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Author: Duit, Reinders

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Research in the field under review here started with investigating the role of students' pre-instructional conceptions in learning science concepts and principles in the mid '70s. In the beginning it was mainly students' conceptions on the content level which were taken into consideration. A few years later, students' conceptions of a more inclusive kind were regarded (including, for instance, conceptions of science and conceptions of the learning process). As well as this, teachers' conceptions of various kinds were given attention. The constructivist view has been the most important driving force in widening the original narrow perspective. When the term "students' conceptions" is applied in this paper it is embedded in the constructivist framework, i.e. it is employed in the mentioned inclusive way.

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Research on students' conceptions -- developments and trends

Reinders Duit
Institute for Science Education, University of Kiel, Germany

INTRODUCTORY REMARKS

This papers aims at contributing to the discussion on future developments in our research field. In the first part, diagrams are presented that show the number of studies in specific domains of the research field -- mainly over the past 20 years. In the second part the significance of the constructivist view is discussed on the background of recent critiques of this position.

Research in the field under review here started with investigating the role of students' pre-instructional conceptions in learning science concepts and principles in the mid '70s. In the beginning it was mainly students' conceptions on the content level which were taken into consideration. A few years later, students' conceptions of a more inclusive kind were regarded (including, for instance, conceptions of science and conceptions of the learning process). As well as this, teachers' conceptions of various kinds were given attention. The constructivist view has been the most important driving force in widening the original narrow perspective. When the term "students' conceptions" is applied in this paper it is embedded in the constructivist framework, i.e. it is employed in the mentioned inclusive way.

ON THE DEVELOPMENT OF THE RESEARCH FIELD AS REFLECTED BY THE NUMBER AND KINDS OF ARTICLES PUBLISHED

The data presented in the following are based on the articles contained in Pfundt and Duit's (1993) bibliography which has been compiled since 1977. Around 40 journals have been reviewed on a regular basis - among them - the most important international journals of science education and a number of international journals of cognitive psychology that publish papers on students' cognitive development in science from time to time. Further bibliographical sources are:

- books that contain chapters on students' conceptions in science,
- other bibliographies (most notably the bibliography by Carmichael, Driver, Holding, Phillips, Twigger, & Watts, 1990),
- proceedings of conferences and workshops,
- papers presented at conferences and workshops,
- papers that are sent to me by the authors.

The international networks (such as the Special Interest Group of the American Educational Research Association on "Subject matter knowledge and conceptual change" and an "Invisible College") also provide valuable help to keep informed on new developments. Therefore, the bibliography appears to reflect the state of affairs in the research field under review here fairly well although it is far from including all articles published and all papers presented elsewhere.

Total number of studies in certain domains

Figure 1 presents the number of articles in the bibliography by years of publication. The state at the beginning of the listed years in figure 1 is portrayed (more precisely put, the number of publications in the bibliography with a year of appearance less than 1993, 1989 etc. is given).

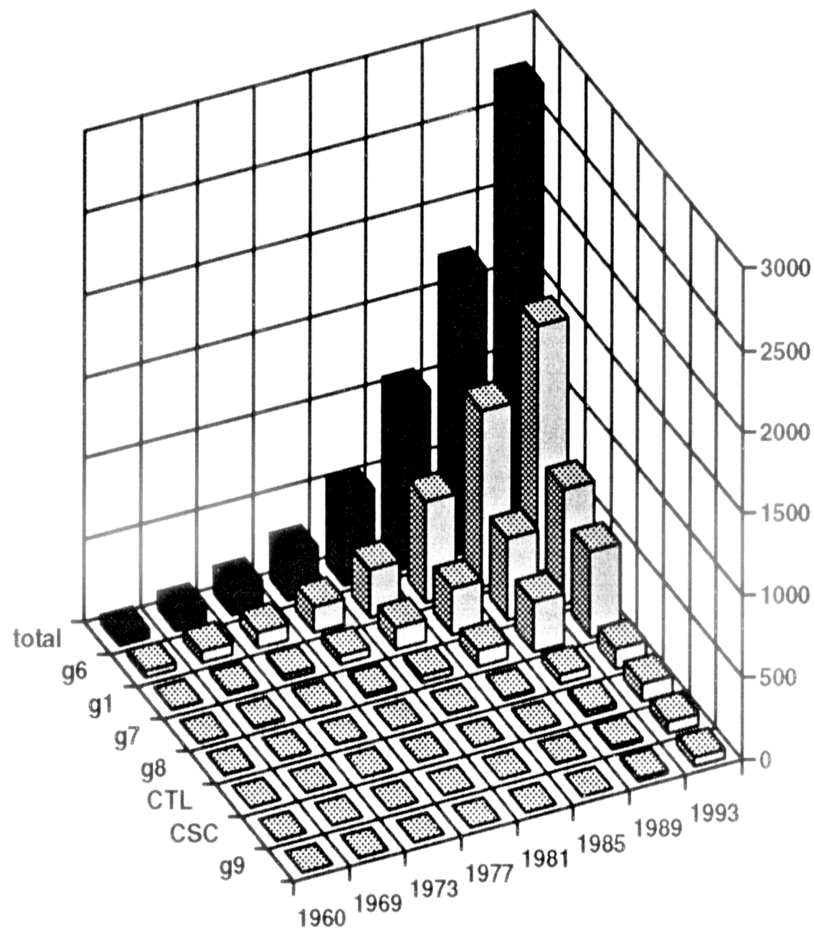

Figure 1: Number of publications in the bibliography by Pfundt and Duit (1993) by years of publications (before 1960, before 1969, etc.). The following abbreviations are used:

total: total number of publications
g6: Empirical investigations of students' conceptions

g1: General (theoretical) considerations concerning research in this field
g7: Studies on new approaches taking students' conceptions into account
g8: Empirical investigations of teachers' conceptions
CTL: Empirical investigations of students' and teachers' conceptions of teaching/learning
CSC: Empirical investigations of students' and teachers' conceptions of science
g9: New approaches of teacher education

The first line provides the total number of articles. Currently, there are around 2800 publications in the bibliography that appeared earlier than 1993. It may be speculated as to whether the progression is exponential or not and how long a similar increase of publications will last. The data show that the current "boom" of research on students' conceptions started in the mid '70s and that the research field is still flourishing. It has to be noted that the number of studies in the bibliography that appeared before 1960 certainly does not represent the total number of studies available in that period very well. The number of studies in the review by Oakes (1947) that concern students' conceptions in science already exceeds the number of 51 publications as listed in the bibliography.

The other curves in figure 1 provide the development in a number of domains. In figure 1, the keywords used in the bibliography are given. Most papers published (g6) contain empirical studies on students' conceptions in various science content domains (see for more details table 1 below). The number of studies on new teaching and learning approaches (g7) is much smaller. Figure 1 clearly shows that the main emphasis has been given to investigating students' conceptions and that the development and empirical evaluation of new teaching and learning approaches has been given substantial emphasis, however with a certain delay. The third line (g1) in figure 1 indicates that theoretical work has played an important role in the research field. Around 25% of all publications available contain theoretical considerations. The lines g8 to g9 indicate exciting developments in the research field despite their small numbers as compared to the total number of articles available or as compared to the number of studies in g6. g9 gives the number of new approaches to teacher training in science based on research findings in the field under review here. g8 stands for studies on teachers' conceptions of various kinds. The absolute number of 123 studies available at the moment is quite impressive. Similar remarks concern studies on students' (and teachers') conceptions of learning and teaching (CTL) and studies on students' (and teachers') conceptions of the nature and range of science (CSC). Currently, in total, 108 (CTL) and 74 (CSC) studies respectively are available. Where studies on conceptions of science (CSC) are concerned it should be noted that the bibliography at the moment only includes the studies carried out within constructivist settings. A recent review by Lederman (1992) showed that there is a long standing tradition of studies on students' and teachers' conceptions of science. A number of studies, for instance, had already been carried out in the '60s and '70s. It is worth noting that there is, in general, a growing interest in the interplay of the philosophy and the history of science on the one hand and science education on the other. A group of researchers has formed and has met at conferences (see the proceedings edited by Herget, 1989, 1990 and Hills, 1992). Also, a new journal, Science & Education, with a referring focus started in 1992.

Number of studies in four-year periods

Figure 2 provides another view on the development of research. Starting in the mid '70s the number of studies published in four-year periods (e.g., from 1977 to 1980) is presented. Also here, the dominance of studies on students' science content conceptions (g6) becomes obvious. But it is also to be seen that studies on new teaching and learning approaches (g7) are well represented in the last two four-year periods. Furthermore, the growth of the studies indicated by g8 (teachers' conceptions), CTL (conceptions of teaching and learning), CSC (conceptions of science), and g9 (new approaches of teacher education) is more adequately portrayed in figure 2 than in figure 1.

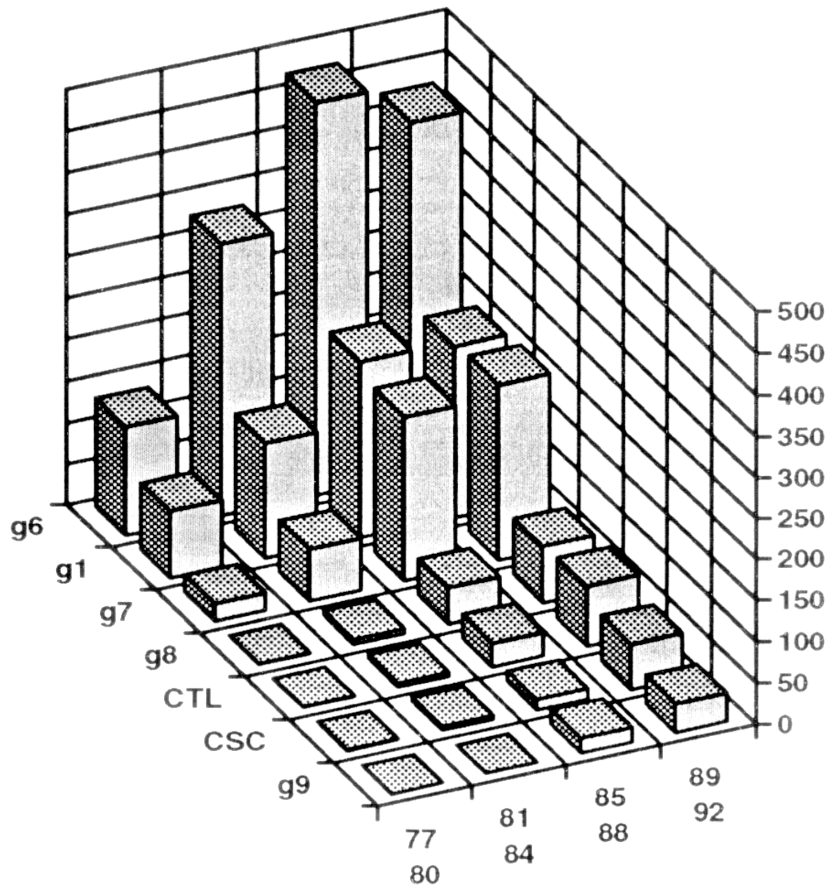

Figure 2: Number of publications in the bibliography by Pfundt and Duit (1993) within four-year periods (1977 to 1980, 1981 to 1984, etc.). For the abbreviations used see figure 1.

Number of studies on students' conceptions in different science content areas

Table 1 presents the number of studies on students' conceptions in different science content areas (g6). There is a strong dominance of studies in the area of physics. Figure 3 indicates that 66% of the studies on students' conceptions deal with physics content, 20% with biology content, and only 14% with chemistry content. It is open to speculation why physics dominates. One reason appears to be that cognitive psychologists have often chosen physics examples when they carried out their research in a science domain. Maybe the assumption that physics is more mathematically and hence logically structured than the other sciences (which is a dubious assumption) has been a major factor.

Table 1 shows that a broad variety of major science content areas have already been researched. Some are even "over-researched" areas like the interplay of force and motion and the simple electric circuit in physics. But there are still important areas waiting for more (or for more substantial) studies. This is even true for physics. The area of modern physics, for instance, does not appear to be greeted with much enthusiasm by students' conceptions researchers. 25 of the 28 studies are on quantum mechanics, they were mostly carried out in Germany (this fact is interesting in that otherwise there is no such dominance of a country concerning studies in a content area).

Table 1
Number of Studies of Students' Conceptions in Different Science Content Areas (based on information in Pfundt & Duit, 1993)

General Area	No. of studies	Specific Topics
Mechanics	343	Force and motion; work, power, energy; speed, acceleration; gravity; pressure; density; floating; sinking
Electricity	181	Simple, branched circuits; topological and geometrical structure; models of current flow; current, voltage and resistance; electromagnetism; danger of electricity
Particles	103	Structure of matter; explanation of phenomena (e.g., heat, states of matter); conceptions of the atom; radioactivity
Optics	90	Light; light propagation; vision; color
Energy	89	Energy transformation; conservation; degradation
Heat	68	Heat and temperature; heat transfer; expansion by heating; change of state, boiling, freezing; explanation of heat phenomena in the particle model
Astronomy	46	Shape of the earth; conceptions of the universe; characteristics of gravitational attraction; satellites
"modern" Physics	28	Quantum physics; special relativity

…………………………		
Biology	274	Plant nutrition; photosynthesis; osmosis; life; origin of life; evolution; human circulary system; genetics; health; growth
…………………………		
Chemistry	194	Combustion; oxidation; chemical reactions; transformations of substances; chemical equilibrium; symbols, formulas; mole concept; electrochemistry

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TRENDS AS PORTRAYED BY THE DATA PROVIDED

Research started in the middle of the 70s with a strong emphasis on investigating students' conceptions of science content areas such as heat, force, electric circuits, the process of burning, chemical reactions, photosynthesis etc. (see Table 1). Students' conceptions before instruction and the development of these conceptions during -- mostly traditional -- instruction were investigated. It became very apparent that science instruction was not as successful as had been taken for granted until then. Students' pre-instructional conceptions (many of them stem from everyday language and sense experiences, but a considerable number are also induced by previous science

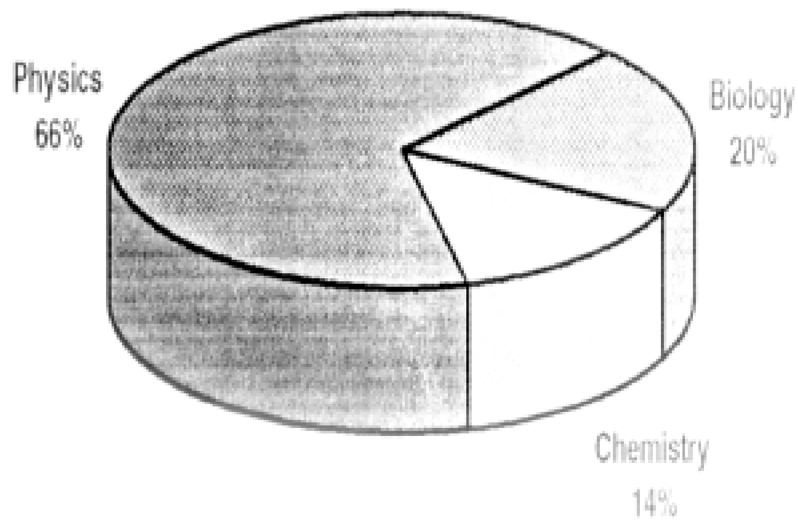

Figure 3: Percentages of studies on students' conceptions in biology, chemistry and physics (based on information in Pfundt & Duit, 1993)

instruction) were frequently not in accordance with the science concepts to be learned and these pre-instructional conceptions were rather resistant to change. Most studies carried out are still focused on students' conceptions of science content areas and many of them just portray pre-instructional conceptions or compare conceptions before and after mainly traditional instruction. As has been noted above, there is still a need for studies of this kind in a number of major areas of science instruction.

It also seems appropriate here to mention an urgent need for attempts to summarize what is known about students' conceptions in specific content areas. Such summaries would be most valuable aids for science teachers but also for researchers, especially those who are starting to join the field. There are summaries of this kind available (see e.g., the volume by Driver, Guesne, & Tiberghien, 1985) but they are not always up to date.

A brief remark on the design of studies on students' conceptions may also be added. Whereas most studies are designed according to the "snapshot" or "multiple snapshots" model (i.e., investigate students' conceptions at only one time or at a series of times) the number of true learning process studies is still small but has been growing in recent years (see, for instance, the proceedings of a workshop that focused on learning process studies in physics, edited by Duit, Goldberg, & Niedderer, 1992). Glaser and Bassok (1989) pointed out that learning process studies are rare in instructional design research in general and have argued that such studies are necessary for further improvement of both instructional theory and practice.

The teaching and learning approaches developed on the basis of the research findings as mentioned above were not always more successful than the traditional approaches (c.f., Driver & Erickson, 1983; see also further remarks on this issue below). It became obvious that solely addressing students' pre-instructional conceptions of the above content type would not result in considerable progress. As a consequence conceptions of a much more inclusive type (see e.g. in figure 4) were given attention. First the major focus was on the students' side but later also teachers' conceptions of various kinds were included. The constructivist view that developed as the leading theoretical framework of research in the beginning of the 80s undoubtedly was a most powerful driving force towards taking students' and teachers' conceptions of a broad variety into account.

Media (e.g., Textbook) Used in Instruction

1. Conceptions of science topics (e.g., energy, particles, photosynthesis)
2. Conceptions of the nature and range of science

Students	**Teachers**
1. Conceptions of science	1. Conceptions of science
2. Conceptions of the nature and range of science	2. Conceptions of the nature and range of science
3. Conceptions of the aims of science instruction	3. Conceptions of the aims of science instruction
4. Conceptions of the purpose of particular teaching events	4. Conceptions of the purpose of particular teaching events
5. Conceptions of the nature of the learning process	5. Conceptions of the nature of the learning process
6. Attitudes to science, to specific science topics to learning science, to the teacher, to being in school in general	6. Attitudes to science, to specific science topics, to being a teacher, to the students
	7. Conceptions of students' conceptions 1. to 6. opposite

Figure 4: Significant "variables" within a constructivist view of teaching and learning science

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Also here a cautious note appears to be necessary. The developments towards more comprehensive constructivist approaches are most promising. There are already a number of interesting and convincing approaches available. But there is also the danger that the research and development of new approaches may get lost in the complexity of the many conceptions to be taken into account. Furthermore, there appears to be a tendency in a number of studies that investigate, for instance, conceptions of teaching and learning (i.e., issues addressed by approaches of meta-cognition) or conceptions of science (i.e., philosophy of science issues) to investigate these conceptions separately. The interplay of content conceptions, meta-cognitive conceptions and conceptions about science is a field that needs more attention in the future.

FURTHER TRENDS

There are, of course, a number of trends in the research field, that are not portrayed by the data provided so far, which are mainly "surface" data. One most important trend is the switch from the view of false (from the science perspective) pre-instructional conceptions to a view that takes students' conceptions more seriously into account as conceptions in their own right, i.e., as conceptions that facilitate quite successful action in daily life situations and quite pleasing (from the point of view of the students) interpretation of phenomena. Originally the term "misconception" stood for the view that students' pre-instructional ideas are wrong and have to be eliminated (extinguished, replaced) by the correct science view. It is true that from the very beginning of research in the middle of the 70s (and also before) there were influential researchers who took the counter-position. Driver and Easley (1978) coined the label "alternative frameworks" for this position already in an early stage of development of current research on students' conceptions (there have been a number of other ways of expressing that students' conceptions should not simply be viewed as wrong, for instance, employing the metaphor of the "child as scientist"; see for a review of reference terms used in the research area Abimbola, 1988; Duit, 1987). But it took some time before this position was widely accepted. Now the term "misconception" is seldom used in the above-mentioned original meaning. Very often it now stands for false conceptions (viewed from the science point of view) that have been induced by science instruction. Yet still there is a (small) minority position in the research field that explicitly or implicitly draws on the original meaning of misconception as a starting point for taking students' preconceptions into account.

The development from the false-conception-view to the alternative-framework-view which is briefly presented above, is also mirrored by the way the change from students' conceptions to science conceptions has been seen. The false-conception-view aimed at erasing these false ideas. Now the view dominates that the aim of science instruction is a kind of coexistence between students' preconceptions (students' everyday conceptions) and the science conceptions to be learned in school. More precisely put, students have to learn that their conceptions may be quite valuable in certain situations and daily life contexts but that in other contexts science conceptions are the only ones that provide fruitful understanding and facilitate fruitful acting. There are two main reasons for this development. First, research has shown that the many attempts in science classes to extinguish students' conceptions are deemed to failure. Students stick to their conceptions because they have been very valuable in certain contexts. Indeed, also professional scientists are not totally free of these conceptions. Especially in areas with which they are not very familiar they hold at least some relics of the old ideas. But they have learned to be careful and to switch to the science conceptions when necessary. Secondly, to extinguish conceptions that have been proven to be valuable and that are continually supported by everyday experiences may result in the inability of students to communicate with others in daily life contexts. Where the concept of energy is concerned, for instance, it is well known from research that the everyday energy concept (i.e., the meaning energy is given in daily life contexts which includes the use of energy in mass media and in information materials on energy supply issues) is substantially different from the science energy concept. If it is the aim of science instruction to provide students with conceptions that may help them to understand energy supply issues in society and if science instruction were successful in totally extinguishing the everyday conceptions of energy there would be a strange result. Students would no longer be able to understand everyday talk on energy issues. That means science instruction would miss a main aim of energy education (see for more details, Duit & Haeussler, 1992).

There is another important trend concerning research on students' conceptions that is worth mentioning, namely the change of emphasis towards qualitative research methods. Qualitative methods played an important role from the very start. Piaget's method of clinical interview is genuinely qualitative. It was developed in the '30s and has been used (in a number of variants, of course) since then to investigate students' conceptions. Qualitative methods also played a significant role in the beginning of the current boom of research on students' conceptions in the mid '70s. But there were a considerable number of studies in a more traditional quantitative format too. They were often affiliated with the above mentioned "false-conception-view". The constructivist view that deeply influenced research since the beginning of the '80s led to a dominance of qualitative methods. Interpretive and ethnographic studies came more and more into use. Case studies and studies on students' and teachers' learning processes were carried out during the past decade (see above). At first, i.e., even at the beginning of the 80s, the US journals of science education, that were oriented towards the traditional quantitative format, were somewhat hesitant to accept qualitative research. In recent years, a change has taken place here. The National Association for Research in Science Teaching (NARST), for instance, decided to support qualitative research in science education. The guidelines for reviews of their Journal of Research in Science Teaching were changed to meet qualitative research features more adequately.

It is worth a side-remark that the mentioned developments in the field of methods appear to lead to new approaches of assessment in general. Not only methods of assessing new teaching and learning approaches may be qualitative and interpretive in nature now. There are also attempts to overcome the traditional assessment practice in school that is quantitative in nature and starts from the illusion that it is possible to boil down the many facets of students' development in the field of knowing science and knowing about science in a single number only. Portfolios are an example of this new trend (Duschl & Gitomer, 1991; Champagne & Newell, 1992).

ON THE SIGNIFICANCE OF CONSTRUCTIVISM IN SCIENCE EDUCATION

There is no doubt that the constructivist view has been a most powerful and fruitful driving force in research on students' (and teachers') conceptions, i.e., on research that seriously takes the conceptions of all the actors in instructional settings, such as science instruction in school, into consideration (Driver, in press; Duit, in press; see also other contributions in Steffe's, in press, volume on constructivism in education). Also critics of the constructivist view like Matthews (1993), for instance, admit that this perspective inspired researchers and curriculum developers, at least partly, to valuable and desirable practice:

> "There is much that is laudable, insightful, and progressive about constructivist theory and practice. It is far superior to the behaviorist theory of mind and learning against which Piaget and early cognitive psychologists, such as Bruner, struggled." (Matthews, 1993, 359)

But there is no doubt that constructivism has also been a fashionable item. It has become fashionable in some way to be a constructivist. Or to say it more ironically, there appears to be a desire among researchers to be a member of the constructivist party in order to be taken seriously and in order to be part of mainstream research. The somewhat ambiguous role of the constructivist view may be also stated in this way. There are colleagues among us in the constructivist party who were already constructivists before they knew, there are colleagues who claim to be constructivists but in fact are not or at least only in a superficial way, and there are colleagues who share major ideas with those in the constructivist party but do not want to be called constructivists because they have some reservations about and objections to constructivism.

It is far beyond the scope of this paper to analyze the role of the constructivist view in science education during the past decade in great detail. It is only possible here to sketch main lines of development and to summarize major arguments that are used against this view in the reference literature.

ON THE CORE OF THE CONSTRUCTIVIST VIEW IN SCIENCE EDUCATION

It is surprisingly difficult to outline in a few sentences the major ideas that are shared by all members of the constructivist party in science education. Of course, all members will agree with Ausubel's famous dictum:

> "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly". (Ausubel, 1968, vi)

But this dictum is very general and allows many different interpretations beyond those Ausubel may have had in mind within the framework of his theory. Read without this framework in mind the dictum simply says that learners' pre-instructional conceptions play an important role when learning something new. In which way preconceptions influence learning and what "teach him accordingly" may mean remains open.

Strike (1987) summarizes the core of common concern among constructivist science educators in two principles. The first is:

(1) The idea that the mind is active in constructing knowledge.

This in fact appears to be the main principle for this group if it is combined with Ausubel's dictum (see also the first principle of radical constructivism as presented below). The essence then is that learning is viewed as active knowledge construction on the basis of the already known (the already existing constructions). But also here the principle is rather vague or to say it in another way, it is open for many slightly different interpretations. What exactly is meant by saying, the learner (or the mind) has to be active? What does "construction" mean? Ernest (1993, 90) points out that this idea (he refers to the first principle of radical constructivism cited below) "does not strictly imply or disqualify any teaching approach" and "does not rule out any teaching technique in principle". Strike's critique is similar.

Strike's second principle is this:

(2) The idea that concepts are invented rather than discovered.

This principle has strong logical relations with the first. If, namely, knowledge in general is constructed by a learner then new knowledge is also constructed by scientists who acquired that knowledge the first time. Also here the principle is open for many different interpretations. It may be accepted by those who mainly take a critical realist position and also by those who are more on the idealist side of ontology. Strike (1987) argues that this principle is accepted by almost everyone who come from both traditional and constructivist perspectives (see Ernest, 1993, 90, for the same conclusion).

The principles are given different flavors by different researchers in the field of constructivist research in science education and, by this, often achieve less vague meanings (see the table of "words to modify constructivism" in Good & Schlagel, 1992, 418-419). Matthews (1993) mentions the following positions that are taken: Piaget's genetic epistemology, the new theories of science movement in the '60s and '70s that may be indicated by names like T.S. Kuhn, Feyerabend, Lakatos and others, the new sociology of science, postmodernist views about science, Kelly's theory of personal constructs, social constructivism, especially the theory of language acquisition as developed by Vygotsky. In general, the constructivist view appears to be within a mainstream of contemporary thinking not only in philosophy of science or in cognitive psychology but also within the many domains that are influenced by the ideas of the new theories of self-organizing systems and deterministic chaos. In short, the constructivist view is a broad spectrum of ideas that share a common core (a common denominator, to employ a mathematical metaphor). Matthews (1993, 361) uses the metaphor of constructivism being a mansion containing many rooms.

The appeal of the constructivist view, therefore, partly appears to be due to its being within a mainstream of contemporary thinking. But there also seems to be another issue that allows the constructivist view to serve as a uniting view, namely its vagueness or to say it more positively its openness as outlined above. Because there is room for interpretation of the core ideas, quite different views may be integrated. It may be surprising that the openness is not only responsible for the fact that the constructivist view has become so fashionable. Also the mentioned positive power of constructivism is at least partly due to the openness in that it allows creative development of thinking within the broad frame of constructivism. A very closed theory with precisely defined terms would certainly not allow such an amount of creativity.

A SKETCH OF RADICAL CONSTRUCTIVISM

As mentioned, constructivism is a rather heterogenous movement. In science and mathematics education von Glasersfeld's radical constructivism (Glasersfeld, 1989, 1992a, in press) is most often employed as a reference position. Glasersfeld's constructivism includes many facets of Piaget's genetic epistemology. This becomes most obvious in the biologist's idea of adaptation that is central in Piaget's thinking and in Glasersfeld's constructivism as well (for a discussion of Piaget's and Glasersfeld's constructivism see O'Loughlin, 1992). There are two basic principles of constructivism that may be viewed as the radical constructivist way of stating Strike's (1987) principles that have been discussed above. In the following Ernest's (1993, 89) phrasings of the principles are given:

> Principle A: The 'Trivial constructivist principle': 'knowledge is not passively received but actively built up by the cognizing subject.'
>
> Principle B: The 'Radical constructivist principle'. 'the function of the brain is adaptive and serves the organization of the experiential world, not the discovery of ontological reality.'

The idea of "viability" may be added to the principles because it is at the centre of von Glasersfeld's position. Only those constructions "survive" that prove to be successful in dealing with the world around the constructor. It is this principle where relations between von Glasersfeld's radical constructivism and pragmatism become most obvious. To call the first principle "trivial constructivist" appears to be an ill-chosen term (Ernest, 1993). First, it is far from being trivial to put this principle into practice. Secondly, there are strong logical relations between the two principles, as has been outlined above.

THE CONSTRUCTIVIST VIEW AS THE NEW IDEOLOGY OF CONTEMPORARY SCIENCE EDUCATION?

Radical constructivism is deliberately an epistemology, a theory of knowledge as von Glasersfeld points out when he discusses the significance of his position for learning science and mathematics (von Glasersfeld, 1992a). Hence the emphasis of the constructivist view in science education usually has been on the issue of knowledge acquisition. But there also has been be a tendency sometimes to associate constructivism with progressive science teaching in general. Of course, there are strong relations between such progressive "science education for all" (Fensham, 1986), i.e., between gender inclusive and STS (the interplay of science, technology and society) inclusive science education on the one hand and constructivism on the other. All these movements focus on students' interests and needs in a broad sense. They try to make science instruction more understandable and meaningful and hence more significant for students. Also teaching strategies like project work and more open forms of instruction in general are in accord with all these movements. But the label constructivism should not be employed to indicate all that is seen as progressive in science education. It simply would lose meaning and hence the creative power it has had so far if it really became the ideology of contemporary science education. To put it into other words: the constructivist view in science education has been a most powerful driving force of progress but it is far from being the cure for every problem in science education.

SUCHTING'S CRITIQUE OF RADICAL CONSTRUCTIVISM

In the preceding paragraphs some critical arguments against constructivism in general and the constructivist view in science education in particular have already been presented. In the following, further points of critique have been summarized.

A most rigorous critique of von Glasersfeld's radical constructivism has been provided by Suchting (1992) in an article on "Constructivism Deconstructed". He analyzes an article by von Glasersfeld (1989) in a scrupulous exegetical manner. He comes to the following conclusion:

> "Firstly, much of the doctrine called "constructivism", as presented in this paper ... is simply unintelligible. Secondly, to the extent that it is intelligible enough to provide some foothold for understanding and criticism it is simply confused. Thirdly, there is a complete absence of any argument for whatever positions can be made out. In all these respects certain words are repeated like *mantras*, and while this procedure may eventually produce in some what chanting is often designed to do, namely, produce a certain feeling of enlightment without the tiresome business of intellectual effort, this feeling nearly always disappears with the immersion of the head in the cold water of critical interrogation. Fourthly, the key problem of intersubjectivity is not successfully addressed." (Suchting, 1992, 247)

Some remarks on Suchting's method of deconstructing constructivism are necessary. First, it appears most unlikely that many writings on issues of learning science would withstand Suchting's rigorous way of analysis. Second, Suchting appears not to be fair in every respect when dealing with Glasersfeld's writing. Glasersfeld (1992b), in his reply to the critique points out that, in several places, Suchting analyzed sentences and parts of them which were taken out of the original context. In general, the way of arguing and also the style of writing (see the summary quote above), indicate that there is a certain emotional loading in Suchting's critique against the "obscure" (Suchting's word in the abstract of the critique) position of radical constructivism (see also the letter by Suchting to the editor of the journal Science & Education, 1993). Third, it is a little doubtful whether it may be justified to refer in such a substantial critique on radical constructivism in general to one single article only that is about the same length as the critique. Fourth, it is most disappointing that Suchting does not explicitly point out the philosophical position on which his critique rests. It is a key insight of hermeneutics (and radical constructivism as well) that a line of argument becomes understandable only if the general framework in which it is embedded is known to the reader.

Nevertheless, the critique points to a number of weak features of radical constructivism in general and of the analyzed article in particular. The terminology of radical constructivism is indeed weak and in fact allows to trivialize the main ideas as principles that are shared by almost everyone, like the insight that there is a certain aspect of human construction in all scientific knowledge (see above). This weakness is an issue that is widely addressed (see e.g., Nuese, Groeben, Freitag, & Schreiber, 1991). Furthermore, there is, of course, some sort of irony in the fact that von Glasersfeld's constructivism, besides others, refers to a philosopher, namely Vico, who undoubtedly was one of the key opponents against the scientific revolution started by Galilei and others in the 18th century (see also Matthews, 1993, 364). Another issue of critique concerns a certain "empiristic" nature of radical constructivism that has been raised by Suchting (1992) and that has been followed up by Matthews (1993). It is difficult to see the justification of these arguments. The claim, in constructivism as well as in empiricism, experiences are the key source of learning is not sufficient. In constructivism, unlike empiricism, there is no new knowledge coming from experiences alone. Rather sense impressions, for instance, have to pass, so to speak, the filter of prior conceptions in order to make sense to the observer. What appears to be appropriately argued in Matthew's (1993) discussion on the relationship between empiricism and constructivism is the emphasis put on the individual in both positions. This issue will be addressed in more detail below.

In short, Suchting's critique draws attention to a number of weaknesses (not all have been mentioned above) of radical constructivism. Further elaboration of this epistemology is urgently needed -- not so much in order to defend this point of view but to save the valuable power this epistemology undoubtedly has for learning science and other topics.

ONTOLOGICAL ISSUES

It is a common feature of critiques on Glasersfeld's radical constructivism that this position leads to the denial of the existence of a physical world outside (see, for instance, a discussion on this issue between Ernst von Glasersfeld and Walter Jung in Duit & Graeber, 1993; see also Goldin, 1989; Suchting, 1992; Matthews, 1993). Ernest (1993) points out that this is an incorrect conclusion because von Glasersfeld points out in a number of his articles that radical constructivism is ontologically neutral (Glasersfeld, 1992a, 32). Radical constructivism is consistent with the idea of a real existing world outside. All it denies is the possibility of any certain knowledge of that reality. That means that the constructivist view does not necessarily lead to an idealist position (and hence not to solipcism) but is compatible also with a critical realist view.

THE INDIVIDUAL AND THE SOCIAL

It has already been mentioned that Matthews (1993) states a focus on the individual, and hence a neglect of the social in his discussion on empiristic issues in constructivism. In a number of other critiques on constructivism, especially radical constructivism, it is pointed out that the focus is the inner subjective world of the individual and the individual construction processes (Ernest, 1993; O'Loughlin, 1992; Marton & Neuman, 1989). This is seen as a major weakness of radical constructivism. Glasersfeld (in press), of course, admits that the social context which the individual learners are part of when they construct their knowledge is an important issue. But the social issue is not addressed further in his radical constructivism.

Phenomenological (Marton & Neuman, 1989; McCarty & McCarty, 1992) as well as social constructivist perspectives (Glasson & Lalik, 1992) point out that the focus on the individual in the radical constructivist approach leads to the separation of the individual and the world. The individual and the world are divorced from each other. Marton and Neuman (1989), for instance, argue in the following way:

> "The main problem with constructivism (including radical constructivism) is in our view that the individual and the world are seen as separated from each other. This leads to paradoxes. For example, according to the constructivist view of thinking, the individual can never get in touch with the reality that he is divorced from. As all knowledge is assumed to be derived from the individual's construction activity it is very difficult to see how he can find out about the constraints imposed by the surrounding world that would lead to accommodation. After all, the constraints imposed by the surrounding world must be -- according to the constraint assumption -- *constructed* constraints and these must be formed in accordance with the properties of already given scheme activities." (Marton & Neuman, 1989, 36)

O'Loughlin (1992) argues in a similar way. In general, he presents an inclusive critique of Piagetian and radical constructivism with regard to their consequences for learning science (as well as other school topics). It is a critique on the basis of what he calls a "sociocultural model of teaching and learning" that may be viewed as a social constructivist approach. The theme of the article, as outlined in the abstract, includes the following issues:

> "Despite the appeal of the notion that the learners construct their understanding, I argue that constructivism is problematic because it ignores the subjectivity of the learners and the socially and historically situated nature of knowing; it denies the essentially collaborative and social nature of meaning making; and it privileges only one form of knowledge, namely, the technical rational. … My central thesis is that constructivism is flawed because of its inability to come to grips with the essential issues of culture, power, and discourse in the classroom." (O'Loughlin, 1992, 791)

O'Loughlin (1992) argues, on the one hand, along similar lines as others (e.g., Ernest, 1993) who are of the opinion that constructivism puts too much emphasis on the individual aspect of construction. On the other hand, his critique goes far beyond that issue of socially constructed meaning. He discusses, for instance, the key idea of constructivism that learners actively construct their own interpretations of events. He admits that this emphasis on students' own activity may, in fact, empower students' to take responsibility for their own learning. But he also claims that it has to be taken into account that a certain amount of power is put onto the students to be active. He asks, for instance, in whose interest is it to exercise this power over students. He further argues that in constructivist instruction which aims at students' activity (to put it another way, that demands it), this activity may degenerate to a ritual to be followed in order to please the teacher and to play the game of the school (O'Loughlin here refers, besides others, to studies by Edwards and Mercer, 1987). It is the very strength of O'Loughlin's paper that also those kinds of social issues are discussed. It appears that constructivist approaches, so far, have often neglected the issue that the new approaches have to fit the power structures of the school system in general.

THE ISSUE OF THE CONSTRUCTIVIST VIEW BEING SIMPLY COMMON SENSE

Strike's (1987) critique of the constructivist view is based on the assumption that the above cited two principles of constructivism are simply common sense, i.e., are shared by almost everyone who deals with science education. As has been mentioned above, others share this assumption. Indeed there is, as has also been argued, a substantial vagueness or openness of these principles of active construction on the basis of the already known and of the idea that knowledge of every type is human construction. Strike's critique is most valuable in order to incite constructivist science educators to further elaborate their ideas and to develop the constructivist view from a vague guiding set of valuable ideas toward a theory of science education. But Strike appears to ignore what has been researched in recent years (see the referring papers in the bibliography by Pfundt & Duit, 1993) that namely students' and teachers as well very often hold rather limited views of the nature of science (i.e., limited philosophy of science views; see the review by Lederman, 1992) and limited views of the learning process (i.e., meta-cognitive views; see e.g., Baird, 1988). There are further findings (e.g., Fischler, 1993) that teachers who "learned" this view, i.e., express this views in interviews, do not necessarily act according to it in classroom situations. Therefore, some caution is necessary when it is stated that these principles are widely accepted and hence simply common sense.

CONSTRUCTIVIST TEACHING AND LEARNING APPROACHES

In order to avoid misunderstandings of the term "constructivist teaching and learning approaches" it has to be pointed out from the outset that, of course, there is no "constructivist learning" but simply learning. In other words: students actively construct their own knowledge whenever they learn something -- also in settings that are not informed by constructivist ideas, i.e., even in strictly traditional settings that start from a passive reception view (Millar, 1989). Constructivist teaching and learning approaches aim at helping students to make the constructions that lead to understanding of the scientific point of view. This process is a delicate balance of students' own activity and guidance by the teacher (or by a teaching medium). Of course, it is absurd to expect that students could be able to construct science conceptions without any guidance on the basis of the already existing conceptions alone. It appears to be most valuable to view students' "self-development" and "being-developed" as complementary issues as proposed by activity theory (Wolze & Walgenbach, 1992). This would address an important aspect of the critiques mentioned above that namely constructivist approaches focus on the individual, i.e., on the issue of "self-development". Actually, science learning is also a process of enculturalisation, a process of introducing the students' into a cultural heritage that needs considerable guidance. In fact, most constructivist teaching and learning approaches include substantial guidance at some stage. In that, the above mentioned critique does not necessarily meet school practice that is informed by the constructivist view. But frequently, surprisingly little attention is given to the aspect of guidance in the rationales of the referring approaches. It seems then, that the aspect of self-development (i.e., students' own activity) is only viewed as genuinely constructivist. The guidance then is solely given the status of something that deplorably cannot be avoided. It is, therefore, necessary that constructivist teaching and learning approaches explicitly address the interplay of guidance and self-development in their rationales and instruction be designed accordingly.

		/ starting from students' conceptions
continuous	(evolutionary)	
		\ reinterpretation
discontinuous	(revolutionary)	

Figure 5: Pathways from students' conceptions towards science conceptions

There are many different pathways from students' conceptions towards the science conceptions followed in constructivist teaching and learning approaches (for a review of pathways see Scott, Asoko, & Driver, 1992; brief overviews are provided by Duit, 1987, 1991). Figure 5 presents an attempt to categorize these pathways. There is the distinction between two kinds of knowledge acquisition underlying the differentiation between continuous and discontinuous pathways, namely a gradual process of growth and attuning and a discreet process characterized by stages of growing expertise. Alluding to the distinction by Kuhn (1970) they may be also indicated by the terms evolutionary and revolutionary (Nussbaum, 1989). Among the continuous approaches there are two variants. The first is the most obvious pathway. It starts with aspects of students' pre-instructional conceptions that are already mainly in accord with science conceptions. This kernel of harmony is developed step by step. Brown and Clement's (1989) strategy of "bridging analogies" is a paradigmatic example of an approach that tries to arrange a continuous pathway. The second kind of a continuous pathway in figure 5 is called "reinterpretation" (Jung, 1986). Also here resemblances between students' pre-instructional conceptions are the starting point but in a somewhat different manner compared to the first case. It is, for instance, a well-known students' alternative conception in basic electricity that the current is used up in the bulb so that less current flows back to the battery. To deal with this conception the reinterpretation approach appears to be fruitful. Instead of students' ideas being judged wrong they are told that their way of thinking is adequate in certain respects. In fact, there is something needed in order to let the bulb shine. But what is needed is not called current in physics but energy.

Discontinuous approaches usually contain the cognitive conflict as a key element. There are several kinds of cognitive conflict. First, frequently in science instruction experiments are arranged to "show" students that something is wrong with their conceptions. Other kinds of cognitive conflict may occur between conceptions, between students' conceptions and the science conception and between different students' conceptions when the students' ideas are discussed in class, for instance. From the constructivist perspective, cognitive conflict has to be viewed with certain caution. What appears as a cognitive conflict from the teacher's point of view is not necessarily a cognitive conflict from the students' standpoint. What matters is the students' perspective. Further, even if students realize that there are differences (between their predictions and the actual result of an experiment or between ideas) they do not necessarily take them seriously. In other words, these differences are not necessarily viewed as a conflict that has to be resolved. That means it is necessary, in cognitive conflict settings, to convince students that it is important that there are different ideas or results.

Except for the continuous and discontinuous distinction there is another important differentiation between pathways. Most pathways explicitly address students' conceptions during instruction. Usually there is a stage (see e.g., the "elicitation phase" in Driver's, 1989, constructivist teaching sequence) where students' are given the chance to discuss their ideas. Walter Jung is of the opinion that it may be wiser not to elicit students' conceptions explicitly because they may be given higher status and thus be supported just by discussing them. He and his co-workers, therefore, prefer strategies that guide students to the science view without explicitly making them aware from the outset in which way their intuitive views are different from the scientific view (for an example in the area of optics see Wiesner, 1992).

As mentioned above, new teaching and learning approaches at the end of the 70s that addressed students' conceptions focused on altering students' science content conceptions by just addressing these content issues. There is an interesting development towards more "truly" constructivist approaches. These approaches very fundamentally change traditional instruction. Traditional aims of science instruction and traditional content structures as well as traditional teaching strategies and media are altered. Further, meta-cognitive issues and sometimes issues of a constructivist view of science are included.

The multiplicity of facets that are different in constructivist teaching and learning approaches makes it difficult to evaluate the success of the new approaches as compared to the old traditional ones. This is especially true because, as mentioned, also the general aims and the content oriented aims are altered. Hence there is the problem of what to base the measure of comparison on. Do the categories have to come from the old or the new approaches? Simplistic "horse race evaluation" (Aikenhead, 1992, 32) between traditional and constructivist approaches should be avoided.

Guzzetti and Glass (1992) have presented a meta-analysis of conceptual change approaches that included 70 studies investigating various intervention strategies. But only such studies were investigated that reported statistically significant differences between a particular intervention and a control group that was given more traditional treatment. It is for that reason that this meta-analysis includes only studies that mainly alter one feature of traditional instruction (e.g., investigate the impact of a new teaching strategy or a new content structure). More "truly" constructivist studies were not regarded. Nevertheless, the meta-analysis comes to an interesting conclusion regarding success of constructivist approaches:

> "Based on the accumulated evidence from two disciplines [i.e., reading and science education; R.D.], we have found that instructional interventions designed to offend the intuitive conceptions were effective in promoting conceptual change. The format of the strategy (e.g., refutational text, bridging analogies, augmented activation activities) seems irrelevant, providing the nature of the strategy includes cognitive conflict. Despite recent self-criticism of their earlier positions (Strike & Posner, 1992), the genre of instructional strategies described earlier by Strike and Posner (1985) that produces dissatisfaction with current conception and show the scientific conception as intelligible, plausible and applicable, has been effective." (Guzzetti & Glass, 1992, 42)

CONCLUDING REMARKS

The purpose of this paper was to provide data and issues that may be of help in discussing future trends and developments of research on students' conceptions. Therefore, no concise conclusions concerning future developments are presented in these concluding remarks. In fact, it is difficult to see where research will lead us in the coming years. There is no doubt that it will remain in full bloom for the next few years. But whether this will still be a full summer bloom or a final fall bloom cannot be predicted now.

From my point of view there is no doubt also that the constructivist view (whether under this label or not) will be a most powerful and influential perspective also during the next years -- if the critiques summarized above are adequately addressed. As far as I can see, the critics do not question an epistemology and hence a view of science learning with the core idea that knowledge acquisition may be conceptualized as construction. What is questioned appears to be weaknesses and one-sidenesses of the current constructivist view. Not even Suchting (1992) seems to question that there are such construction processes involved in the gain of new knowledge.

Regarding the critiques summarized above, any sort of exaggeration should be avoided. It makes no sense to throw out a healthy baby with the dirty bathwater. The constructivist view not only allows a surprisingly consistent explanation of major empirical findings concerning the significance of preconceptions in the learning process. It also facilitates predictions of outcomes of instructional settings and hence it is of invaluable help in designing new teaching and learning approaches.

I think that the further development of radical constructivism should not be a major concern of science educators. There are already very interesting and powerful pieces of a constructivist theory of science education available that do not necessarily need the philosophical backup of radical constructivism (Matthews & Davson-Galle, 1992). But it is necessary to further develop these pieces towards a more comprehensive theory of science teaching and learning. Where comprehensiveness is concerned there should be a certain "humility". An all embracing theory of science education that includes all "progressive" issues mentioned above will be too general to be of help in addressing students' learning difficulties and students' (lacking) interests adequately.

The issue of the social and the individual in its many facets should be given considerable attention. This includes also the balance between self-development and guidance. Constructivist approaches should not focus as much on the self-development side as appears to have been the case so far. It has been argued that the constructivist view has led to a more inclusive kind of conception. The interplay of conceptions on the content level on the one side and the "beyond science content conceptions" (especially meta-cognitive conceptions of the learning process and conceptions of science) on the other side should be further researched. Where the interplay of content conceptions and conceptions of science is concerned a view borrowed from activity theory may be valuable. In this theory (Wolze & Walgenbach, 1992) these two kinds of conceptions are viewed as complementary, i.e., there is a dialectial relationship between them.

Whenever science content is taught, something about conceptions of science (i.e., something of a philosophy of science nature) is also implicitly taught. Also when conceptions about science are explicitly addressed the referring content becomes more understandable to students.

Most constructivist teaching and learning approaches have not explicitly taken the constraints coming from the power structures of the school system into consideration. In other words, these approaches appear to assume that they may be performed in an area of splendid isolation from what is going on in other lessons. It is a most important issue to investigate further whether constructivist approaches fit into the existing school system and to what extent this system may be altered so that they fit into it.

Another issue that is very much affiliated with the one just mentioned refers to "bringing the message of the new constructivist science education" to teachers. There are most interesting and powerful approaches of constructivist teacher education. Furthermore, there are many attempts to inform teachers about research results on students' conceptions and on a new view of teaching and learning. But much more has to be done to make a more substantial number of science classroom "constructivist" -- whether under this label or under another.

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