Symposium:
Development of research on learning science from various constructivist perspectives

Organizer: Local committee (Reinders Duit, IPN Kiel, Germany)
Chair and Discussant: John Gilbert, University of Reading, UK

Constructivist views have been the dominating epistemological orientations shaping research on learning science over the past two decades. Whereas radical constructivist perspectives as developed, for instance, by Ernst von Glasersfeld significantly influenced the development of conceptual change approaches in the 80s and early 90s more recently there are strong tendencies towards more inclusive views. These comprise the major issues of radical constructivism on the one hand and social-constructivist and social-cultural views on the other that have become increasingly prominent over the 90s. Clearly, fundamental critiques on radical constructivism (see the contributions in the volume by Matthews, 1998) have substantially contributed to these developments. The four papers presented in this symposium address the issue of "constructivism and learning science" from various perspectives. It appears that this symposium provides a valuable theoretical background for the poster sessions on "Research on students' conceptions and conceptual change" which follow the symposium.

Gaalen Erickson will present a retrospective review and analysis of research on science learning conducted in the past two decades in the domain of "students' conceptions of science". Philip Adey focuses on the theoretical framework of the CASE (Cognitive acceleration through science education) project in the UK which is substantially based on Piagetian ideas. He will critically analyse this orientation, for instance, from a Vygotskian perspective. He thinks that "metaconstructicism" could be a term indicating ways out of limitations of "middle of the road" constructivism which still dominates so many studies on learning science. The following two papers address the issue of further developing the theoretical underpinnings of conceptual change which has become the term indicating constructivist instructional settings. Stefan von Aufschnaiter outlines a research program at the Institute for Physics Education of the University of Bremen (Germany). The key idea of this approach is to view learning, and hence conceptual change, as a process of increasing complexity. Reinders Duit takes, in a certain way, a broader perspective in discussing tendencies in research on learning science towards inclusive views (or multi-perspective views) of conceptual change.

Reference.
Research Programmes and the Student Science Learning Literature
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The primary purpose of this paper will be a retrospective review and analysis of research conducted over the past fifteen years in the students' conceptions of science literature. In the paper I will identify a number of significant themes and issues emerging from the literature drawing upon my own analysis of the literature as well as examining some of the significant reviews that have already been undertaken in this area in recent handbooks (e.g. the International Handbook of Science Education, the Handbook of Research on Teaching, and the Handbook of Research on Curriculum).

I will use as my point of departure an article that I co-authored with Rosalind Driver sixteen years ago, which represented a critical review of the body of literature that we referred to at the time as "students' conceptual frameworks in science". An underlying assumption that we made was that there appeared to be an emergence of a number of research programmes examining the nature of student learning in the field of science education and we claimed that some conceptual distinctions were necessary to bring some coherence to this rapidly expanding literature. We framed the article around a hypothetical reconstruction of "the argument used by researchers, either implicitly or explicitly, to justify their research programme"(Driver & Erickson, 1983, p.39). This argument contained three empirical premises and one value premise along with a conclusion. The conclusion we articulated was: "We [the research community] ought to engage in research endeavours which will uncover student frameworks, investigate the ways they interact with instructional experiences and utilise this knowledge in the development of teaching programmes"(p. 40).

One of the more contested distinctions that we made in this paper was the extent to which a research agenda was "problem-oriented as opposed to theory-oriented" (in hindsight we probably should have used the term 'practice-oriented' to better capture the distinction we were making). The primary conceptual point we were trying to make is that many of the research studies that were emerging at the time seemed to be focussed primarily on the improvement of instructional approaches or practices and were not directly addressing, or even acknowledging, any underlying theory of cognition or learning (the "problem-oriented programmes"). The predominant "theory-oriented programmes" of the day which focussed on cognition were either Piagetian in nature (e.g. Lawson, 1982; Rowell & Dawson, 1983; Shayer and Wylam, 1981) or some form of an information processing model of cognition (e.g. Larkin et al., 1980). A research programme that might be considered to be on the border of this distinction was called a "theory of conceptual change" (Hewson, 1981; Hewson & Hewson, 1981; Posner et. al., 1982). The critical distinguishing feature between these two types of research programmes was whether the underlying frame, or theory, was subject to inquiry and change – if it was then we argued that the programme was more "theory-oriented". Although we represented this distinction as a dichotomy at the time, it seems self-evident to me at present that it would have been much better to describe these two types as the anchoring points of a continuum.

While it is not my intent in this paper to perpetuate this particular distinction, it is
noteworthy that I think many of the studies reported in the literature today can still be characterized along this continuum. Rather, what I intend to do is to take a selective look at the literature in the field over the past fifteen years to determine the nature of the changes that have occurred in the field since we last attempted to develop some preliminary charts for this terrain. This review will be guided by a number of overarching questions. These questions are outlined below:

- What are the current research programmes in the literature on student learning in science?
- How have these research programmes matured or changed over the past fifteen years?
- Can we identify significant findings emerging from these research programmes that represent major advances in our understanding of student learning?
- What criteria can be advanced for making the claim regarding these seminal findings?
- What are some of the critical issues in the field that still require further conceptual and empirical work?
- What research programmes seem to be emerging as the most promising in terms of addressing some of these critical issues?

To address some of the above questions, I intend to use Imre Lakatos's notion of a "research programme". For Lakatos, a research programme consists of a cluster or series of interconnected hypotheses/theories which permit their proponents to explain existing phenomena of interest, but as importantly, to point the way to new, interesting questions in the field that need to be addressed. It is this heuristic aspect of research programmes that I think has potential applicability to social science theories in general and the area of the student science learning literature in particular. One of Lakatos's prime criteria for looking at the viability of research programmes was it's potential to make predictions about "novel facts, which had been either undreamt of, or have indeed been contradicted by previous or rival programmes" (Lakatos, 1978, p. 5). While the focus on the prediction of novel facts may not be the best characterization of contemporary social science and pedagogical theories, I think that the overall category of a research programme will permit me to identify particular research groups and agendas that have made a significant contribution to our understanding of the complex issues associated with the learning of science in different educational contexts. For instance, his notions of a "progressive research programme" and "progressive problemshifts" will be used to discuss the trajectory of particular research agendas and to search for some insights into why they have been successful or not, as the case may be. His associated concepts of the "hard core" and "protective belt" features of a research programme will be used to make some conjectures about the future viability of these research programmes. I will also introduce the related concept of "pedagogically progressive research programmes to analyze what I judge to be the most important issues and questions facing the community of science educators with respect to student learning.

By comparing some of the existing research programmes in the literature today, one of my primary concerns will be to assess the impact of these research programmes on the understandings and practices of classroom teachers. This latter pedagogical
setting will provide the context for identifying what I consider to be some of the most perplexing issues on student learning that continue to challenge the science education community. In particular, I will be drawing upon some recent synthetic reviews of the literature such as those developed by Duit and Treagust (1998) and White (in press) to compare both the analytical framework used and our respective conclusions about the direction in which the field is moving. Finally, some emerging theoretical perspectives on student learning (Marton & Booth, 1997; Sumara & Davis, 1997; Varela, Thompson & Rosch, 1991) that show considerable promise in addressing these issues will be discussed. I will examine these perspectives in terms of their potential for becoming the new research programmes for the next generation of science educators.

References.


Revisiting cognitive conflict, construction, and metacognition, and discovering metaconstructivism

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Abstract.

Some of the underlying principles of the Cognitive Acceleration through Science Education (CASE) project will be examined, subjecting the notions of cognitive conflict, metacognition, and construction to analysis in the light of 20 years of experience in their use, and the new notion of metaconstruction proposed.

We have been in the business of "Cognitive Acceleration” through science education (CASE) for many years now, working with students aged 12 to 14 years in secondary schools and their teachers. New work with five-year olds, in their first year of schooling, has re-focused my attention on the source of activities in science and maths contexts which are likely to be generative of cognitive stimulation, and in this paper I would like to describe a return to the work of Bärbel Inhelder and Jean Piaget as a rich source of activities, and the principles by which these activities are converted from descriptions of children’s reasoning into classroom activities.

CASE has provided teachers with activities and methods which will enable them to raise their students' levels of information processing capability such that they will better be able to make sense of all of the academic instruction that they receive Adey & Shayer, 1994; Adey, Shayer & Yates, 1995). We have used Inhelder & Piaget (1958) description of formal operational thinking as our characterisation of High Level Thinking because it is rich in practical detail and specific about the logical structure of different types of thinking.

On cognitive conflict.

Productive cognitive conflict occurs when a student encounters a problem in which he knows the basic meaning of all the terms encountered, but the problem structure is just a little too complex for him to be able to solve easily. The student has to struggle with the problem, and may well need some help in the form of leading questions, or having his attention drawn to particular features, before the elements come together and a solution unfolds. Vygotsky (1978), who says that “the only good learning is that which is in advance of development”, would describe this as work in the Zone of Proximal Development (ZPD). In terms of cognitive structures, what we suppose happens is that the structure responsible for interpreting an event finds itself just not complex enough to provide comprehension to the individual. Managing the conflict to cause accommodation in the structure is a substantially difficult task.

Reflections on metacognition.

A second main principle for cognitive acceleration has been the generation of metacognitive reflection. Piaget described this as reflective abstraction, looking back on one’s own thinking, and becoming conscious of one’s own problem-solving methods. Inspecting one’s own thinking, identifying a type of reasoning (proportional thinking, for example) and naming it, should make it more likely to be available as a general schema for use when another problem requiring that type of thinking presents itself, whatever the context. In spite of some difficulty over defining
metacognition (Brown, 1987), it is now generally recognised by cognitive psychologists as being an important correlate of effective learning and development (Brown, 1994; Bruer, 1993; Perkins, 1992). The encouragement of metacognition in children is much more a function of the quality of teaching than it is of any particular curriculum activity.

More recently I and some of my colleagues and students have started to question the precise nature and role of metacognition in cognitive acceleration. To start with, there is a major problem in trying to assess whether metacognition is occurring. It proves to be a construct with very elusive external indicators, so that although we can all discuss it and imagine what it is like from our own experience, it is very difficult to recognise it in children. This is partly, but not entirely, due to the problem of definition. I suspect that the highest level of metacognition, that which Piaget refers to as reflective abstraction and describes as a characteristic of adolescent (i.e. formal) thought is a spontaneous tendency to think about one's own thinking. At a lower level, a student, when asked, explains how he solved a problem, the steps he took, and what he was thinking while he did it. This too is very rare, but experience from CASE suggests that it is an ability which can be fostered in students by continual questioning of the right kind.

A lower level again is instanced by the student who can label a reasoning pattern as, for example, 'compensation' or 'equilibrium'. It is not at all obvious that this learning, by the student, of the names that we teachers ascribe to schema of formal operations actually has any great significance. To be useful, the names must also be associated with a fairly rich understanding of the characteristics of each schema, and the ability to recognise that type of thinking in new contexts.

**Construction.**

Everyone is a 'constructivist' nowadays. That is, no one believes that information can simply be transmitted from one person to another. The recipient has to take ownership of the information by re-constructing it for herself. What can we as teachers do to maximise the effective construction of knowledge by our students? In particular, if we are interested in cognitive acceleration, what can we do to maximise the chance of students constructing for themselves new schema, new ways of thinking about the world. This is a special type of construction, which I have called meta-construction. The distinction between construction of knowledge and metaconstruction of schema is that the former is not necessarily constrained by processing capability, while the latter is by definition concerned with the construction of higher level processing ability.

Level of processing ability will impact on normal knowledge construction if the concept to be constructed is at a higher level than the student can currently cope with. Consider the famous difficulty that junior secondary students have in understanding the way current flows in a circuit through various elements (resistances, switches, bulbs, etc.), providing energy for those elements while remaining the same rate of flow of electrons. Even excellent constructivist teaching fails to deliver this understanding to students who are still using concrete operations as their main mode of processing information (Gauld, 1986). This is because a full understanding requires the multi-variable processing characteristic of formal operations. But constructivist teaching works extremely well and efficiently, and in a fairly straightforward manner, when one is trying to build up a network of
understanding about a topic which lies within the students’ processing ability. The key requirement is an opportunity for as many students as possible to contribute their views and to listen to others, and be guided in the process of evaluating evidence for hypotheses and what further investigation might be required. So, construction involves much use of language, sharing of meanings, probing for explanations and for justifications, and for re-interpretation of conclusions reached so that students must go much deeper than producing the formula of words that keeps teacher happy.

Metaconstruction requires the same pedagogical techniques, but its’ subject matter is different. Rather than being concerned with science concepts as such, it is concerned with constructing in students’ minds the processing capability necessary to comprehend (to construct) more complex concepts. By its nature metaconstruction is a slow and uncertain process, and even students on the threshold of a new stage of cognitive development may take months to build a new schema so that it becomes an internal part of they way they process information, rather than just a set of rules, learned without full understanding.

Starting again.

We now have a new project of funded work with five year olds, that is in the first year of compulsory schooling in the UK. In the paper I will re-visit the ideas discussed above in the light of this new level of invention which we are starting upon.

References.
Development of complexity by dealing with physical qualities:  
One type of conceptual change?  

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Abstract.
At the Rome conference in 1997 we introduced our research program of investigating individual learning processes. We focused on the complexity of situated cognitions (cognitive productions in specific situations) (v. Aufschnaiter & Welzel 1997a). The theoretical part of the present presentation deals with similarities and differences between our theoretical approach and the proposal of diSessa and Sherin to interpret concepts as "coordination classes for reading a certain type of information out from the world" (diSessa & Sherin, 1998). In the empirical part I will report the results of a laboratory study with 30 students of 11th grade. All activities of these students solving 55 experimental tasks in the field of electrostatics were videotaped and the videos were carefully analyzed. We tried to find out the students' individual processes of developing concepts while working on the same tasks. Besides other things we found out that concepts of a certain complexity (special coordination classes) can only be produced after the learner has had enough experience with these concepts at lower levels of complexity (other aspects of the information). So conceptual development might be interpreted as the development of increasingly complex "concepts" or "coordination classes".

Subject / Problem.
For more than 10 years we have been investigating the dynamics of individual cognitive processes. We have videotaped small groups of students while acting or talking in real learning environments and analyzed the videotapes carefully. For the interpretation of the empirical data we have developed a neurobiologically oriented theoretical frame. Neurobiological orientation means that cognitive interpretations of students' actions or verbal descriptions should be consistent with the actual findings and interpretations of neuronal processes and structures (Greenfield, 1997; Calvin, 1997).

In our approach we systematically distinguish different levels of description:

- **Information** or **instruction** from the learning environment which (as sensory signals) orients the students' perceptions, recollections, expectations and actions and which may be changed or completed by the specific actions of each student.

- **Cognitive processes** (the firing of neurons in neuronal networks) on a time scale of a few seconds to a few minutes which coordinate sensory signals, recollections, expectations, and actions in sequences of "Images-of-now" (Damasio 1994; Pöppel 1994). We call these processes situated cognition (or situated action) (Clancy 1993). "Situated" here primarily means situated in time.

- **Cognitive structures** (neuronal networks) which produce or construct the cognitive processes (Images-of-now) named before. Cognitive structures or neuronal networks may change on a time scale of a few minutes to several months and we call these changes (one form of) learning.
To analyze the dynamics of situated cognitions (sequences of Images-of-now) in a special domain we have developed and tested a model with different levels of complexity. So we can describe the students' "handling" of physical qualities like electrical charge or physical objects like an electroscope as a development of a "concept" with respect to its complexity.

diSessa and Sherin have developed - as I see it - a similar theoretical frame by introducing coordination classes as a model of concepts. "Coordination has a double meaning. First it refers to the fact that, within a given situation, multiple observations of aspects may need to be coordinated to determine the necessary information. This version of coordination might be described more precisely as integration. Second, it refers to the fact that, across instances and situations, the knowledge that accomplishes readout of information must reliably determine the same information. [...] This latter sense of coordination might be called invariance" (diSessa & Sherin, 1998, 1172). In the first part of my presentation I will discuss the similarities and differences of the two theoretical frames.

**Design, procedure and data analysis.**

In the second part I will demonstrate the matching of our theoretical frame with the results of a learning study under "laboratory conditions". In this study (which was funded by the German Science Foundation, DFG) we videotaped 10 groups each of three 11th grade students doing the same experimental tasks and explaining the results.

We had worked out 55 tasks which were written on cards, with enough space for the students to write down their observations and explanations. The tasks were of increasing complicatedness and normally were handled in a fixed order. (Complicatedness of a task denotes the complexity of situated cognitions which is necessary for successfully solving this task.) A teacher was present but she did not give the students any hints concerning the tasks. However, at certain points (which had been planned in advance) she offered them additional information about physical laws of definitions, which were also written on cards but did not have the form of tasks.

On the average the students needed 180 minutes to solve the tasks, distributed over three sessions. We administrated questionnaires during these sessions and also undertook two extra sessions with concept maps and interviews but I will not talk about them in this presentation. The sessions were videotaped and transcribed and then we tried to reconstruct the students' ideas with respect to what diSessa calls "physical qualities" (v. Aufschnaiter & Welzel, 1997b; Welzel, 1998). As an example I will present the ideas students developed concerning the electroscope.

**General interest and findings.**

The most important research questions were (1) to find out whether the students constructed "concepts" ("coordination classes") with different complexities when solving the same tasks, (2) how different groups of students developed "new concepts" (in the sense of changing the complexity of "the same concept") by solving a sequence of tasks, and (3) when and how they used the additional information
Our results were:

- On the whole students often used some physical "words" ("concepts") which were also written on the cards to express their cognitions.
- With respect to these "words" students developed descriptions of "the same concept" of different complexities.
- As regards the successive use of these "words" ("concepts"), students first created descriptions of lower complexity but then - and only as a consequence of their own experiences - often produced descriptions of higher complexity.
- When working on the same task students used descriptions of higher complexity only when they had already developed, for "this concept", descriptions of lower complexity when solving previous tasks.
- Instructions of high complexity were only used spontaneously by students who had practiced producing this kind of description in previous situations.

By presenting our results of the laboratory study on the electroscope I want to put up for discussion the increase in levels of complexity of situated cognitions produced by students as a possible interpretation of conceptual change.

References.
Towards inclusive views of conceptual change

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Abstract. Conceptual change has become the key term denoting learning science. It also has been employed in studies on learning and instruction in a number of other domains (Vosniadou, 1994). Conceptual change in general stands for learning in such domains where the pre-instructional conceptual structures of the learners have to be fundamentally restructured in order to allow understanding of the intended knowledge (e.g., the acquisition of science concepts). Conceptual change denotes learning pathways from students' pre-instructional conceptions to the science concepts to be learned. Major developments of the "classical" conceptual change approaches of the 80s and early 90s that were based on more radical constructivist epistemological positions with a certain overemphasis of the individual's learning processes and on the initial theory of conceptual change by Posner, Strike, Hewson, & Gertzog (1982) with a focus on the rational towards more inclusive views of conceptual change will be outlined. It appears that these inclusive views offer a potential to overcome limitations of the "classical" approaches and hence may lead to more efficient and pleasing science teaching and learning for teachers as well as for students.

Key characteristics of conceptual change.

Briefly outlined research in the domain of conceptual change started in the 70s with the investigation of students' pre-instructional conceptions in various science domains. It became clear that students encounter science instruction with deeply rooted conceptions and ideas. Usually these are not in harmony with the science views or even in stark contrast to them. Over the years students' pre-instructional conceptions in the major science domains have been investigated. It is noteworthy that still a remarkable number of studies on students' learning in science primarily investigate such students' conceptions. The 80s saw the growth of studies investigating the development of students' pre-instructional conceptions towards the intended science concepts in "conceptual change" approaches. The theory of conceptual change by Posner et al. (1982) which may be indicated by the quadriga of "dissatisfaction-intelligible-plausible-fruitful" became the paradigmatic framework of these "classical" conceptual change approaches. They were embedded in radical constructivist epistemological views with an emphasis on the individuals' conceptions and their development. These conceptual change approaches have proven superior over more traditionally oriented approaches (Guzetti, Snyder, Glass & Gamas, 1993). However, progress was still somewhat limited.

There appear to be a number short-comings that are responsible for the limited success of the classical conceptual change approaches. First, conceptual change primarily has denoted changes of science concepts and principles, i.e. cognitive development on the science content level. Often it has been overlooked that these changes usually are closely linked to changes of views of the nature of science concepts and principles. It has not been taken into consideration that understanding science includes knowledge of science concepts and about science concepts.

Second, there is, as mentioned, a certain focus on the rational, i.e. on issues following the logic of the science content structure. This holds for science education research as well as for cognitive science research on conceptual change. A
prominent example for the latter is the theory of conceptual change by Chi, Slotta, & de Leeuw (1994). It has been often neglected that learning of the science content has to be embedded in learning environments that support the acquisition of these rational issues (Pintrich, Marx, & Boyle, 1992). Third, the epistemological orientation has been questioned. Clearly, the fundamental critique on radical constructivism underlying to a certain extent classical constructivist approaches (cf. Matthews, 1992) was overstated. However, epistemological views merging radical and social-constructivist approaches appear to be more promising than monistic views proposed by the one or the other side. There have been developments over the past few years towards such inclusive epistemological views that seem to provide not only powerful frames to understand learning processes as they happen in real learning situations but may also lead to more fruitful teaching and learning environments. There are current tendencies towards theories of teaching and learning science paying even attention to the individual and social aspects of learning.

Recently Vosniadou and Ioannides (1998) provided a critique of classical conceptual change approaches that follows similar lines as the above mentioned. Their main claims appear to be the following. First, they argue that the conceptual change approaches as developed in the 80s and early 90s put to much emphasis on sudden insights facilitated especially by cognitive conflict. They claim that learning science should be viewed as a "gradual process during which initial conceptual structures based on children's interpretations of everyday experience are continuously enriched and restructured" (p. 1213). They also point out that conceptual change involves "metaconceptual" awareness of the students. In other words, students will be able to learn science concepts and principles only if they are aware about the shift of their initial metaconceptual views towards the metaconceptual perspectives of science knowledge. Finally, they argue in favor of a theory of science learning that includes the individual cognitive development and the situational and cultural factors facilitating it.

Towards multi-perspective views of science learning and instruction.

Conceptual change approaches as developed in the 80s and early 90s contributed substantially to improving science learning and teaching. However, there are a number of short-comings that will have to be overcome in the next years. There are promising tendencies towards new approaches that are multi-perspective in several ways:

> **Towards multiple conceptual changes** Conceptual change at the content level are closely linked to changes at meta-levels such as views about the nature of science knowledge and meta-cognitive views about learning. So far not much is known about the interactions of these conceptual changes. Research should put more emphasis on that.

> **Towards merging cognitive and affective domains** There is ample of evidence in research on learning and instruction that cognitive and affective issues are closely linked. However, the number of studies on the interaction of cognitive and affective factors in the learning process is limited. There are, for instance, many studies on the relations between interests and acquisition of science concepts. However, these studies are usually restricted to correlations between interests and cognitive results of learning. The interplay of changes of interests and conceptual change is investigated only in a small number of studies. The multi-dimensional framework for
interpreting conceptual change by Tyson, Venville, Harrison & Treagust (1997) includes, for instance, an affective domain, but it is not fully elaborated so far. It appears that it is fruitful to merge ideas of conceptual change and theories on the significance of affective factors like the one by Deci and Ryan (1985).

> **Towards merging moderate and social-constructivist views of learning**

Studies on learning (science) so far were mostly oriented at views of learning that are monistic to a certain extend. Only recently there are powerful developments towards admitting that the complex phenomenon learning needs pluralistic epistemological frameworks (Greeno, Collins, & Resnick, 1997) in order to address the many facets emphasised by different views of learning adequately. In science education there is a growing number of multi-perspectives views which appear to be rather promising to improve science teaching and learning (Duit, 1999).

**References.**


