conclude that the selected items were generally reliability but for three. More interestingly, the authors suggest that the responses from VOSTS can be used to obtain a profile of students' views and indeed can serve as a form of diagnostic tool to give direction on efforts at appropriate science education.

Bryce, T. G. K. & Robertson, I. J. (1985). What can they do? A review of practical assessment in science. *Studies in Science Education, 12,* 1-24.
The authors contend that this is a neglected area in assessment, although science is taken to be a practical oriented subject. They argue that in view of the emphasis given to it by different educational systems as their review revealed there should be a succinct definition of its purpose and assessments directly and not indirectly. They advocate the teaching of basic practical skills no matter the global goal of any laboratory activity. They identified methods used to assess practicals as evidenced in the literature as the external practical examination (a one-off examination); the internal practical examination (enquiry-oriented examination, stations technique, involving predetermined skills); and the continuous and quasi-continuous internal practical examinations (emphasis on grading written laboratory reports). The paper went further to identify methodological issues involved in these assessment approaches and the reasons for the failure of some of them. The authors offered the way ahead as involving the prescription of detailed checklists of practical skills, product checks, and being cautious with assessment of experiments and practical investigations. They recommend that assessment of practicals be 'practical and integral to laboratory work and given the statistically different outcomes of practical work between schools and teachers that teachers be appropriately equipped for practical assessment and guidance of students.

Danili, E. & Reid, N. (2005). Assessment formats: do they make a difference? *Chemical Education: Research and Practice, 6(4),* 204-212.
This paper compared the scores of first year upper secondary school pupils (age 15-16year old) obtained from different paper and pencil formats of classroom assessment. The aim was to test the validity of results from such assessments. The formats involved include multiple-choice, short answer, and structural communication grid. The tests were assumed equivalent because they assessed the same knowledge and understanding from the same topics. They obtained correlation coefficients of between 0.3 and 0.71. This suggests that the performance of the students were not perfectly matched. The authors raised a number of questions relating to the validity and use of different assessment techniques as a result of this study

Duschl, R. A. & Gitomer, D H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment, 4(1),* 37-73.
The authors make a proposal for assessing students for understanding in the science classroom. Its premise is that present agenda for science education is to develop thinking reasoning and problem solving skills. They describe a form of assessment, the assessment conversation that is enmeshed in classroom activities. A curriculum unit developed along the line of a portfolio instruction and assessment (SEPIA) and the actual implementation of the curricula unit by two teachers were documented. SEPIA was described in details with the criteria that will guide the formation and assessment of students' explanations. The challenges faced by the teachers as well as those facing portfolio assessment with special reference to assessment conversation were discussed.

Friel, S. & Johnstone A. H. (1978). A review of the theory of objective testing. *School Science Review, 59(209),* 733-738.
In this review, the authors assert that multiple-choice objective testing is by the far the most widely used at the time. They however acknowledge that there are many criticisms regarding its use. They therefore reviewed research findings on multiple-choice objective tests under the following the headings: effect of guessing, effect of changing the initial response, effect of item order alteration, optimum number of choices, position response set, and assessment of partial knowledge. The authors did not express any opinions at the end.

Friel, S. & Johnstone, A. H. (1988). Making test scores yield more information. ***Education in Chemistry, 25(2),*** **46-49.**
The investigators applied the 'modified caution index' of Harnish to 100 year three students (age 16) scores on a 40-item four –choice multiple-choice test. They found that using this method yields diagnostic information of students' response patterns and better criteria for item selection on a test. The paper offered details of how this can be used.

Herman, J. L. (1997). Large scale assessment in support of school reform: lessons in the search for alternative measures. ***International Journal of Educational Research, 27(5),*** **395-413.**
The importance of this work lies in the recognition of the new trend in assessment, which is in the types of assessment being used and the policies and practical purposes they are expected to serve. The meaning of alternative assessment was articulated. Its place as a key to reform was also discussed. Its link to learning and cognition was addressed. Issues and status in establishing technical quality of alternative assessment were also addressed. The author argues that these forms of assessment can model good instruction.

Hodson, D. (1992). Assessment of practical work. ***Science and Education, 1(1),*** **115-144.**
The trend toward assessment of skills as index of laboratory outcome was criticised by this paper. It alluded to the efforts at making laboratory assessment more effective with the efforts tending more and more towards skill-based approaches. This approach the author argues is fraught with flaws being philosophically unsound, educationally worthless and pedagogically dangerous. He proposes an alternative approach that will be in line with valid scientific practices.

Johnstone, A. H. & Ambusaidi, A. (2000). Fixed response: what are we testing? ***Chemistry Education: Research and Practice in Europe, 1(3),*** **323-328.**
The paper was introduced by briefly tracing the history of fixed response testing and its advantages. Some concerns were raised about this mode of testing and then literature was reviewed dealing with fixed response assessment. The aim of the paper was to stimulate thought and debate among examiners and to alert them to be cautious.

Kempa, R. (1986). ***Assessment in science.*** **Cambridge: Cambridge University Press.**
Kempa begins by considering the uses of examinations and assessment in science education. He identified and reviewed the three modes of assessment techniques, the multiple-choice tests, short answer and structured questions and free-response questions that were commonly used at the time. The nature and quality of measurements deriving from these were discussed, and the ways in which they can be manipulated to measure process kills and practical abilities were detailed. The author then considered attitudes and affective aspects of learning and identified three broad classes of assessment tools, interviews, written tests and inventories and direct observation. The shift away from norm referencing to criterion referencing was addressed and implications of the trend to future assessment of learning were suggested.

Krueger, B. And Wallace, J. (1996). Portfolio assessment: possibilities and pointers for practice. ***Australian Science Teachers' Journal, 42(1).*** **http://weblinks2.epnet.com**. (accessed on 4th November, 2005).
The authors perceive portfolio assessment as one of the assessment procedures that assists learning and shows students' progress towards set goals. It identifies the differences between portfolios and other forms of collection of students' work and from traditional methods of assessment. It considers the different forms of evidence needed in portfolio assessment as well as the design and development of assessment portfolios. It briefly considers the use of portfolios in assessment and criteria for scoring visual presentations.

Liu, X. (1996). The internal consistency of a concept mapping scoring scheme and its effect on prediction validity. ***International Journal of Science education, 18(8),*** **921-937.**
Contending that results from research has not been conclusive on the prediction validity of concept mapping assessment technique and adducing this to a number of reasons such as scoring schemes, formats of concept mapping, students' experience with this technique; the author set out to investigate the internal consistency of Novak and Gowin's scoring scheme and its effect on the prediction validity. The investigation involved four grade seven science classes in a two-phase investigation. During the first phase, two classes in experienced with concept mapping, were administered concept mapping and conventional test. During the second phase, two fairly experienced classes were administered a conventional and a concept mapping test. It was found that there was no correlation between students' concept mapping scores and scores from the conventional tests. It was suggested that teachers should focus on the structure of a whole concept map rather than on the correctness of specific concept mapping attributes or else to develop new scoring procedures for concept mapping assessments.

McClure, J. R., Sonak, B. & Suen, H. K. (1999). Concept map assessment of classroom learning: reliability, validity, and logistical practicality. ***Journal of Research in Science Teaching, 36(4),*** **475-492.**
Sixty-three undergraduates and twelve graduate students took part in this study which was geared to assess the effect of scoring method on reliability of assessment by concept map; the validity of assessment by concept maps; and the applicability of assessments by concept maps in classroom situations. The sixty-three undergraduates were given 90 minutes of training and were then required to produce concept maps based on concepts from a course they were studying. The graduate students were paired, each pair scored the concept maps using one of six scoring modes. The highest reliability was demonstrated when the mode evaluated separate propositions represented (corroborating Safayeni et al. 2005) for a dynamic representation. Five out of the six modes of scoring were found to be valid whereas the logistics were found to be compatible with classroom practices.

Mintzes, J. J., Wandersee, J. H. & Novak, J. D. (Eds.) (1999). ***Assessing Science Understanding: A human constructivist view.*** **San Diego: Academic Press.**
This book edited by three academics has twenty contributors and fifteen chapters. It is meant to present assessment tools for teachers teaching for scientific literacy and conceptual change. This is necessary because, as the editors claim, commonly used assessment practices have serious limitations and destructive effects and do not capture successes in creating, learning and using knowledge. The chapters are situated firmly in the constructivist paradigm. Each of twelve of the fifteen chapters is devoted to a mode of assessment, including concept maps, Vee diagrams, structured interviews, interactive protocols, image-based test, observation, portfolios, computer-based assessment, multiple-choice tests, and written tests. Other important issues on assessment were also discussed. This is a timely book given the present trend in science teaching that emphasises understanding and personalisation of knowledge, that is, meaningful learning. This book is highly recommended for science teachers and science curriculum planners of this twenty first century.

Nicoll, G., Francisco, J. & Nakhleh, M. (2001). A three-tier system for assessing concept map links: a methodological study. ***International Journal of Science Education, 23(8),*** **863-875.**
The investigators developed a method of assessing non-hierarchical concept maps. The emphasis was on how links are formed and the use, stability and complexity of each link. This method is of particular importance because it affords the opportunity of understanding students' propositional representations in a particular domain. Concept maps from 56 students were analysed and graded by using this method to demonstrate its power in analysing students' understanding and knowledge representation. Each node and link was coded and the coding given point scores.

Novak, J. D. & Gowin, B. (1984). ***Learning to learn.*** **Cambridge: Cambridge University Press.**
The book is sewn together by two assumptions of the authors, that people think with concepts and that knowledge has structure. The aim of the book was therefore to explore how to help students and teachers understand the process of knowledge construction and the structure of knowledge. Two strategies were employed, the use of concept maps and Vee diagrams. The book addressed the use of concept mapping in meaningful learning by considering its nature and meaning and activities and ways of helping students construct concept maps and scoring criteria. The use and scoring of Vee diagrams were also detailed. Their uses as evaluation, research planning and interview instruments were discussed as well as their use as instructional design aids. The book is commended for its fine details on concept maps and Vee diagrams.

Rice, D. C., Ryan, J. M. & Samson, S. M. (1998). Using concept maps to assess student learning in the science classroom: must different methods compete? ***Journal of Research in Science Teaching, 35(10),*** **1103-1127.**
One hundred and thirteen seventh-grade students participated in the study. These were trained in the construction of concept maps. Data was then collected from the students by means of concept maps. Using a test blueprint, the authors developed a scoring procedure for the concept maps. The students were also given a multiple choice test. The scoring of the concept maps was based on the propositions they contain and not just on hierarchy and branching. The investigators found a high correlation between the concept map scores and the scores from the objective tests administered to the students. They also found high correlations between the scores from the concept maps and state criterion-referenced and national norm-referenced standardised tests. They concluded that the method of scoring used in this investigation is a departure from former practices and handles the questions of validity that had plagued the use of concept maps. They suggest that it should compliment other conventional test and not seen as an alternative.

Rowntree, D. (1987). ***Assessing students: how shall we know them?*** **London: Kogan Page.**
Rowntree addresses various issues that concern assessment of students. He considered the meaning and purposes of assessment, the interpretation and side effects of assessment, what and how to assess and how to report the product of assessment. Rather than look at specific assessment techniques, the book considered enduring matters for selection, inclusion and use of assessment modes and techniques, that is a tool for evaluation of assessment practices for schools.

Sadler, P. M. (1998). Psychometric models of student conceptions in science: reconciling qualitative studies and distractor-driven assessment instruments. ***Journal of Research in Science Teaching, 35(3),*** **265-296.**
Discusses the advantages of the multiple test assessment strategy in view of present knowledge about the process of science learning and the different stages its development has gone through. These include the classical test theory, and the item response theory, the use of the latter in assessment of alternative conceptions was identified. Using 2562 students, the author determined the impact of different instructional strategies on students' construction of astronomical concepts. With the aid of three items from the pool of 47, the author analyzed the instrument, for ability to discriminate among different ability levels and susceptibility to alternative conceptions, progress toward understanding of correct scientific conceptions. Implications for the curricula and sequencing of concepts were drawn form the result of the study.

Savinainen, A. & Scott, P. (2002). The Force Concept Inventory: a tool for monitoring student learning . ***Science Education, 37(1),*** **45-52.**
The authors perceive the Force Concept Inventory as a vital tool in physics education. This is a multiple-choice test designed to monitor students' understanding of the concepts of force and kinematics at both the upper high school and university levels. In this paper, the authors examine the development of the instrument, and review the findings from its implementation. The article also outlines the principal conceptual dimensions of the target subject matter and the key sub-features of these dimensions were identified. The reasons for the success of the FCI were documented including its ability to analyze students' thinking in relation to patterns of misconceptions.

Slater, T. F. (2006). Performance assessment.
http://www.flaguide.org/extra/download/cat/perfass/perfassw97.doc (accessed, 13/06/06)
This paper proposes a form of assessment that evaluates knowledge of methods and procedures as well as analysis skills that provide context. The paper discusses the three distinct parts that make up the strategies of performance assessment. The purposes of performance assessment were addressed, its requirements and limitations discussed. The author suggested its uses for diagnostic purposes, instructional purposes, and monitoring purposes.

Stoddart, T., Abrams, R., Gasper, E. & Canaday, D. (2000). Concept maps as assessment in science inquiry learning – a report of methodology. ***International Journal of Science Education, 22(12),*** **1221-1246.**
With new curriculum standards that emphasise the development of students as autonomous learners in active inquiry-based constructivist instructional environments, the authors contend that assessment is made very cumbersome and difficult. The paper suggested the challenge being met by assessing student learning using open-ended concept maps. The paper describes the methodology of this assessment complete with the rubrics that extract quantitative information about the quality of understanding from each map.

Toppino, T. C. & Brochin, H. A. (1989). Learning from tests: The case of true-false examinations. ***Journal of Educational Research, 83(2),*** **119-124.**
In a two by two factorial design, 64 students were assigned to four groups. The students were given biographical passages of 12 U.S. presidents. A true-false test was administered after a one-hour study. The test was re-administered a week later, with an additional requirement of the students indicating their confidence in the validity of each statement on a 7-point scale. They demonstrated the negative suggestion effect and indicated that exposure to a statement on a true or false test increased students' tendency to believe that the statement was true regardless of whether it was true or false. This was discussed in the light of literature on true-false tests.

Vazquez-Alonso, A. & Manassero-Mas, M. (1998). Response and scoring models for the 'Views on Science-Technology-Society' instrument. ***International Journal of Science Education, 21(3),*** **231-247.**
The authors suggested a new response model for the 'Views on Science-technology-Society' instrument, an instrument that assesses students' views on STS issues. The response model will allow multiple responses from students. A scoring model for the response mode was developed which will define a local system of meanings and weights. The paper documents the processes involved in this development and their implications.

Welzel, M. & Roth, W. (1998). Do interviews really assess students' knowledge? ***International Journal of Science Education, 20(1),*** **25-44.**
Working with 26 students the investigators sought to explain the dynamics of students' cognitive processes, the influence of interviewers' questions and cues on the cognitive processes of the interviewee and how the expectations of the interviewer and interviewee interact to mediate cognition during interviews. They found that the interview revealed the dynamic nature of cognition and that changes in the context of the activity may change the level of performance. To the second issue, it was found that assessment outcomes were dependent on the actions of the interviewer and the interviewee. And finally, the expectations of the two parties mediate the effect of interviews. They inferred from these results that interview can only provide clues to the processes of cognition and made recommendations there from.

8. Attitudes Relating to Physics

Demìrcì, N. (2004). Students' attitudes toward introductory physics course. ***Hacettepe Üniversitesi Eğitim Fakűltesi Dergisi, 26,*** **33-40.**
This paper examines the gender differences in attitude of students towards physics as well as differences between academic major and attitudes toward physics. A likert-type instrument with 10 options was used to elicit responses from 176 university freshmen. It was found that male students show a more positive attitude toward physics than their female counterparts; and there were differences among the students' academic areas and their attitude toward physics. Specifically, the attitudes of physics and space students were more positive than others and negative attitudes were found in biology, environmental and oceanography students than the other departments.

Gardner, P. L. (1996). The dimensionality of attitude scales: a widely misunderstood idea. ***International Journal of Science Education, 18(8),*** **913-919.**
The author points out that there is lack of understanding or complete neglect of the dimensionality of attitude scales and that this results from not conceptualising the constructs in the instruments. He considers the issues related to the principle of psychometrics under complete neglect, conceptualising without considering dimensionality, available evidence about dimensionality ignored and exemplified them with works in the attitude literature. The paper asserts that part of this confusion stems from the confusion of internal consistency and uni-dimensionality and then offered a model for good practice.

Johnstone, A. H. & Reid, N. (1981). Towards a model of attitude change. ***European Journal of Science Education, 3(2),*** **205-212.**
The authors in this paper proposed a model for attitude change with the aim was to bring together studies done in this area by showing its power in rationalising a wide range of experimental data and generating problems for research. To do this, they reviewed earlier works and definitions of attitude, and types of attitudes. They also addressed the relationship between attitude and cognition. The model took into consideration the experimental development of attitude and the stability of attitudes.

Jones, T. G. (2006). University students' attitudes towards physics. (accessed 13/06/06)
The paper asserts that there is declining enrollment and that this calls for science teachers to make informed decisions as to the appropriateness of current instructional approaches and curricula. A sample of 286 university students responded to a three-point rating scale. Although making interpreting statements about attitudes of university students to physics was difficult, the author recommended that assessment and teaching approaches in physics should incorporate both the mathematical and conceptual approaches. Implications for curriculum developers and physics instructors were drawn.

Ramsden, J. M. (1998). Mission impossible: can anything be done about attitudes to science? ***International Journal of Science Education, 20(2),*** **125-137.**
The paper is born out of the concern to the author of the disparity between the decline of interest in attitude research and teachers' increased concern about the attitude of students to science education. The paper thus clarified the meanings and definitions of key terms e.g. science, attitude, interest, motivation and the distinction between scientific attitudes and attitude to science. It raised the questions of the constructs of attitude and attitude development. Other issues discussed are those of research instrument design and methodology and nature and purpose of research into pupils' affective responses to science. The author addressed the implications for research.

Reid, N. (2006) Thoughts on attitude measurement. Research in Science and Technological Education, 24(1), 3-28.
The author introduced the paper by discussing the history of the study and measurement of attitude and that attitudes have three components, the cognitive, the affective and the behavioural. It was noted that attitudes and behaviour are closely related and that although attitudes are fairly stable, they are open to change and development. The relationship between attitude and science education was explored and attitude targets in science education as well as scientific attitudes were identified and explained. Approaches to attitude measurement were detailed with particular reference to the types of questions asked, and the methods of questioning; issues of reliability and validity; and attitude scaling techniques. The problems with scaling were listed, and specifically, correlation issues were addressed and so was loss of details. The way forward was proposed with principles given for better attitude studies and analysis.

Reid, N. & Skryabina, E. A. (2002). Attitudes towards physics. *Research in Science and Technological Education, 20(1),* 67-81.
This study is a detailed investigation into the attitudes of 850 pupils and 208 level 1 and 2 university students' (aged between 10 and 20 years) attitudes towards physics. Data were collected by means of questionnaire and interviews. The factors attracting students into a study of physics were described. The paper also described the patterns of attitude changes that take place with age. The picture obtained highlighted certain critical features of the curriculum, which made physics more attractive than other subjects. Suggestions were made for consideration by curriculum planners.

Stokking, K. M. (2000). Predicting the choice of physics in secondary education. *International Journal of Science Education, 22(12),* 1261-1283.
The study was carried out on two cohorts of students, with two measurements per year for a period of two years. They used data from 1371 students who took part in all four measuring occurrences. The data were subjected to various complementary statistical analyses, including multilevel analysis. It was found that the main predictor of the choice of physics in secondary school is its future relevance. The relevance of the findings to curriculum construction was highlighted.

Woolnough, B. E. (1994). Why students choose physics, or reject it. *Physics Education, 29,* 368-374.
This article identifies the factors that are responsible for why students choose to or not to continue in physics. These were placed under three categories, factors internal to school physics, for example, teacher variables; factors involving individual differences, e.g. student abilities; and psychosocial environment factors, e.g. reward for undertaking physics related careers. It then considers the effect of changes in the school curricula.

9. Approaches and Strategies to the Teaching of Physics

Aikenhead, G. S. (1986). The content of STS Education. *STSRN Missive, 2(4),* 17-23.
The author addresses what STS science teaching entails in terms of the function of science teaching, the content, the structure and the sequence. In summary, it portrays STS teaching as being student oriented and presenting science in context and enumerates the goals. It also presents STS as having both science content and STS content (social aspects internal and external to the scientific community). These were elaborated on and the teaching methods compatible with STS teaching discussed. It also proposed an eight-category scheme for integration of the content.

Anderson, B. & Bach, F. (2005). On designing and evaluating teaching sequences taking geometric optics as an example. *Science Education, 89,* 196-218.
The study adopted a problem driven approach. The major aim is to help solve the problem arising from lack of understanding among majority of students. This is based on the belief that integrating research-generated knowledge and the experiences of teachers can enhance learning. They designed a teaching sequence during the design phase tried it out during the implementation phase. They argued that the interaction of the structure of the knowledge and students' prior knowledge (and its effect on understanding) is very critical in knowledge delivery. The paper identifies key alternative conceptions in the area of light and optics as a starting point for the teaching sequence. It outlined the development of the teaching sequence and the subsequent teachers' guide that emerged from this. The interpretation of the trial teachers was used to improve the teaching sequences. They found that the students from this experiment performed better than the national sample and students from the control group, although the former used more teaching time than the latter. Methodological issues were discussed, prospects outline and issues in the composition of teachers' guides, reproducibility and terminology were highlighted.

Cohen, S. M. (2005). Active learning in lectures introducing magnetic induction. *American Journal of Physics, 73(3),* 284-285.
The paper discusses an experiment used to introduce magnetic induction to introductory physics students. It argues that students should be allowed to follow qualitative reasoning, understand basic concepts and see their underlying validity. This is as against the traditional practice of building on previously learned materials. The argument is to begin at the macroscopic.

Driver, R and Oldham, V. (1986). A constructivist approach to curriculum development. *Studies in Science Education, 13,* 105-122.
Driver and Oldham documented a practical attempt at curriculum development using the knowledge from research in cognitive psychology and science education. The paper briefly presented the status of understanding reached in research about children's ideas, the constructivist view of learning, and the process of learning as conceptual change. They present five assumptions underlying their work, and a pictorial presentation of their model for curriculum development. They proceeded to record in an outline form the processes they went through for the curriculum development programme and the general features of a constructivist pedagogy.

Driver, R., Newton, P. & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84,* 287-312.
Starting from the importance of argumentation in science and to scientists, the paper moves on to make a case for the emphasis of argumentation in the science education enterprise. The authors contend that present science education is still shrouded in the cloak of positivism. The meaning and issues in argumentation are explained; the epistemology of science considered and review of the place of argument in science made. A case was made for education about science and the place of argumentation in science education addressed. Among others they argue argumentation theory will enhance developing conceptual understanding and investigative competence; understanding of the epistemology of science, understanding science as a social practice. Literature on argumentation in the science classroom was reviewed and implications were highlighted for research in argumentation in teaching science.

Fischler, H. & Lichtfeldt, M. (1992). Modern physics and students' conceptions. *International Journal of Science Education, 14(2),* 181-190.
This paper attempts to design a new approach to the teaching of quantum physics. The argument is that many of students' difficulties in the understanding of modern physics are because the teaching has retained elements of the classical physics. The approach was used to design 32 lessons based on five principles. This led to a structure for the teaching units based solely on quantum physics. This was used to teach students in a pretest/posttest design. They concluded in comparison to a control group, the teaching unit achieved higher cognitive conflict and thus a better conceptual change.

Geer, U. C. & Rudge, D. W. (2002). A review of research on constructivist-based strategies for large lecture science classes. *Electronic Journal of Science Education, 7(2),* December, 2002.
In light of the *status quo* in large lecture classes of the use of lectures rather than the research informed strategies of interaction, the authors proceeded to analyze the constraints to the implementation of proven strategies among faculty members. These factors were identified to include physical considerations, and systematic factors. More than these are factors related to pedagogical content knowledge such as lack of familiarity with relevant science education literature, difficulty in interpreting the results of education research, and problems of translating practical techniques from others to their own teaching contexts. The article then presented a bibliography that addresses constructivism, and reform efforts as well as research findings regarding strategies in the teaching of the different disciplines of science.

Hall, R. H., Dansereau, D. F. & Skaggs, L. P. (1992). Knowledge maps and the presentation of related information domains. *Journal of Experimental Education, 61(1),* 5-18.
A sample of 92 students was assigned to two groups. The experimental were taught by the use of concept maps whereas the control was taught by the traditional method of using text. The two groups were presented with knowledge in two different domains and in two different forms. It was found that students in the concept map group had higher immediate gains than students in the text only group in one of the knowledge domains but not in the other. The reasons for this domain sensitive differential were identified and discussed.

Hobson, A. (2004). Energy flow diagrams for teaching physics concepts. *The Physics Teacher, 42(2),* 113-117.
The author submits that energy is the central unifying concept in physics. The paper describes and discusses energy flow diagrams for some simple and complex processes. This the author believes is necessary because to teach physics conceptually, which is the present call in physics (science) education, the concept of energy has to be used to organise the teaching. He argues that every physical process involves the energy transformation of

some sorts. Energy flow diagrams according to this article provide visual and quantitative presentations of these transformations.

Hoellwarth, C., Moelter, M. J., & Knight, R. D. (2005). A direct comparison of conceptual learning and problem solving ability in traditional and studio style classrooms. ***American Journal of Physics, 73(5),*** **459-462.**
The study compared two groups of students. The data was collected over a two-year period from 40 students studying introductory calculus-based physics sequence in a university. The students were place in one of two groups, one in a traditional physics class (with distinction between practicals and lectures) and another group with the integration of both (studio class). Data was collected by means of the Force Concept Inventory and the Force and Motion Conceptual Evaluation. It was found that the studio group had large gains which were significantly different from the traditional group in conceptual learning while no significant difference existed in their quantitative problem solving.

Houpt, S. (2004). Egg drop competition involving only toothpicks and glue. ***The Physics Teacher, 42(4),*** **205-207.**
This article is a description of the egg drop competition, a competition that has become popular in physics education. The rules for the competition were stated, and the criteria for winning enumerated. This is according to the practice of Winston Science in Dallas, TX, USA. This competition is seen as a useful way of enhancing conceptual understanding in physics.

Howes, R. H., Baumann, T., Thoennessen, M., Brown, J., DeYoung, P. A., Finck, J., Hinnefeld, J., Kemper, K. W., Luther, B., Pancella, P. V., Peaslee, G. F., Rogers, W. F., & Taber, s. (2005). Fabrication of a modular neutron array: A collaborative approach to undergraduate research. ***American Journal of Physics, 73(3),*** **122-126.**
The paper is introduced by an assertion that active participation in creative and publishable research plays an important role in preparing undergraduates for career in physics and motivating them to study further physics. The paper highlighted problems faced by physics undergraduates and presented two approaches to handling these. The first is involving them in vacation research by large corporations as NASA and paying them stipends for their participation. The second was a proposal by the authors of this article, involving students from small physics departments at large user facilities. The advantages of the latter were presented both for the user facility and for physics faculties.

Lambiotte, J. G. & Dansereau, D. F. (1992). Effects of knowledge maps and prior knowledge on recall of science lecture content. ***Journal of Experimental Education, 60(3),*** **189-201.**
In a 2 x 3 factorial design, the investigators compared the effects of presenting information (key concepts and details) as a concept map, outlines or lists. Students heard the lecture auditorily and after were presented the key concepts in the three forms. Students were classified into those that have high prior knowledge and those with low prior knowledge. The authors found that there was no significant difference in the overall performance of the students. However, when the interaction between prior knowledge and form of presentation, It was found that concept maps was more advantageous when students' prior knowledge was low and the reverse was the case for high prior knowledge students. This was explained in terms of influence of prior knowledge on organisation of incoming information.

Lan, B. L. & Jones, L. J. N (2005). Balancing act: students explore their understanding of forces. ***Physics Education, 40(3),*** **204-206.**
Working from the premise that competition aids in the development of creative, problem solving, as well as communication skills, teamwork, perseverance and self-confidence, the paper describes a competition among some introductory physics students. The students were presented with a block-stacking competition. This required their use of the knowledge of forces, torque, centre of mass and static equilibrium to solve the problem. The students were given handouts that contained the objectives of the competition, information needed for the work and instructions of the report format. The students worked in groups.

Lan, B. L., Ooi, G., & Keh, C. Y. (1999). Pencils solution to an egg-citing problem. ***The Physics Teacher, 37(2),*** **127-128.**
This article emphasised the importance of higher order skills such as creative problem solving. The authors describe an egg-citing contest for undergraduate students that will allow the development of such skills. They also argue that this will enhance students' interest while primarily developing problem solving skills.

Maclaren, H. M. (1980). Physics projects in sixth-year studies in Scotland. ***Physics Education, 15(1),*** **44-48.**
The author did an extensive analysis of the Scottish school system and curriculum requirements. Sources of project titles were outlined; the guidelines on project writing, teachers' roles and the methods of carrying out projects and their assessment procedures were documented.

Marìn, N., Benarroch, A. & Gómez, E. J.(2000). What is the relationship between social constructivism and Piagetian constructivism? An analysis of the characteristics of the ideas within both theories. ***International Journal of Science Education, 22(3),*** **225-238.**
This article is premised on the notion that social constructivism is at variance with Piagetian constructivism. The authors therefore sought to highlight the similarities between the two in order to build bridges between them. The paper thus established the meaning of the key terms used in this consideration, schema and conception. Based on the meaning so established, the authors gave the characteristics of these two terms as perceived by the social constructivists and Piagetian constructivism. They considered the points at which the two converge and drew the conclusion that the general characteristics of conceptions, as defined by social constructivism can be lodged within the framework of Piagetian constructivism.

Milner-Bolotin, M. (2004). Tips for using a peer response system in a large introductory physics class. ***The Physics Teacher, 42(4),*** **253-254.**
The author gave tips for making a large introductory physics class interactive. The factors affecting success of such classes were discussed and real-time interaction between students and lecturers was made problematic in this paper. The article sets out the disadvantages arising from this factor and explained how peer response system can handle this problem. This is because of the instantaneous feedback that can be generated during the lesson.

Rehfuss, D. E. (2004). Current concepts consolidated. ***The Physics Teacher, 42(2),*** **103-107.**
The author contrasts the common use of conceptual analogies between water pipes and electrical circuits and the rare use of this in related transport equations. He suggests that the use of such for concepts such as Laws of Fourier, Ohm, and Poiseuille may enhance students understanding. He concluded that understanding physics concepts will be enhanced if formal similarities between concepts and their every day analogies are examined. Suggestions were made on how this can be done.

Roelofs, E. & Terwel J. (1999). Constructivism and authentic pedagogy: state of the art and recent developments in the Dutch national curriculum in secondary school. ***Journal of Curriculum Studies, 31(2),*** **201-227.**
This article evaluates the implementation of the Dutch curricula in mathematics and English Language. Responses form 1000-1400 students and some teachers were used to judge the extent to which the aims of the new curricula were being achieved. Situation-specific questionnaires were used to elicit responses on four indicators of authentic learning, the type of learning advocated by the curricula. The theoretical bases of these innovations were constructivism and situated learning and the four indicators were, construction of knowledge, connectedness to students' personal worlds, value of learning activities beyond school and co-operation and communication. The results revealed very minimal achievements in the four indicators. Part of the reasons adduced for this trend was the textbooks in use and the teachers' lack of prowess in implementing such curricula. This study is interesting because it claims the Dutch curricula embrace the tenets advised by research and yet not much progress is made. It might be worthwhile to do an in-depth study of the Dutch case.

Sabaz, L. (2006). Can bubbles explain viscosity? ***Physics Education, 41(2),*** **112-114.**
Starting from the standpoint that certain concepts in physics create problems of application to real life situations, the author contends that the problem is relating the definitions or technical meanings of these concepts to different life contexts. Using different liquids e.g. water, olive oil, vinegar, glycerol and shampoo he explained how these could be used to investigate Stokes' Law and Reynolds number. He then raised many questions that can be used to direct students' activities in the concept of viscosity.

Safayeni, F., Derbentseva, N. & Cañas, A. J. (2005). A theoretical note on concepts and the need for cyclic concept maps. ***Journal of Research in Science Teaching, 42(7),*** **741-766.**
This paper reviewed literature on concept map as a mode of knowledge representation. It captures the need for concept maps and the debate on the structure of concept maps. The paper reflects on the relationship between categories, their relations and concept maps and makes a case for an improvement on present structures of concept maps, which are hierarchical and static in the representation of knowledge. Asserting that knowledge is dynamic, the authors proposed a cyclic concept map structure to capture the dynamic relationships among concepts. This was illustrated and discussed and the research implications were put forward.

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Savinainen, A. & Scott, P. (2002). Using the Force Concept Inventory to monitor students learning and to plan teaching. Science Education, 37(1), 53-58.
The authors suggest that research- or evidence-based approaches to teaching of benefit and demonstrated the benefit accruing from one such case. This paper presents the development of a new teaching approach. The design and implementation of this approach was informed by the use of the Force Concept Inventory (FCI) as a diagnostic assessment tool. The approach referred to as Interactive Conceptual Instruction has four features: conceptual focus, classroom interactions, research-based materials and use of texts. They outlined the details of these four features. This was tried on 24 Finnish students (age 16). They demonstrated how insights and evidence from physics education research can be drawn upon to improve performance. The FCI was then used to evaluate this new approach and analyze students' learning. By comparison to more traditional approaches it was found that the new approach compare favourably in terms of learning gains.

Shaffer, P. S. & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. ***American Journal of Physics, 60(11),*** **1003-1013.**
This is the second part of two closely related investigations. The results obtained from the first part were now used to construct curricula in introductory electric circuits. This was strictly laboratory-based and was designed to accommodate the constraints presented by a traditional introductory physics class. The curriculum was intensively evaluated and the results were in turn used to enrich the research base.

Stinner, A. (2000). Providing a contextual base and a theoretical structure to guide the teaching of high school physics. ***Physics Education, 29,*** **375-381.**
The author argues that although the use of appropriately designed contexts are motivating to students, teachers run into problems while trying to incorporate large contextual settings into conventional textbook centred teaching of physics. The paper therefore recommends that the teaching of physics should be connected to philosophically and historically valid theoretical structure. These structures are embodied in the contexts of inquiry, which was discussed extensively.

Taber, K. S. (1994). Students' reaction on being introduced to concept mapping. ***Physics Education, 28,*** **276-281.**
The paper considered the meaning of concept mapping, and described students' reaction on exposure to concept mapping. The students were engaged in a one-year study in physics. The students had an initial practice with the topic blood before proceeding to the concept of energy. The misconceptions associated with this concept among the students were diagnosed. They had three hours to prepare their concept maps and at the end of this, they were asked to note their reactions to the exercise. Many reported it was fun and metacognitive strategies were developed from the exercise.

Taber, K. S. (2001b). When the analogy breaks down: modelling the atom on the solar system. ***Physics Education, 36,*** **222-226.**
Using the model of the solar system the author considers the advantages and potential difficulties that present themselves in using analogies. The differences between models, analogies and metaphors are presented. A detailed treatment of a good analogy was made. The article, thus, highlighted the limitations in the use of analogies, and the difficulty arising from use of unfamiliar analogues. The paper concluded by giving a checklist for teaching with analogies.

Taber, K. S. (2005). What's in a name? Looking at physics as a curriculum subject. ***Physics Education, July 2005,*** **311-312.**
The author argues that a damaging feedback cycle has been set up by the approach adopted in physics education, with particular reference to science education in England. This indeed is interesting given the call of the science education community over a period of three decades now to teach science rather than the different science disciplines as a way of enhancing scientific literacy. England is one of the nations that have experimented on this, including only the broad discipline of science in its curriculum for the compulsory school years of 5-16years. He raises a number of critical issues arising from this approach including the invisibility of physics, the teaching of physics by teachers not qualified, not enthusiastic and insecure to teach science; lack of role models

for students. The implication for 'authentic science' as advocated by science educators he concludes is to find a way to reflect both the commonalities and the differences in the sciences without confusing students. The contention is that this cannot be found in teaching of science as single disciplines such as biology, physics and chemistry nor by lumping everything together under the banner of science. He concludes by advocating a science that gives students a feel of the distinct characteristics of the main disciplines of science including astronomy, geology together with the traditional disciplines.

Volkmann, M. J., Abell, S. K. & Zgagacz, M. (2005). The challenges of teaching physics to preservice elementary teachers: orientations of the professor, teaching assistant and students. *Science Education, 89,* 847-869.
This study examined the experiences of a professor, teaching assistant and students in an inquiry-based physics instruction. The instruction lasted for six-weeks and involved an introductory physics unit for undergraduates in physics. The research was built around an orientation framework of learning and teaching. The challenges (dilemmas and conflicts) felt by the team were analyzed based on this framework. This followed the four science-teaching orientations of activity driven, didactic, discovery and conceptual change. They demonstrated that the instructor's scaffolding efforts did not provide the kind of support needed by students. Instead of confidence students became less sure and more anxious and frustrated.

10. Science Learning and Teaching Theories

Adey, P. (1987). Science develops logical thinking – doesn't it? Part I. Abstract thinking and school science. *School Science Review, 68(245),* 622-630.
This article is one of the first articles emanating from the CASE works at King's College, London. The author, as in works at the beginning of any scientific invention, mused on the truism of the fact that science develops abstract thinking. He discussed nine major areas of abstract thought related to science. These included control and exclusion of variables, ratio and proportion, compound variables, conservation involving models, compensation and equilibrium, correlation, and probability. He also addressed sketchily, three subsidiary areas including, combinatorial thinking, coordination of frames of reference and classification.

Adey, P. (2005). Issues arising from the long-term evaluation of cognitive acceleration programmes. *Research in Science Education, 35(1),* 3-22.
This paper presented once more the theory base of the Cognitive Acceleration which claims that students' intellectual development and cognitive processing capacities can be enhanced through science programmes. It also re-presented some of the data from past investigations. Some general issues of long-term issues were addressed. The author concluded that longitudinal studies are offer the best approaches to the evaluation of intervention programmes and urged funding organisations to increase funding of such researches; as well that researchers undertake such researches.

Adey, P. & Shayer, M. (1993). An exploration of Long-term far-transfer effects following an extended intervention programme in the high school science curriculum. *Cognition and Instruction, 11(1),* 1-29.
Reasoning that the general thinking skills can be taught, the authors designed a set of activities, set in the context of science and at the formal operations level. Four features were identified from literature to be characteristics of the activities to effect long-term transfer. These were elaborated on in this paper. Nine schools (of different demographic characteristics) and twenty-four classes were assigned to either the experimental or control group. The experimental groups were taught once every two weeks with the materials in place of the normal science classes for a period of two years. They employed the Science Reasoning Tasks to obtain data relating to the cognitive development of the students, common achievement tests for achievement and the GCSE results as measure of far-transfer. They found that the intervention accelerated cognitive development immediately after the programme and this dissipated one-year after the programme. The delayed achievement test a year later revealed a difference in favour of the experimental subjects although not statistically significant. The older boys had a higher effect size in the GCSE, there was no difference for the younger boys and older girls. The younger girls had higher gains than the control although not as large as those of the boys. They explain the results in terms of confidence, language training, and general cognitive development. Generalisations were made from the results and interpretations. These however are not justified by the results in the paper.

Adey, P & Shayer, M. (2002). Cognitive acceleration comes of age. In M. Shayer & P. Adey (Eds.) *Learning intelligence: Cognitive acceleration across the curriculum, from 5 to 15 years* (pp1-16). Buckingham: Open University Press.
Describes the proposed paradigm of cognitive acceleration (CA) based on the works of Piaget and Vygosky. The formulation is that there are some general intellectual functions in children, which develops with age and is influenced by environment. The major tenet is to refocus the aim of education toward intellectual development. The CA instructional design has six principles- (i) abstracting underlying concepts from schema theory of Piaget (ii) concrete preparation (introduction to the would-be problem context and vocabulary) (iii) cognitive conflict (creation of dissonance in the students' cognition) (iv) social construction (negotiation of knowledge in a social environment) (v) metacognition (an awareness of the individual learner's thinking processes) and (vi) bridging (transfer to other contexts). Finally, the paper gave an overview of the different projects where this has been applied in science mathematics and arts education.

Adey, P., Shayer, M. & Yates, C. (1989). *Thinking Science: The Curriculum Materials of the Cognitive Acceleration through Science Education (CASE) Project.* Surrey: Thomas Nelson and Sons Ltd.
This pack contains 30 activities, which are aimed at helping the students develop thinking skills. It consists of a guide for teachers, a guide for technicians and the activities as well as worksheets for the students. It explicitly specifies and emphasised the teaching style to be adopted in using the pack. It is not meant to replace the curriculum but it is advised that it be used as a supplement. It was not recommended for any level of students but the teacher is to assess a particular student and use it as appropriate.

Bliss, J. (1995). Piaget and after: the case of learning science. *Studies in Science Education, 25,* 139-172.
The author critiqued Piaget's work in the light of the different variables involved, that is, stage theory and genetic epistemology. He also examined science educational programmes, theories and interventions that have arisen as a result of Piaget's work. These include the cognitive acceleration programme, constructivism and mental model theories. Endorsed the use of mental models on the grounds of its incorporation of institutional variables encountered in actual classroom situations or situated learning.

Brünken, R., Plass, J. L. & Leutner, D. (2004). Assessment of cognitive load in multimedia learning with dual-task methodology: auditory load and modality effects. *Instructional Science, 32,* 115-132.
Employing the dual task methodology the investigators used 10 female students to test (a) the comparative demand of presenting verbal and pictorial materials as audiovisual or visual-only form on the phonological loop and (b) if the inclusion of music to an audiovisual presentation would increase the phonological cognitive load. The major aim of the work is to validate the limited capacity assumption of the cognitive load theory using direct measures of resource demands. They found a strong evidence to support the assumption of a limitation in auditory capacity.

Chinn, C. A. & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching, 35(6),* 623-654.
The authors emphasise the place of anomalous data in present science education methods. They review current methods in science education and show how these employ anomalous data in their theorising and trace the origin to Piaget and Thomas Kuhn. Next, the benefits of taxonomy of how students respond to anomalous data were expounded. A theoretical framework for understanding how people respond to anomalous data was presented consisting of two parts: taxonomy of seven possible responses to anomalous data and factors influencing people's responses. Using 168 undergraduates, they tested the taxonomy. Results upheld the seven categories but revealed another response not accounted for the seven categories. The importance of understanding this to practicing teachers and science education researchers was highlighted.

Goldman, S. R. (2003). Learning in complex domains: when and why do multiple representations help? *Learning and Instruction, 13,* 239-244.
This article is a commentary on work done in the area of learning in complex domains. The author categorises these works into three generations and identified the features characteristic of each generation. The first generation works deal mainly with the three processes in which the learner has to engage in order for learning to take place. These include selection, organisation and integration of information. The second generation works are believed to be concerned with media-enabled affordances and computational efficiency, active processing, and limits set by prior knowledge. The commentary concluded that what stands out in the papers in the issue where it appeared and which form the direction for future research and understanding of learning in complex domains, such as physics, are the efforts to push for deeper understanding of the dynamics of learning by trying to characterise in detail the role of the different forms of representations in facilitating learning. The reasons for the roles they play were also identified as important for the future.

Hynd, C., Alvermann, D. & Qian, G. (1997). Preservice elementary school teachers' conceptual change about projectile motion: refutation text, demonstration, affective factors, and relevance. *Science Education, 81,* 1-27.
This is a study of the complex interactions of factors that lead to conceptual change. Five hypotheses were formulated to guide the study. The research conditions involved different designs, experimental and exploratory. The subjects were drawn from a pool of 94 fourth year elementary pre-service science class and two conditions were manipulated. These include a combination of demonstration and text. The second is the reading of a text only. Different tests were used as instruments. One of these measured the students' preconception about the concept of projectile motion. Data was analyzed both qualitatively and quantitatively. Results indicate that the demonstration-text group and the text only group achieved long term retention, however this was better under short term. They also found that telling the subjects about a forthcoming teaching assignment did not influence their understanding. They found that most of the subjects have naïve epistemological backgrounds. Apparently, the effort to move from students' own conceptual understanding to correct scientific conceptions sometimes led to other nonscientific conceptions about projectile motion. They also found that positive attitude enhanced conceptual change.

Johnstone, A. H. & Al-Naeme, F. F. (1991). Room for scientific thought. *International Journal of Science Education, 13(2),* 187-192.
Drawing on works done in the past, this paper makes a case for patterns of performance for novice students and more mature students based on their working memory capacities and level of embeddedness. It explores the idea of potential and usable working memory, suggesting that differentiating between 'noise' and 'signal' can make a great difference between the performance of students and that this in turn is determined by a combination of the students' working memory capacity and field dependency. Strategies for manipulating these and helping the student to filter 'noise' from' signal' were proposed.

Johnstone, A. H. & Kellett, N. C. (1980). Learning difficulties in school science – towards a working hypothesis. *European Journal of Science Education, 2(2),* 175-181.
Following earlier work done by Johnstone and various other colleagues on the difficulty students experience in the sciences, the authors came up with the hypothesis in this paper that difficulty is as a result of students being unable to 'chunk' materials in the working memory. This is in direct relationship to the capacity of the working memory which is placed at 7 ± 2. This paper discussed this relationship using the area of organic chemistry. Implications for the curricula were addressed and strategies offered for the science teacher to use in order to help students overcome this difficulty.

Leo, E. L. & Galloway, D. (1996). Conceptual links between Cognitive Acceleration through Science Education and motivational style: a critique of Adey and Shayer. *International Journal of Science Education, 18(1),* 35-49.
This paper analyzed the results obtained from CASE intervention programme in the light of theoretical model of motivational style. In view of the fact that the results demonstrated differential effects for different groups of students, the authors claim that the motivational style of the different groups can account for the differential effect of the intervention. This is after detailing three motivational styles and relating them to the techniques of CASE.

Mbano, N. (2003). The effects of a cognitive acceleration intervention programme on performance of secondary school pupils in Malawi. *International Journal of Science Education, 25(1),* 71-87.
The paper reported that students perform poorly in the sciences in relation to other school subjects in Malawi. It then identified some of the reasons for this pattern of performance and elects to explore the area of the mismatch between cognitive ability and curriculum demands. Working with 425 pupils and employing the quasi experimental design of the pre-test post test non-equivalent control group model the investigator sought to compare the effect of the CASE intervention programme on performance over a three-year period. The Science reasoning Task and results from the final national examinations were used to collect data. In addition, an interview was carried out with 15 students and six teachers. They found that there was a positive attitude of students to the CASE programme; that the intervention accelerated the cognitive development of the students by comparison to the control. However, the finding is that the intervention achieved a differential effect in performance of the experimental group students in favour of younger boys to older boys and girls. They conclude that cognitive development levels account for a small percentage of performance and suggest that CASE works through different mechanisms to improve school achievement; and pointed to motivational factors as well as learning styles as mediators.

Posner, G. J., Strike, K. A., Hewson, P. W. & Gertzog, W. A. (1982). Accommodation of scientific conception: toward a theory of conceptual change. *Science Education, 66,* 211-227.
Conceptual change was first suggested in this article. The authors drew on Kuhn and Lakatos conceptions of the scientific revolution in propounding this theory. They assume that learning is a rational process involving the use of concepts to organise and interpret phenomena. The paper discusses two levels in the cognitive structure at which conceptual change can occur leading to reorganisation or discarding of a schema. Four conditions for conceptual change are prescribed and the notion of an appropriate cognitive ecology put forward. Strategies arising from the explanations were addressed.

Psillos, D. & Kariotoglou, P. (1999). Teaching fluids: intended knowledge and students' actual conceptual evolution. *International Journal of Science Education, 21(1),* 17-38.
The authors in this paper describe the role prior knowledge play in the actual construction of a scientific model of fluids, including an intensive concept, pressure and an extensive concept, force. Ten student teachers participated in the study, working in groups of three and four. They followed specially prepared worksheets and the procedure was audio and video recorded. Data was collected from transcribed materials as well as teacher diary, pre- and post completed questionnaire and individual interviews. They suggested that evolutionary and conflict experimentally oriented strategies should be used in complimentary rather than mutually exclusive ways; and that the properties of the intensive variables, which are equivalent are not always obvious to students and need special treatment during any teaching sequence. There was evidence of conceptual evolution and limited range of pathways followed by students in constructing the intended knowledge.

Shayer, M & Adey, P. (1981). Towards a science of science teaching: cognitive development and curriculum demand. London: Heinemann Educational Books.
The book was written for science teachers and grew out of the need to reduce the mismatch between curriculum demands and expectations of students and their abilities. The aim was to formulate a model that would predict likely successes and failures in the school as well as address learning materials and students' cognitive processes. They restricted their modelling to the cognitive aspects of the learner, thus using the Piagetian stage-wise theory of cognitive development as an underpinning psychological theory. The book reports the development of two instruments, the Science Reasoning Tasks and the Curriculum Analysis Taxonomy. The former was to assess students' level of cognitive development and the latter to analyze the curriculum. This was then applied to the Nuffield curricula, showing it to be flawed by way of being not suitable to many students level of cognition. The book detailed the characteristics of the concrete and formal operational stages of Piaget's theory and how this can be used to develop class tasks. The book also reported a number of investigations carried out to the use of the model in selecting objectives and learning activities; determining the validity of the theory with regards to the UK population. The investigations revealed a mismatch between the abilities of the students and the cognitive demands of the curricula in use then (The Nuffield curricula). Strategies were proffered to rectify the mismatch. This marked the beginning of the Cognitive Acceleration Theory.

The amount of work undertaken by Shayer, Adey and colleagues as reported in this book is commendable. It also offers useful insights to the characteristics of students at the secondary school level as well as the demands placed on them. But their aspiration of developing a 'general model' of learning and one that would address learning material and pupils' thinking processes cannot be said to be realised. The model does not capture the influence of previous knowledge and alternative conceptions on learning as well as the very process of learning (for instance processes of concept formation). Matching a cognitive level with appropriate tasks does not necessarily translate to success. Neither does it consider the interaction between domain specific knowledge and task complexity. Present state of knowledge makes the model incomplete.

Shayer, M. & Adey, P. (Eds.) (2002). *Learning intelligence: Cognitive acceleration across the curriculum, from 5 to 15 years* . Buckingham: Open University Press.
This book has eleven chapters and eleven contributors. It describes the tenets and applications of cognitive acceleration in schools. The work so far done in this area is fully described in the book and the results of evaluation of some of the projects are specified.

Shymansky, J. A. Yore, L. D., Treagust, D. F., Thiele, R. B., Harrison, A., Waldrip, B. G., Stocklmayer, S. M. and Venville, G. (1997). Examining the construction process: a study of changes in Level 10 students' understanding of classical mechanics. *Journal of Research in Science Teaching, 34(6),* 571-593.
This study employed an intact group, repeated measures design to do a confirmatory study. The aim was to determine the patterns of growth, no growth, or regression of understanding existed among Level 10 students. The study explored the concepts of force, vectors, centre of gravity, pressure, hydraulics, buoyancy, kinematics, Newton's laws of motion, falling bodies, work, energy, simple circuits, gas laws and waves. A combination of student generated concept maps and follow-up interviews were used to monitor students' progress and the depths of processing at four different stages of the study. There was no observation of patterns of progressions and regressions in the knowledge structures of the students.

Strike, K. A. & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. T. West & A. L. Pines (Eds.). *Cognitive Structure and Conceptual Change* (pp. 211-231). Orlando: Academic Press, Inc.
The major tenet of the conceptual change theory was set out in this paper as the belief that learning is a rational process. Conceptual change epistemology was compared to empiricist epistemology and individual learning is described as having generic structural features. The conditions for conceptual change include dissatisfaction with existing conceptions, presence of anomalous data, intelligibility, plausibility and fruitfulness of a new conception. Conditions for an accommodation were also set out. These were applied to the conception of Freudian psychology and extended to the concept of understanding. The authors distinguished three different ideas, minimal understanding, fuller understanding and accommodation and comment on the usefulness of the conceptual change theory to pedagogy.

Sweller, J. (1988). Cognitive load during problem solving: effects on learning. *Cognitive Science, 12,* 257-285.
Sweller in this paper pioneered the research on problem solving and schema formation. He reflected on the expert-novice literature and categorised these into three: memory of problem state configurations, problem solving strategies, and features used in categorisation. He considered schema acquisition as deriving from the type of problem learners solve or the means through which they solve these problems. He tendered that problem solving and acquiring schema require unrelated cognitive processes by selective attention, and that conventional problem types make heavy demand on processing capacity, leaving very small processing capacity for a dual task such as schema formation. Literature was analysed to show the consequences of different problem types on processing capacity. He detailed a production system designed to measure relative cognitive load imposed by different problem types. This was applied to an experimental situation and it was found that solving problems with non-specific goals transferred to other problems with fewer errors and faster performance at later times. Conclusions were drawn from the theoretical and empirical analysis.

Sweller, J. (2004). Instructional design consequencies of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science, 32,* 9-31.
The paper examines how the human cognitive architecture and its processes are likened to evolution by natural selection and its processes. It considers the longterm memory as a central executive that is implicated in many of the cognitive processes save in novel situations and likens it to the genetic code. It paints a pictorial analogy of the two. The major function of instruction is therefore to provide the missing central executive in novel situations and to build up information in the longterm memory that will guide learning. It then reviewed ways cognitive load theory has devised to manipulate the cognitive architecture of man. These are given as, the worked example effect, the completion effect, the redundancy effect, the expertise reversal effect, the modality effect, the split attention effect, the imagination effect, the isolated interacting element effect, the element interactivity effect, the guidance fading effect, and the goal-free effect.

Taber, K. S. (2000a). Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education, 22(4),* 399-417.
This paper claims that an individual learner can hold simultaneously in cognitive structure several alternative stable and coherent explanatory frameworks that are applied to the same concept area. It therefore refuted the claim of the learners' thinking being incoherent, fragmentary and context-bound. Employing a grounded theory approach the investigator explored the concept of the chemical bond among A-Level students. Data were gathered through interview and the use of Kelly's repertory test. They concluded from the analysis of one student's thinking that students may hold stable manifold conceptions in cognitive structure and that there may be a progression from the use of one framework to another. Therefore transition periods exist and conceptual revolutions may actually be at different stages and may never really attain completion. This, the paper asserts, calls for a review of the assessment techniques in school.

Taber, K. S. (2005b). Destructive associations disrupt the learning construction zone. *Physics Education, 40(5)*, 403-404.
This article documents the effort of a trainee teacher in teaching physic to a group of students taking GCSE. The lesson was based on the student's understanding of the fact that students' schemata are at a rudimentary stage and that the learning process is not a straightforward process. It was found that despite the efforts of the teacher, the technical words used remained permeable to everyday interpretations and made processing of information more difficult. The author observed that although the teacher had a well designed teaching episode, the complexity of teaching and learning made the outcome less desirable. He therefore tenders that the teaching of physics is challenging.

Taber, K. S., de Trafford, T. & Quail, T. (2006). Conceptual Resources for constructing the concepts of electricity: the role of models, analogies and imagination. ***Physics Education, 42(2),*** **155-160.**
The view that the lower secondary school should be a time of schema construction in preparation for the later years of schooling when models of physics concepts would be built, is adopted in this article. The focus is on the difficulty faced by lower secondary school students in understanding the curriculum models in physics. The authors believe that what is so obvious to the science teacher may be ambiguous and indiscrete to the beginning learner. The fact also that the expert can chunk and has learnt to ignore redundant materials while paying attention to the relevant issues in any classroom or experimental set up was also emphasised. This is not so with the beginner. The place of models in the conceptualisation of phenomena was explored by two student teachers on placement in English comprehensive schools. They contended that without models it is impossible to construct robust explanations of the 'whys' of phenomena, which enable application to novel situations. The teaching sequences were based on the understanding of the nature of physics, student prior conceptions in this area and learning principles. It was found that although students did not acquire absolute conceptions of circuits and resistors they progressed somewhat towards the correct scientific conceptions. They also found that animistic and anthropomorphic thinking can be antithetical to correct scientific thinking and conceptions.

Tytler, R. (2000). A comparison of year 1 and year 6 students' conceptions of evaporation and condensation: dimensions of conceptual progression. ***International Journal of Science Education, 22(5),*** **447-467.**
This work reports the exploration of the major differences in the thinking of different age groups about the concepts of condensation and evaporation in order to ascertain the factors vital in the teaching process. Data was collected by means written responses and interviews. From the data collected a critical evaluation was made of earlier claims concerning the progression of students in their understanding of the two concepts. Results showed that the older children showed an advance over the younger children in all the dimensions of progression.

11. Psychological Underpinning

Ausubel, D. P., Novak, J. D. & Hanesian, H. (1978). ***Educational Psychology: a cognitive view.*** **New York: Holt, Rinehart and Winston.**
This book is primarily concerned with meaningful learning. Although it emphasises reception learning, it recognises other forms of learning. Interestingly, the popular statement set out before the preface fits tightly to the notion of conceptual change and has been used by conceptual change advocates as the pillar of the theory, the book dealt with concept formation as an appendage to meaningful verbal learning. The fabrics of the book are woven around its major tenet that existing cognitive structure plays a great role in the process of new learning. The authors treated different issues (for example meaningful problem solving, discovery learning cognitive factors in learning intellectual ability practice). Ways of providing for individual differences. Psychosocial factors especially authority structures in the classroom and principles of measurement and evaluation were also addressed.

Baddeley, A. (1997). ***Human memory: theory and practice.*** **Hove: Psychology Press Ltd.**
In this book Baddeley considers the human memory in its historical, ecological and relational perspectives. It also concerned itself with clinical evidence, clearly showing present status of understanding about the human memory in all its ramifications. It justifies the study of the human memory, considers perception and remembering and the types of memory. It addresses the role of memory in cognition and dealt in details with the working memory and long-term memory and their roles in cognition. It considers the processes involved in learning and habit formation and how the memory architecture interacts with other cognitive factors in determining outcomes of memory functions. Finally, it looks at implicit and recollective memory. The first edition being one of the first of its kind, used a lot of persuasive language and empirical evidence.

Kuhn, T. S. (1970). ***The structure of scientific revolution. International Encyclopedia of Unified Science, 2(2).*** **Chicago: The University of Chicago Press.**
The author declared that development by accumulation can no longer explain the process of scientific revolutions or 'discoveries'. He discussed the route to normal science emphasising the place of paradigms in the development of scientific knowledge. Using different examples from the history of science he discusses how paradigms proclaim the field of science. The book discusses the nature of normal science as provided by not so much as a paradigm being an object of replication, instead, it is an object for further articulation and specification under new and more stringent conditions. Activities so generated can be placed under three problem categories: determination of significant facts, matching of these facts to theories, and articulation of theory. Normal science is thus seen as puzzle-solving rather than as ground breaking. He articulated the relationship between rules, paradigms and normal science. Normal science gives way to scientific discoveries when anomalies arise from the violation of the paradigm-induced expectations that govern it. Discoveries are characterised by three features: awareness of an anomaly, the gradual and simultaneous emergence of both

observational and conceptual recognition and the consequent change of paradigm. Just as anomalies precede discoveries, crises precede new theories.

Mathews, M. R. (2004). Thomas Kuhn's influence on science education: What lessons can be learned. *Science Education, 88,* 90-118.
The author contends that Kuhn has made an impact in the field of science education just as in many other fields. This impact according to the author is mitigated by a number of factors. It thus discussed Kuhn's philosophical position, and the belated recognition of Kuhn by the science education community. It traces the evolution of Kuhn's ideas and shows its relationship to conceptual change theory and constructivism in science education. Kuhn's positivism was addressed and the lessons to be learned from the Kuhnian theory were outlined. Notable among these is that the science education community has to contend with powerful disciplinary, institutional and subcultural barriers in order to engage in historical and philosophical scholarship.

Medin, D. L. & Smith, E. E. (1984). Concepts and concept formation. *Annual Review of Psychology, 35,* 113-138.
This paper reviews the three theories of concept formation as at the time, the classical view, the probabilistic view and the exemplar view. It considered the role of the classical view. Category cohesiveness was considered and the theories on which these are based were discussed. Categorisation processes with prototype concepts and acquisition of prototype concepts were discussed. This was related to learning and the strategies employed in building up prototypes were explained. The goal-derived concepts, person concepts and event concepts were described as the different types of prototype concept. The categorisation of complex categories was elucidated. The authors muse on the possibility that there is more to categorisation than the similarity theory.

Miller, R. L. (1980). Ausubelian psychology – help for learning difficulties. *Physics Education, 15(3),* 186-190.
This article reviews Ausubelian psychology, detailing the different kinds of cognitive processes and the demand on the students. It also considers the different ways in which ideas can be presented to students. The author identified three kinds of organisers, advance, expository and comparative organisers. He then explains how these are related to the cognitive structure of the students. This was applied to physics teaching, suggesting in the process the fundamental concepts in this field as relativity and quantum theories. Six guidelines are outlined to evaluate the effectiveness of any teaching sequence. Deriving from a consideration of assimilation theory and its implication for classroom practice, was the reason for the difficulties experienced by some students in gaining understanding of some abstract ideas. The limitations of the theory were highlighted.

Moore, W. S. (2006). "My mind exploded": Intellectual development as a critical framework for understanding and assessing collaborative learning. www. (accessed: 26 May, 2006).
This paper is premised on the assertion that collaborative environments are powerful forces in higher education today. The author noted that the goals of higher education, which can be summarised as the transformation of learners, are not adequately assessed by the assessment techniques prevalent in many higher institutions. The paper proffers the Perry scheme of intellectual and ethical development as a framework for assessing collaborative learning the author's espoused approach to higher education. This scheme is presented as a multidimensional indicator of student progress toward fundamental outcomes of higher education. The paper made an overview of Perry's work and connected it to collaborative learning. The paper presented evaluative self-reports of some students' reflection on how learners view and understands knowledge and learning; themselves and peers; and the role of the teacher. Examples of higher education centres where these have been used were given.

Murphy, G. L. & Medin, D. L. (1985). The role of theory in conceptual coherence. *Psychological Review, 92(3),* 289-316.
This paper sets out to explore the coherence of concepts. It argues that the ideas of similarity, correlated attributes, and other categorisation theories (such as the probabilistic view, the exemplar view) are insufficient to account for the coherence of concepts. They therefore propose that concepts are coherent to the extent they fit the theories of the world held by individuals. These theories form the basis for relationships and grant structure to the attributes that are internal to a concept. The paper also discusses the importance of theories in cognitive development.

Novak, J. D. (1978). An alternative to Piagetian psychology for science and mathematics education. *Studies in Science Education, 5,* 1-30.
Novak in this paper traced the historical rise of the Piagetian psychology to the lime light and events leading up to it. It introduces Kuhn's concept of scientific revolution and uses this to lay a foundation to the trend away from extrapolating Piagetian developmental psychology to science learning to the trend towards concept formation. The paper then pitches Piagetian ideas against Ausubel's ideas about meaningful learning and shows where and how they are similar as well as where they differ. With evidence from the review of empirical studies and from own studies, Novak arrives at the conclusion that it is better to aid a child in concept development which will eventually transfer to ability to solve problems and highly formal and abstract thinking. He therefore called for well designed educational experiences that will be a scaffold to well developed frameworks of concepts relevant for science learning.

Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's developmental stages. *Acta Psychologica, 32,* 301-345.
The author uses 5-, 7-, 9-, and 11-year olds with a compound-stimuli visual information type of task to test quantitatively the *M* construct. The *M* space is seen as a central processing space that is able to hold a number of discrete information at any time and increases in a lawful manner during development. Contrary to the inference from Piagetian task of the *M* space being deterministic in performance, the author asserts that other factors such as cognitive style, motivation, prior knowledge mediate the performance of individuals. He therefore suggests the distinction of a 'functional *M*' space as against a 'structural *M*' space.

Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* San Francisco: Jossey-Bass Publishers.
This book outlines the stages of cognitive development of individuals during the adolescent period and beyond. The study was carried out with 31 students over a period of four years. Each student was interviewed at the end of every session and the interview was tape-recorded. From the analysis, a scheme was developed that runs through nine positions. These positions are often compressed into three: dualism (positions 1 & 2), multiplicity (positions 3 & 4), contextual relativism (position 5 and 6), commitment within relativism (positions 7 – 9). The book addressed the implications of this scheme to education. The book adopted two terms, 'intellectual' and 'ethical' to reflect the two distinct aspects of students' development. The intellectual development deals fundamentally with cognitive structural change toward increasing differentiation and complexity of thinking. The ethical development deals with issues of identity and personal meaning-making in a relativistic world.

Appendix 2: List of Journals Consulted

1. Acta Psychologica full text available from ScienceDirect (http://www.sciencedirect.com)
2. American Journal of Physics Fulltext available from http://scitation.aip.org/dbt/
3. Annual Review of Psychology Fulltext available from Psychology and Behavioural Sciences Collection (http://weblinks2.epnet.com); Expanded Academic ASAP (http://infotrac.galegroup.com); Business Source Premier Publications (http://weblinks2.epnet.com); Annual Reviews (http://arjournals.annualreviews.org);
4. Research in Science Education Fulltext available from Springer LINK (http://www.springerlink.com)
5. Chemical Education Research and Practice (Chemistry Education: Research and Practice in Europe merged with University chemistry education to form Chemistry Education Research and Practice) Full text available on http://www.uoi.gr/cerp
6. Cognition and Instruction Full text available from Professional Development Collection: from 01/01/1984 to 1 year ago; Full text available from Psychology & Behavioral Sciences Collection: from 01/01/1984 to 1 year ago.
7. Cognitive Psychology Full text available from ScienceDirect (http://www.sciencedirect.com)
8. College Science Teaching Full text available from); Expanded Academic ASAP (http://infotrac.galegroup.com)
9. Educational Assessment Full text available from Professional Development Collection: from 01/01/1993 to 1 year ago; Full text available from Psychology & Behavioral Sciences Collection: from 01/01/1993 to 1 year ago
10. Educational Research Full text available from Professional Development Collection (http://weblinks3.epnet.com); Taylor and Francis (http://www.metapress.com); Psychology and Behavioural Sciences Collection (http://weblinks2.epnet.com); SwetsWise online content (http://www.swetswise.com).
11. Education in Chemistry Full text available from http://www.rsc.org/Education/EiC/index.asp
12. Electronic Journal of Science Education Full text available from AERA SIG Communication of Research (http://unr.edu/homepage/jcannon/ejse/ejse.html)
13. Instructional Science ; Full text available from Springer LINK: from 01/01/1997 to present (http://www.springerlink.com)
14. International Journal of Educational Research ScienceDirect (http://www.sciencedirect.com)
15. International Journal of Science Education (formerly known as European Journal of Science Education) Full text available from Taylor and Francis (http://www.metapress.com)
16. Journal of Chemical Education http://jchemed.chem.wisc.edu
17. Journal of College Science Teaching , schmidt@periodicals.com
18. Journal of Computer Assisted Learning , Full text available from Blackwell-Synergy: from 01/03/1997 to present; Full text available from IngentaConnect: from 1997 to present; Full text available from Professional Development Collection: from 01/03/1998 to 1 year ago
19. Journal of Curriculum Studies Full text available from Professional Development Collection (http://weblinks3.epnet.com); Taylor and Francis (http://www.metapress.com)
20. Journal of Educational Research Full text available from Periodicals Archive Online (PAO) (http://pao.chadwyck.co.uk/journals); Professional Development Collection (http://weblinks3.epnet.com); Psychology and Behavioural Sciences Collection (http://weblinks2.epnet.com) and Expanded Academic ASAP (http://infotrac.galegroup.com)
21. Journal of Experimental Education Full text available from Expanded Academic ASAP ((http://infotrac.galegroup.com): from 22/09/1997 to present; Full text available from PCI Full Text: from 1932 to 1995; Full text available from Professional Development Collection ((http://weblinks3.epnet.com): from 01/01/1994 to present; Full text available from Psychology & Behavioral Sciences Collection ((http://weblinks2.epnet.com): from 01/01/1994 to present

22. Journal of Interactive Learning Research Full text available Expanded Academic ASAP (http://infotrac.galegroup.com)
23. Journal of Research in Science Teaching Full text available from Wiley Interscience Journals http://eu.wiley.com/WileyCDA/WileyTitle/productCd-TEA.html
24. Journal of the Learning Sciences Full text available from Professional Development Collection (http://weblinks3.epnet.com); Psychology and Behavioural Sciences Collection (http://weblinks2.epnet.com)
25. Learning and Instruction Full text available from ScienceDirect Elsevier Science Journals: from 1995 to present
26. Linguistics and Education full text available from ScienceDirect (http://www.sciencedirect.com); SwetsWise online content (http://www.swetswise.com).
27. Physics Education Full text available from SwetsWise Online Content: from 1996 to present (http://www.swetswise.com); Institute of Physics from 01/05/1966 to present (http://www.iop.org/EJ/journal).
28. Psychological Review Full text available from Journals@Ovid PsyAtices (http://gateway.uk.ovid.com/gw2)
29. Report on Progress in Physics Full text available from Institute of Physics (http://www.iop.org/EJ/journal); SwetsWise online content (http://www.swetswise.com)
30. Research in Science and Technological Education Full text available from Professional Development Collection ((http://weblinks3.epnet.com): from 01/05/1990 to 1 year ago; Psychology & Behavioral Sciences Collection ((http://weblinks2.epnet.com): from 01/05/1990 to 1 year ago; Full text available from Taylor & Francis Journals (http://www.metapress.com): from 01/05/2000 to present
31. Science and Education Fulltext available from Springer LINK (http://www.springerlink.com)
32. Science Education Full text available from Wiley Interscience Journals: from 1997 to present
33. School Science and Mathematics Full text available from Professional Development Collection ((http://weblinks3.epnet.com); Expanded Academic ASAP (http://infotrac.galegroup.com)
34. School Science Review http://www.ase.org.uk/htm/journals/ssr/index.php
35. Staff and Educational Development International
36. Studies in Science Education
37. The Physics Teacher Full text available from SwetsWise online content (http://www.swetswise.com)
38. University Chemistry Education

The Higher Education Academy
Physical Sciences Centre

...enhancing the student experience in chemistry, physics and astronomy within the university sector.

Physical Sciences Practice Guides are designed to provide practical advice and guidance on issues and topics related to teaching and learning in the physical sciences. Each guide focuses on a particular aspect of higher education and is written by an academic experienced in that field.

This report presents a summary of the main findings from the science education research literature relating to physics education. These findings are used to offer guidance in developing a curriculum in physics at higher education levels.

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