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Science Education Research Internationally: Conceptions, Research Methods, Domains of Research

Reinders Duit
IPN – Leibniz - Institute for Science Education, Kiel, GERMANY

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Disappointing results of international monitoring studies such as TIMSS (Third International Mathematics and Science Study) and PISA (Programme for International Student Assessment) have fuelled another general debate on the need for a sufficient level of scientific literacy and the necessity to improve the quality of science instruction in school. Science education research has played essential roles not only in analyzing the actual state of scientific literacy and the actual practice in schools but also in improving instructional practice and teacher education. A conception of science education research that is relevant for improving school practice and teacher education programs will be presented here. This conception is based on a Model of Educational Reconstruction which holds that science subject matter issues and students' learning needs and capabilities have to be given equal attention in quality development attempts. Further, research and development activities have to be intimately linked. It is argued that science education research drawing on this framework is an indispensable prerequisite for improving instructional practice and hence for the further advancement of scientific literacy.

Keywords: Science Education, International Perspectives, Research Conceptions, Research Methods, Research Domains

MULTIPLE REFERENCE DISCIPLINES OF SCIENCE EDUCATION

Science education is a genuinely inter-disciplinary discipline. Clearly, science is a major reference discipline but there are competencies in various other disciplines which are also needed (Figure 1).

Philosophy of science and history of science provide thinking patterns to analyze the nature of science critically, and the particular contribution of science to understand the "world", i.e. nature and technology. Pedagogy and psychology provide competencies to consider whether a certain topic is worth teaching and to carry out empirical studies whether this topic may be understood by the students. There are further reference disciplines that come into play also, such as linguistics

Correspondence to: Reinders Duit, Prof. Dr.
IPN, Institut für die Pädagogik der Naturwissenschaften an der Universität Kiel, Olshausenstr,
62 D 24098 Kiel Germany,
E-mail: duit@ipn.uni-kiel.de

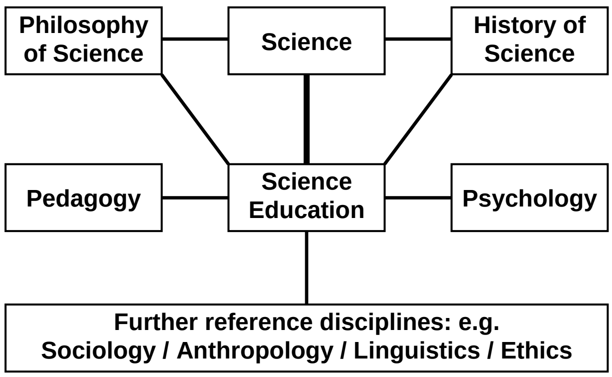

Figure 1. Reference disciplines for science education

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which may provide frameworks for analyzing classroom discourse or conceptualizing learning science as an introduction into a new language or ethics for framing instruction on moral issues.

The interdisciplinary nature of science education is responsible for the particular challenges to carry out science education research and development. Of course, sound competencies in science are necessary but also substantial competencies in a rather large set of additional disciplines. It is noteworthy that in principle, science teachers need the same broad spectrum of competencies as well. Moreover, for teachers to know science well is not sufficient to teach this subject. At least basic knowledge on the nature of science provided by philosophy of science and history of science as well as familiarity with recent views of efficient teaching and learning provided by pedagogy and psychology are necessary.

Shulman (1987) argued that teachers need a large spectrum of rather different competencies. His conception of "*content specific pedagogical knowledge*" (or briefly: PCK - Pedagogical Content Knowledge) has been widely adopted in science education (Gess-Newsome & Lederman, 1999). The idea is the following. Traditionally, in teacher education programs teachers are taught content knowledge and pedagogical knowledge. The link between the two kinds of knowledge, the content specific pedagogical knowledge, is usually missing. Shulman is of the opinion that this kind of knowledge, the PCK, is the major key to successful teaching. The conception of science education outlined in Figure 1 includes Shulman's idea of PCK. Linking competencies provided by the content domain and competencies from various other disciplines (among them especially pedagogy and psychology) is at the heart of the conception of science education discussed here.

A preliminary explication of the interdisciplinary discipline science education addressing these issues may read as follows:[1]

> *Science education is the discipline dealing with teaching and learning science in schools and outside schools. Science education research includes selection, legitimation and educational reconstruction of topics to be learned, selection and justification of general aims of teaching and learning science, as well as instructional sequencing that takes the learners' cognitive, affective and social preconditions into account. A further domain of science education work is research-based development as well as evaluation of teaching and learning approaches and materials.*

Clearly, the focus of this explication is research on actual teaching and learning situations. However, research on the various contexts in which the teaching and learning situation is embedded should also be included as will be more fully argued in a subsequent section.

TRADITIONS OF SCIENCE EDUCATION RESEARCH AND DEVELOPMENT

In a recent review of science education research, Jenkins (2001) distinguishes two different traditions in research within the past thirty years; he calls them *pedagogical* and *empirical*. "*The pedagogical tradition has, at its primary focus, the direct improvement of practice, practice here being understood as the teaching of science*" (p. 20). "*The empirical tradition, always much more evident in the USA than in Europe, has weakened considerably in the last thirty years. It is associated with positivism and seeks the 'objective data' needed to understand and influence an assumed educational reality, close familiarity with which lies at the heart of the pedagogical tradition*" (p. 21). Using chemistry education as his example Jenkins claims that the followers of the pedagogic tradition are those that teach chemistry in schools, colleges and universities, and who publish in journals like *Education in Chemistry* or *Journal of Chemical Education*. These researchers remain close to the academic discipline of chemistry and many of them "*would strongly resist any attempt to classify them as social, rather than natural, scientists*" (p. 21).

There is no doubt that this is a valuable distinction that indicates main "schools" of science education as a research discipline. It appears however that somewhat different emphases of the two schools' characteristics are necessary. Clearly, on the one side, there is a group of science education researchers who are close to the particular science domain. Their attention is not only near to teaching practice but they also put main emphasis on science content issues in designing new teaching and learning sequences. Sadly enough, however, quite frequently a balance between science orientation and orientation on the students' needs, interests and learning processes is missing. Further, research (especially empirical research on teaching and learning) and development are often badly integrated. On the other side, we find an emphasis on the students' needs in various respects and a strong emphasis on improvement of learning environments often accompanied by a neglect of science subject matter issues. A significant number of conceptual change approaches (Schnotz, Vosniadou, & Carretero, 1999) seem to fall into this category. One could summarize the distinction of the two traditions discussed by calling the one *science-oriented*, the other *student-oriented*. Progress in understanding and learning science appears only possible if there is a balance between the two perspectives. Successful design of science teaching and learning sequences needs to merge the two positions.

[1] This explication is based on a statement by a German association for content specific education (KVFF, 1998, 13f).

Peter Fensham (2001) who is well known for his contributions to a student-oriented science education (Fensham, 2000) points to the necessity of research on teaching and learning to rethink science content, to view it also as problematic[2] (and not only the way the content is taught) and to reconstruct it from educational perspectives. His considerations are integrated into a discussion on the continental European Didaktik tradition versus the Curriculum tradition (Hopmann & Riquarts, 1995). Whereas the curriculum tradition has a certain focus on Jenkins' (2001) *empirical* side and on what has been called *student orientation* above the Didaktik tradition tries to bring key features of the science-oriented and student-oriented sides into balance.

Also Dahncke, Duit, Gilbert, Östman, Psillos and Pushkin (2001) argue in favour of such an integrated view. They claim that the science education community so far has been split into the above two groups and that there are considerable clashes between the groups that even seriously hamper the progress that is so much needed. It is also pointed out that there are clashes between science education and the educational sciences, pedagogy and psychology, and between science education and school practice. They argue in favor of emancipation of science education from both the science reference domains *and* the educational sciences with a particular focus on improving school practice. Science education should be seen as an interdisciplinary research domain in its own right as outlined here in Figure 1.

Psillos (2001) also points to the significance of this conception of science education. He distinguishes three "modes" of research. The *practical* mode denoting issues of the actual classroom, the *technological* mode addressing policy makers' attempts to improve science education, and finally the *scientific* mode representing science education as a research domain in its own right. He argues "*that it is necessary to link the major concerns of all three modes in order to meet the various difficulties of improving science teaching and learning*" (Psillos, 2001, 11).

It is common sense among science educators that improving practice is the primary aim of science education research. However, Millar (2003) is of the opinion, drawing also on arguments by Jenkins (2001), that much research is restricted to "what works in practice". He claims: "*The role of research is not only to tell us 'what works'. Some of the most valuable research studies have been ones that made people aware of problems in current practices. Research can inform practice in a range of ways that stop short of providing clear and definite answers: by providing the kinds of insights that enable us to see the familiar in a new way, by sharpening thinking, by directing attention to important issues, by clarifying problems, challenging established views, encouraging debate and stimulating curiosity*" (Millar, 2003, 7-8).

The conception of science education research outlined in the subsequent sections draws on such a more inclusive idea of improving practice.

THE MODEL OF EDUCATIONAL RECONSTRUCTION

The Model of Educational Reconstruction (Duit, Gropengießer, & Kattmann, 2005) presented in Figure 2 may provide a deeper insight into the interdisciplinary nature of science education research as has been outlined so far. The model has been developed as a theoretical framework for studies as to whether it is worthwhile and possible to teach particular areas of science. It draws on the need to bring science content related issues and educational issues into balance when teaching and learning sequences are designed that aim at the improvement of understanding science and hence may foster the development of sufficient levels of scientific literacy.[3] The model can also be used to structure teacher education attempts as teachers may also be viewed as learners. Furthermore, it provides a framework for the conception of science education research outlined above.

The model is based on the German educational tradition of "Bildung" and "Didaktik" (Westbury, Hopmann, & Riquarts, 2000). Both terms are difficult to translate into English properly. A literal translation of *Bildung* is formation. In fact *Bildung* is viewed as a process. *Bildung* stands for the formation of the learner as a whole person, i.e. for the development of the personality of the learner. The meaning of *Didaktik*[4] is based on the conception of *Bildung*. It concerns the analytical process of transposing (or transforming) human knowledge (the cultural heritage) like domain specific knowledge into knowledge for schooling which contributes to the above formation (*Bildung*) of young people. Briefly put, the content structure of a certain domain (e.g. physics) has to be transformed into a

[2] s. also Fensham, Gunstone, and White (1994)

[3] The Model of Educational Reconstruction has been developed in close cooperation of Ulrich Kattman (University of Oldenburg), Harald Gropengießer (University of Hannover) as well as Reinders Duit and Michael Komorek (IPN Kiel) (Kattmann, Duit, Gropengießer, & Komorek, 1995). A brief overview of the model is presented by Duit, Kattmann and Gropengießer (2005). The model has been the frame of various projects at the IPN in Kiel, e.g. on the educational reconstruction of non-linear systems (Komorek & Duit, 2004). At the University of Oldenburg the model serves as theoretical framework of a science education graduate student program: http://www.diz.uni-oldenburg.de/forschung/ProDid/Prodid-Programm-E.htm.

[4] It is essential to take into consideration that the word "didactic" if used in educational concerns in English has a much more narrow meaning than the German "Didaktik". Didactic (or didactical) merely denotes issues of educational technology.

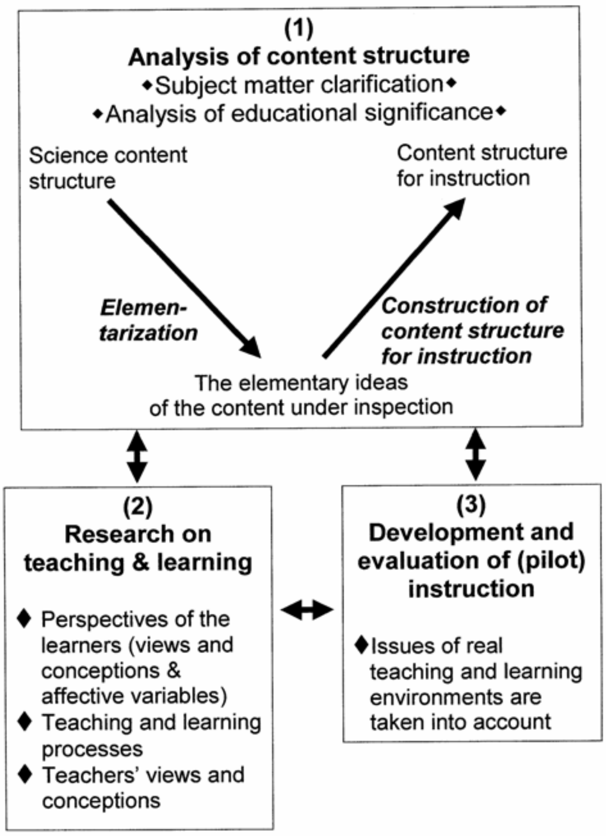

Figure 2. The Model of Educational Reconstruction

content structure *for* instruction. The two structures are substantially different. The science content structure for a certain topic (like the force concept) may not be directly transferred into the content structure for instruction. It has not only to be simplified (in order to make it accessible for students) but also enriched by putting it into contexts that make sense for the learners. Two phases of this process may be differentiated. The first may be called "elementarization". On the basis of this set of elementary ideas the content structure for instruction is constructed. It is a key claim of the *Didaktik* tradition that both processes "elementarization" and "construction of the content structure for instruction" are intimately interrelated to decisions on the aims of teaching the content and the students' cognitive and affective perspectives (Figure 2). These perspectives include students' pre-instructional conceptions and their general cognitive abilities on the one hand and their interests, self-concepts and their attitudes on the other.

Key features of the German *Didaktik* tradition that have been adopted in the Model of Educational Reconstruction will be briefly outlined in the following. A major reference position is the "Educational Analysis" (*Didaktische Analyse*) by Klafki (1969). His ideas rest upon the principle of primateship of the aims and intentions of instruction. They are framing the educational analysis – as is also the case in the model presented in Figure 2. At the heart of the educational analysis are the five questions presented in Table 1. They also play a significant role in our model.

Another significant figure of thought within the German *Didaktik* tradition adopted in the Model of Educational Reconstruction is the idea of a fundamental interplay of all variables determining instruction presented in Figure 3.

The Model of Educational Reconstruction is embedded within a constructivist epistemological framework (Philips, 2000; Duit & Treagust, 1998, 2003; Widodo, 2004). There are two key facets of this epistemological orientation. First, learning is viewed as students constructing their own knowledge on the grounds of the already existing knowledge. The conceptions and beliefs students bring into instruction are not seen primarily as obstacles of learning but as points of departure for guiding them to the science knowledge to be achieved (Driver, & Easley, 1978). Second, also science knowledge is seen as human construction (Abd-El-Khalick, & Lederman, 2000). We presume that there is no "true" content structure of a particular content area. What is commonly called the science content structure (e.g. in Figure 2) is seen as the consensus of a particular science community. Every presentation of this consensus in the leading textbooks, is an idiosyncratic reconstruction of the authors informed by the specific aims they explicitly or implicitly hold (Kattmann, Duit, Gropengießer, & Komorek, 1995). Consequently, also the science content structure for instruction (Figure 2) is not simply "given" by the science content structure. It has to be constructed by the curriculum designer or the teacher on the grounds of the aims affiliated with teaching the particular content. In other words, the science content structure has to be reconstructed from educational perspectives. That is the very essence of the term "educational reconstruction".

Many teachers and also science educators think that the content structure for instruction has to be "simpler" than the science content structure in order to meet students' understanding. Accordingly, they call the process of designing the content structure for instruction "reduction". However, this view misses the point. In a way the content structure for instruction has to be much more complex than the science content structure in order to meet the needs of the learners. It is, namely, necessary to embed the abstract science knowledge into various contexts in order to address learning potentialities and difficulties of the learners.

Table 1. Key questions of Klafki's (1969) Educational Analysis (Didaktische Analyse)

(1) What is the more general idea that is represented by the content of interest? What basic phenomena or basic principles, what general laws, criteria, methods, techniques or attitudes may be addressed in an exemplary way by dealing with the content?
(2) What is the significance of the referring content or the experiences, knowledge, abilities, and skills to be achieved by dealing with the content in students' actual intellectual life? What is the significance the content should have from a pedagogical point of view?
(3) What is the significance of the content for students' future life?
(4) What is the structure of the content if viewed from the pedagogical perspectives outlined in questions 1 to 3?
(5) What are particular cases, phenomena, situations, experiments that allow making the structure of the referring content interesting, worth questioning, accessible, and understandable for the students?

<table>
<tr><td>Intentions
(aims and objectives)</td><td>Topic of instruction
(content)</td><td>Methods
of instruction</td><td>Media
used in instruction</td></tr>
<tr><td>Why</td><td>What</td><td>How</td><td>By What</td></tr>
<tr><td colspan="2">Students' intellectual and attitudinal preconditions
(e.g., pre-instructional conceptions, state of general thinking processes, interests and attitudes)</td><td colspan="2">Students' socio-cultural preconditions
(e.g., norms of society, influence of society and life on the student)</td></tr>
</table>

Figure 3. On the fundamental interplay of instructional variables (Heimann, Otto & Schulz, 1969)

There are three intimately linked components of the Model of Educational Reconstruction (Figure 2).

(1) Analysis of content structure[5] includes two processes which are closely linked, *clarification of subject matter* and the *analysis of educational significance*. Clarification of subject matter draws on content analyses of leading textbooks and key publications on the topic under inspection but also may take into account its historical development. Interestingly, also taking students' pre-instructional conceptions into account that have often proven not to be in accordance with the science concepts to be learned (Driver, & Erickson, 1983) contribute to more properly understanding the science content in the process of subject matter clarification. Experiences show that the surprising and seemingly "strange" conceptions students own may provide a new view of science content and hence allows another, deeper, understanding (Kattmann, 2001; Duit, Komorek, & Wilbers, 1997). Traditionally, science content primarily denotes science concepts and principles. However, recent views of scientific literacy (Bybee, 1997) claim that also science processes, views of the nature of science and views of the relevance of science in daily life and society should be given substantial attention in science instruction (Osborne, Ratcliffe, Millar, & Duschl, 2003; McComas, 1998). All these "additional" issues also need to be included in the process of educational reconstruction.

(2) Research on teaching and learning comprise empirical studies on various features of the particular learning setting. Research on students' perspectives including their pre-instructional conceptions and affective variables like interests, self-concepts and attitudes play a particular role in the process of educational reconstruction. But many more studies on teaching and learning processes and the particular role of instructional methods, experiments and other instructional tools are also available. Furthermore, research on teachers' views and conceptions of the science content and students learning are an essential part.

(3) Development and evaluation of instruction concerns the design of instructional materials, learning activities, and teaching and learning sequences. The design of learning supporting environments is at the heart of this component. The design is, first of all, structured by the specific needs and learning capabilities of the students to achieve the goals set. Various empirical methods are employed to evaluate the materials and activities designed, such as interviews with students and teachers, e.g. on their views of the value of the designed items, questionnaires on the development of students' cognitive and affective variables, and also analyses of video-documented instructional practice. Development of instructional materials and activities as well as research on various issues of teaching and learning science are intimately linked (Duit, & Komorek, 2004).

[5] It may be worthwhile to briefly explain the term "content structure". Content denotes science subject matter, structure points to the significance of the internal structure of the content.

The Model of Educational Reconstruction presented here shares major features with other recent models of instructional design that aim at improving practice. First of all, the cyclical process of educational reconstruction, i.e. the process of theoretical reflection, conceptual analysis, small scale curriculum development, and classroom research on the interaction of teaching and learning processes is also a key concern of the conception of "*developmental research*" presented by Lijnse (1995).

In the field of educational psychology there has been an intensive discussion on whether results of research on teaching and learning are suited to improve instructional practice. Kaestle (1993) published an article with the title "*The awful reputation of educational research*". Wright (1993) asked a similar question, namely "*The irrelevancy of science education research: perception or reality?*" The major argument in both cases was that the particular culture of educational research or science education research, respectively, dominating in the scientific communities is responsible for research results that are not relevant for improving instruction. An intensive discussion as a reaction to these statements substantially contributed to a turn from pure towards applied educational research (Gibbons et. al., 1994; Vosniadou, 1996; Cobb, Confrey, di Sessa, Lehrer, & Schauble, 2003). It has been argued that "*Design Research*" (Cobb et al., 2003) is needed to bridge the gap between research on teaching and learning and instructional practice. Design Research intimately links research and development and also explicitly takes instructional practice into account – in much the same way as the Model of Educational Reconstruction.

This model has not only proven to be a fruitful framework for instructional planning and design but also for teacher professional development. Issues comprising "thinking within the framework of the model" are also seen as essential in attempts to improve teachers' thinking and acting in class (West & Staub, 2003; Kattmann, 2004; Duit, Komorek, & Müller, 2004).

DOMAINS OF SCIENCE EDUCATION RESEARCH

The Model of Educational Reconstruction presented in the previous section allows the identification of three major domains of science education research.

(1) Analysis of Content Structure

There are two processes closely linked, namely *subject matter clarification* and *analysis of educational significance*. It has to be taken into account that content is used here in a more inclusive way as it is usually the case. Not only science concepts and principles but also science processes, views of the nature of science, and views of the relevance of science for society are seen as essential parts of science content.

Research methods for subject matter clarification (concerning the above set of content issues) are analytical (or hermeneutical) in nature, and certain methods of content and text analyses prevail. History and philosophy of science issues come into play here.
Analysis of educational significance will also be analytical in nature, i.e. drawing on certain pedagogical norms and goals. However, in projects on educational reconstruction of large domains empirical studies on the educational significance may be also empirical, e.g. by employing questionnaires to investigate the views of experts (cf. Komorek, Wendorf, & Duit, 2003) or variants of Delphi studies (Osborne, Ratcliffe, Millar, & Duschl, 2003).

(2) Research on Teaching and Learning

This is by far the largest research domain in science education. Most studies published in the leading international journals of science education fall into this domain. Major issues researched are: (a) *student learning* (students' pre-instructional conceptions, representations and beliefs, conceptual change; problem solving; affective issues of learning, like attitudes, motivation, interests, self-concepts; gender differences); (b) *teaching* (teaching strategies; classroom situations and social interactions; language and discourse); (c) *teachers' thinking and acting* (teachers' conceptions of science concepts and principles, science processes, the nature of science; their views of the teaching and learning process; teacher professional development); (d) *instructional media and methods* (lab work; multi-media; various further media and methods); (e) *student assessment* (methods to monitor students' achievement and the development of affective variables).

A large spectrum of methods of empirical research are employed ranging from qualitative to quantitative nature, including questionnaires, interviews and learning process studies. Drawing on methods developed in social sciences (like psychology) and close cooperation with social scientists in developing methods that address science education research needs has proven essential.

Various epistemological perspectives have been used with variants of constructivist views (Tobin, 1993; Steffe & Gale, 1995; Duit & Treagust, 1998; Phillips, 2000;) predominating. But also Piagetian views have played significant roles (Bliss, 1995). More recently, variants of social cultural views drawing, e.g., on Vygotsky (Leach & Scott, 2002) or activity theory (Roth, Tobin, Zimmermann, Bryant, & Davis, 2002) have gained considerable attention.

(3) Development and Evaluation of Instruction/ Instructional Design

As mentioned in the above section on traditions of science education research and development, there are still science education development activities that are not well based on research. It appears that much development work still does not take notice of research findings. The position underlying the Model of Educational Reconstruction points to three significant issues. First, development needs to be fundamentally research based and needs serious evaluation employing empirical research methods. Second, development should be viewed also as an opportunity for research studies to be included. Third, improving practice is likely only if development and research are closely linked.

(4) Research on Curricular Issues and Science Education Policies

The Model of Educational Reconstruction provides a framework for instructional design. Basically, features of the teaching and learning situation are addressed. The wider context of the learning environment, however, is not explicitly taken into account. Therefore, a further domain of science education research has to be added.

This domain concerns features of the educational system in which science instruction is embedded. Research here concerns decisions on the curriculum, on aims and contents of science instruction as well as on implementation, evaluation and dissemination of innovations introduced into the school system. Research on scientific literacy, standards, systemic reforms (quality development) and teacher professional development have become much researched sub-domains in science education the past years. Also international monitoring studies like TIMSS (Third International Science and Mathematics Study; Beaton et al., 1996) and PISA (Programme for International Student Assessment; OECD-PISA, 2005) have to be mentioned here. On the one hand, they provide a large set of data that have been also interpreted from science education perspectives. On the other hand these studies have revealed serious deficits of science instruction in many countries and incited various large scale attempts worldwide to improve science teaching and learning (Beeth, et al., 2003) as also outlined in Figure 4.

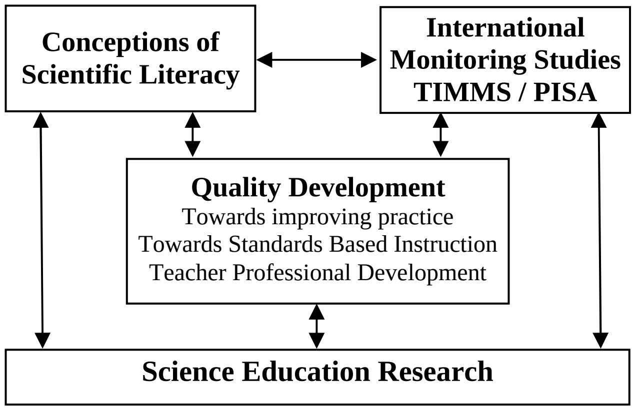

Figure 4. Present large scale attempts to improve science instructional practice

Figure 4 also displays that science education research is one of many "players" in attempts to improve science instruction. A close cooperation with the other players is absolutely essential. This also concerns cooperation with the reference disciplines pedagogy and psychology in Figure 1. To carry out science education research not only requires drawing on theoretical frameworks and research methods of these reference domains but it also has proven rather fruitful to carry out joint research projects where mutual interests exist. Research on teaching and learning a particular content, for instance, may only foster improvement of practice if the above content specific considerations are taken into account – that also holds for research carried out by educational psychology.

MAJOR FOCUSES OF SCIENCE EDUCATION RESEARCH

It is beyond the scope of the present paper to provide a fine grained picture of the research domains and sub-domains that have been given major emphases. As mentioned above, research on teaching and learning has been given major emphases in science education research for a long time. Students' learning was in the focus in the 1980s, later various issues of teachers' conceptions were also taken into account (Duit, & Treagust, 1998). In the 1980s students' learning of concepts and principles was given by far the most attention. It was only in the 1990s when views of the nature of science really developed to become a significant field of research (McComas, 1998). Constructivist views of teaching and learning have developed towards the dominant epistemological foundation of research on teaching and learning – with certain variants of "radical constructivism" at the outset and more inclusive views of "social constructivist" perspectives later (Duit, & Treagust, 1998).

In general, science education research has developed substantially in the past decades (cf. White, 2001). Science education has grown to a truly international community with the number of researchers still increasing. Interestingly, the percentage of female researchers has also increased substantially (White, 2001, 465). The number of journals is still rising, the number of issues per year of the journal has grown also substantially[6], the same is true for the number of international conferences and books. As a result, it has become rather difficult to maintain an overview of research domains and emphases. It appears, however, that major emphases are now on improving practice, i.e. on the development of powerful teaching and learning environments and teacher professional development as displayed in Figure 4. More recently available video-based studies on actual instructional practice, i.e. on the interplay of teaching and learning processes have provided powerful empirical foundations for both quality development of instruction and teacher professional development (Stigler, Gonzales, Kawanaka, Knoll, & Serrano, 1999; Roth et al., 2001; Duit et al., 2005). Anderson and Helms (2001) claim that more studies on the actual teaching and learning practice are urgently needed.

This claim is in accordance with the above argument that in order to improve practice, research should not be restricted to studies on what works in practice (Millar, 2003) but should include studies on the actual state of instructional practice that may inform policy makers, curriculum developers and instructional design of more efficient instructional approaches. It appears that the more recent developments outlined allow us to address this issue.

CONCEPTIONS OF SCIENCE EDUCATION RESEARCH

"*As a research domain science education is diverse, methodologically, conceptually and institutionally*"(Jenkins, 2001, 22). The above sections have shown the rich variety of conceptions in the field. In the following major attempts to review the field are briefly discussed. A particular issue will be to point out in which respects the conceptions differ from the conception developed on the grounds of the Model of Educational Reconstruction presented.

The state of the art is marked by handbooks on science education. The "*Handbook of Research on Science Teaching and Learning*" edited by Gabel (1996) and the "*International Handbook of Science Education*" edited by Fraser and Tobin (1998) appeared in the 1990s. Whereas the focus of the handbook by Gabel is research in North America, the handbook by Fraser and Tobin provides a wider international perspective. Interestingly, in both handbooks a conception of science education research is not explicitly developed. The choice of the domains presented in the chapters of the handbooks is justified on pragmatic grounds by claiming that the structure resulted from a brainstorming of the members of the editorial board (Gabel, 1996, ix) or from a consensus of the editors (Fraser & Tobin, 1998).

Jenkins (2001, 23-24), as already mentioned above, is of the opinion that "*the subsequent chapters of the Handbook* (by Fraser and Tobin), *despite their diversity, seem to assume that science education as a field of activity is exclusively concerned with practice of teaching and learning, together with supporting activities such as assessment, evaluation and teacher education. Correspondingly, research in science education is about improving practice, whether this relates to promoting greater equity, making more effective use of educational technology or developing more informative instruments for formative, diagnostic or summative evaluation. This is a view of research in science education with a long history and it is one that is strongly influenced by the empirical tradition that has dominated science education in the USA throughout the twentieth century*".

It appears that this appraisal also holds for the handbook edited by Gabel (1995). At least in both handbooks the major emphasis is on "what works" (in the above sense of Millar, 2003). Other means of improving practice that are addressed in the conception presented here (e.g. in figure 4) are given less attention. The conceptions of the two handbooks differ in another respect from the conception presented here. Issues of research indicated by "Analysis of content structure" above at best play a marginal role in the chapters of the handbooks. The recent "*Handbook of Research on Science Education*" edited by Abell and Lederman (2007a) provides an international perspective of the actual state of research. However, authors from various countries were asked not only to provide a review of what was done in the particular field they are analyzing but also to present a view of major issues that would need further research in future. There are five major sections and 40 chapters in total. Figure 5 provides an overview of the contents of the chapters of this handbook and hence allows a view at the emphases of actual science education research as seen by the editors. The introductory chapter (Abell & Lederman, 2007b) outlines a conception of science education research that appears to be close to the conception presented here on the grounds of the Model of Educational Reconstruction. Drawing on the above mentioned PCK position of Shulman (1987) subject matter issues and pedagogical issues are, for instance, given equal attention. Further, a major concern is improving practice in the above wider sense demanded by Millar (2003). They explicitly claim that the handbook is written for researchers but that it is the duty of the researchers to interpret and transform its contents for other stakeholders, among them teachers.

[6] White (2001, 463) provides data that also the length of articles in the leading journals has increased substantially (from about 7 pages in 1975 to about 15 pages in 1995) due to a change of style of research from experimental towards descriptive studies. Accordingly, the increase of the number of studies published in the journals is only small (about 10%).

Science Learning

- Perspectives of science learning
- Student conceptions and conceptual learning in science
- Language and science learning
- Attitudinal and motivational constructs in science learning
- Classroom learning environments
- Learning science outside of schools

Culture, Gender, Society, and Science Learning

- Science education and student diversity: Race/ethnicity, language, culture, socioeconomic status
- Postcolonialism, indigenous students, and science
- Issues in science learning: An international perspective
- Special needs and talents in science learning
- Gender issues in science education research
- Science learning in urban and rural settings

Science Teaching

- General instructional methods and strategies
- Science laboratories
- Discourse in science classrooms
- Technology and Science classroom inquiry
- Elementary science teaching
- Interdisciplinary science teaching
- Biology / Chemistry / Physics / Earth Science Teaching
- Environmental education

Curriculum and Assessment in Science

- Science Literacy
- History of curriculum reform in science education
- Scientific inquiry and the science curriculum
- Research on the nature of science
- Perspectives in the science curriculum
- Systemic reform in science education
- Science program evaluation
- Classroom assessment of science learning
- Large scale assessment in science education

Science Teacher Education

- Science teacher as learner
- Science teacher attitudes and beliefs
- Research on science teacher knowledge
- Learning to teach science
- Teacher professional development in science
- Science teachers as researchers

Figure 5. Sections and chapters of the "Handbook of Science Education Research" edited by Abell and Lederman (2007a)

As part of the "Handbook on Teaching" edited by the American Educational Research Association (AERA) White (2001) provides a review of the development of science education as a research field in its own right during the past three decades. He points to major changes of research emphases with a particular focus on the "style" of research carried out. Style includes features of epistemological perspectives of teaching and learning and research methods employed. White (2001, 465) claims that *"at the beginning of this period* (1975)*, most studies of teaching were evaluations of predetermined method, developed and controlled by the researcher. Often the method of interest to the researcher was termed "experimental" and was compared with another less favored methods, which was then termed "control". Each was taken to be representative of a class of similar methods. Researchers intended that teachers and curriculum designers would note their conclusions about the methods and apply them. Largely, they were disappointed. Eventually, this disappointment spurred the revolution. Researchers realized that for their studies to influence practice they must take account of the complex nature of teaching and learning. They turned to describing the complexity in order to understand it before trying to manage it"*. Hence, White argues that explicating the complexity of teaching and learning in descriptive manner has become the major research method in science education. But he also points out that this explication is incomplete as education is interventionist, i.e. needs to discover how to intervene effectively. Therefore, *"the next phase of the revolution could see the return of experiments in a more subtle and complex character than those of the earlier period"* (White, 2001, 467). It appears that this kind of research is a major concern of the present large scale attempts to improve science instruction practice outlined in Figure 4 above. An interesting figure of thought is White's (2001, 467) claim for research on research. He argues that it is essential to know the long-term influences of research on curricula, the nature of texts, teaching methods, and also in which way teachers value the role of research for their practice.

Conceptions of science education research from a different vantage point are discussed by Fensham (2004). Based on interviews with about 75 science educators from around the world he provides an overview of the development of the actual rich variety of conceptions for science education research.

His analysis includes the following three perspectives: (1) the identity of science education as a research field, (2) the researcher as person, and (3) trends in research. He also developed a set of categories to interpret the interviews with researchers on the background of a review of the development of science education research during the past decades. These categories (Figure 6) are explicitly justified on the idea of science education as an interdisciplinary field of research as presented by Dahncke et al. (2001) who draw on the conception outlined in Figure 1 above. It is interesting that the only outcome criteria are implications for practice which is also in line with the emphasis of the conception of science education research presented here. As the intention of Fensham's analyses is to investigate the variety of the different conceptions within the research community it is difficult to briefly summarize major features displayed in the book here.

Structural Criteria
- S1: Academic recognition
- S2: Research journals
- S3: Professional associations
- S4: Research conferences

Intra-Research Criteria
- R1: Scientific knowledge
- R2: Asking questions
- R3: Conceptual and theoretical development
- R4: Research methodologies
- R5: Progression
- R6: Model publications
- R7: Seminal publications

Outcome Criteria
- O1: Implications for practice

Figure 6. Criteria for analyzing science education as a research field (Fensham, 2004)

An overview explicitly based on a close cooperation between science educators and cognitive psychologists is the "Framework for Empirical Research on Science Teaching and Learning" in a review article by Fischer, et al. (2005). The review is based on a "Framework Model of the Analysis of Students Performance" developed by Baumert et al. (2002) for the purpose of interpreting the results of the international monitoring study PISA. This model includes issues on the actual teaching and learning situation but also the influence of variables from contexts in which teaching and learning in schools is embedded. Another major framework is the "Basis-Model" theory of Oser and Patry (1994). According to this theory teachers use a limited number of basis models (such as: learning by experience; conceptual change; problem solving; top-down learning; learning to negotiate). Hence this model may be used to describe teachers' classroom behavior adequately. Of course, a comprehensive overview may not be provided in a single review article. However, valuable insights may be gained, especially from issues (like integration and sequencing of content) that are usually not addressed in the handbooks. Concerning the significance of content issues, Fischer et al. (2005, 334) come to the conclusion that purely content driven approaches do not lead to improving instructional practice. This finding may be seen as a support of the assumption of the Model of Educational Reconstruction and hence of the conception of science education research presented here that content issues and educational issues have to be carefully linked.

Finally, the actual state of empirical research on teaching and learning science with a particular emphases on research oriented towards constructivist perspectives is provided by the bibliography STCSE (Students' and Teachers' Conceptions and Science Education; Duit 2006).

SUMMARY

A conception of science education research that is relevant for improving instructional practice has been presented in the previous sections. It turned out that science education research with this aim needs to draw on a rather large spectrum of competencies from various disciplines and demands to bring content issues and issues concerning learning this content into balance. The Model of Educational Reconstruction discussed provides a frame for research that allows us to address the aim of improving practice. Various facets comprise science education with this orientation. Four major domains of science education research are distinguished:

- *Analysis of content structure*
- *Research on teaching and learning*
- *Development and evaluation of instruction / Instructional design*
- *Research on curricular issues and science education policies*

Duit and Tiberghien (2005) suggested a (preliminary) set of key issues of science education research that may provide an additional overview of the various facets to be taken into account in science education research:

1. *Conceptions of science education as a research domain*
2. *Epistemological and ontological views of science*
3. *Epistemological views of teaching and learning science*
4. *Research methods*
5. *Aims of science instruction / Legitimisation*
6. *Gender and equity issues*
7. *Content of science instruction*
8. *Teaching and learning science*
9. *Teacher professional development*
10. *Assessment and evaluation*
11. *Instructional design*
12. *Curricular issues and science education policies*

These 12 issues provide a framework both for planning research in science education and for analysing research presented in the literature. As more fully discussed above, science education as an academic discipline should be characterized by the following facets:

- Scien*ce education is an interdisciplinary discipline (Figure 1) aiming at improving teaching and learning in various practices.*
- *In order to actually facilitate improving practice, research should not be restricted on investigating what works but should also include studies on the major problems and deficits of normal instructional practice.*
- *Science educators need multiple competencies in science and in a substantially large number of reference disciplines (Figure 1).*
- *Science education research has to link science subject matter issues as well as pedagogical and psychological issues.*
- *Research and development are closely linked and are embedded within an elaborated curricular context. Major emphasis is applied research, e.g. in the sense of design research.*

Science education research oriented towards theses characteristics provides prerequisites for actually improving instructional practice. However, an additional issue has to be given serious attention. Improvement of teacher competencies and quality of instruction is always due to an intimate interplay of many variables. Improvement of student achievement may, for instance, not be expected if chiefly one variable is changed, e.g. new experiments or computer simulations are introduced. Such simple actions usually do not work.

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