The Model of Educational Reconstruction – a framework for improving teaching and learning science

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2. THE MODEL OF EDUCATIONAL RECONSTRUCTION – A FRAMEWORK FOR IMPROVING TEACHING AND LEARNING SCIENCE[1]

OVERVIEW

To improve instructional practices – in schools, universities and in out of school settings has been a major concern of science education research and development. The intensive international debate on *scientific literacy* in the 1990s and the series of international monitoring studies like TIMSS and PISA in the 1990s and in the 2000s have fuelled this debate substantially. Various strands of science education research contribute to the stock of knowledge on more efficient means of teaching and learning science. The Model of Educational Reconstruction (MER) presented in this chapter provides a conception of science education research that is relevant for improving instructional practice and teacher professional development programs. The model is based on European Didaktik and Bildung (formation) traditions – with a particular emphasis on the German tradition. A key concern of the model is that science subject matter issues as well as student learning needs and capabilities have to be given equal attention in attempts to improve the quality of teaching and learning. There are three major emphases that are intimately connected:

(1) The clarification and analysis of science subject matter (including key science concepts and principles like evolution, energy, particles, or combustion, and science processes and views of the nature of science, as well as the significance of science in various out of school contexts).
(2) The investigation into student and teacher perspectives regarding the chosen subject (including pre-instructional conceptions, affective variables like interests, self-concepts, attitudes, and skills).
(3) The design and evaluation of learning environments (e.g. instructional materials, learning activities, teaching and learning sequences).

The first emphasis comprises analyses of subject matter from science *and* educational perspectives. Research and development activities are closely linked.

Doris Jorde and Justin Dillon (Eds.), Science Education Research and Practice in Europe: Retrospective and Prospective, 13–37.

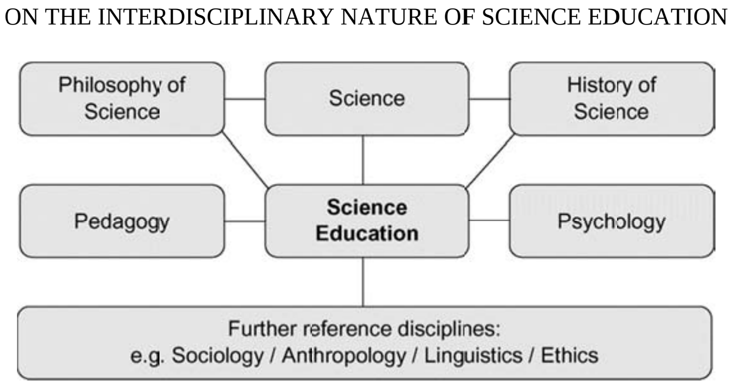

Figure 1. Reference disciplines for Science Education (Duit, 2007).

There are several *reference disciplines* that are needed to meet the challenges of investigating and analysing key issues of teaching and learning science. Philosophy and history of science provide thinking patterns to critically analyze the *nature of science* (McComas, 1998; Lederman, 2008), and the particular contribution of science to understand the "world", i.e. nature and technology (Bybee, 1997; de Boer, 2000). Accordingly, these disciplines allow us to discuss what is special in science (as compared to other disciplines) and therefore what is special in teaching and learning science. 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 also come into play, such as linguistics which may provide frameworks for analysing 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 particular challenges for carrying out science education research and development. Not only sound competencies in science are necessary but also substantial competencies in various additional disciplines. In principle the same set of competencies – though with different emphases – has also to be expected from teachers. To know science well is not sufficient for them. At least some basic insight into the nature of science provided by the philosophy and history of science and familiarity with recent views of teaching and learning science provided by pedagogy and psychology are needed.

Shulman (1987) introduced the idea of *content specific pedagogical knowledge* (briefly: PCK – Pedagogical Content Knowledge). It has been widely adopted in science education (Gess-Newsome & Lederman, 1999; van Dijk & Kattmann, 2007). The key idea is the following. There is a close link between content knowledge and pedagogical knowledge which in traditional approaches is often disregarded. Shulman (1987) holds that the PCK linking the two kinds of knowledge is the major key to successful teaching. The conception of science education outlined in Figure 1 includes Shulman's idea of PCK (for an elaborate analysis, see van Dijk & Kattmann, 2007).

TRADITIONS OF SCIENCE EDUCATION RESEARCH[2]

Dahnke et al. (2001) argued that there is a split in the science education community. On the one side the major focus is on science. Research work in this group is usually restricted to issues of subject matter knowledge or presentation techniques – neglecting the way in which the ideas discussed may be learned by the students. On the other hand, there are science educators who try to find a balance between the mother discipline and educational issues. This is the position depicted in Figure 1. Jenkins (2001) provided another distinction. His *pedagogical* tradition aims at improving practice. He claims that the followers of this tradition remain close to the academic science disciplines. The major concern of his *empirical* tradition is acquiring "objective data" that are needed to understand and influence educational practice.

Clearly, there is a substantial degree of commonality of Jenkins' (2001) distinction and the previous view of Dahnke et al. (2001). This distinction may be seen in terms of differentiating *applied* and *basic* research. It was argued in science education (Wright, 1993) and in research on teaching and learning in general (Kaestle, 1993) that basic research in education is viewed as irrelevant by practitioners. Still there is an intensive debate on overcoming the gap between theory and practice (Luft, 2009). Hence, a fine-tuned balance between the two positions is needed in research that aims at improving practice (Gibbons et al., 1994; Vosniadou, 1996). The most prominent positions merging the above applied and basic research positions seem to be variants of *Design Based Research* (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Sandoval & Bell, 2004; Tibergien, Vince, & Gaidioz, 2009). As will be outlined more fully below the model of educational reconstruction presented here is also based on merging the applied and basic research side.

The two traditions briefly outlined above may be characterised in the following way. 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 the main emphasis on science content in designing new teaching and learning sequences. Frequently, a balance between science orientation and orientation on student needs, interests, ideas and learning processes is missing. On the other side, the group focussing on empirical research on teaching and learning often orients itself on general education and the psychology of learning barely considering the domain and context specific perspectives of the science topic. A significant number of conceptual change approaches (Vosniadou, 2008; Treagust & Duit, 2008) seem to fall into this category. The two positions may be characterized by calling them *science-oriented* and *student-oriented*. Clearly analytical research on a particular science content (like evolution or energy), which is often carried out by science-oriented science educators provides an essential basis for teaching and learning the content. However, it seems that progress in student understanding and learning may only be achieved if there is a balance between the two perspectives. Successful design of science teaching and learning sequences needs to merge the two positions.

Fensham (2001) points to the necessity of research on teaching and learning to rethink science content, to view it also as problematic (see also Fensham, Gunstone, & White, 1994), and to reconstruct it from educational perspectives. These considerations may also be discussed by contrasting the European Didaktik tradition and the Curriculum tradition (Hopmann & Riquarts, 1995). Whereas the Curriculum tradition is very much in line with the above Jenkin's (2001) *empirical* side, the Didaktik tradition aims at a balance of key features of the *science-oriented* and *student-oriented* science education research. This is the above position of the interdisciplinary nature of science education research as outlined in Figure 1 which is also a key concern of the Model of Educational Reconstruction discussed below.

THE GERMAN TRADITION OF BILDUNG AND DIDAKTIK

It is essential to point out first that traditional German pedagogy was strongly embedded in hermeneutical epistemological views as established by Wilhelm Dilthey (1833–1911). It appears that this tradition is a major reason that behaviourist ideas had a much smaller impact on the educational system in Germany as compared to the predominance of the view in the USA.

The German terms *Bildung* and *Didaktik* are difficult to translate into English. A literal translation is *formation*. In fact *Bildung* is viewed as a process. Bildung denotes the formation of the learner as a whole person, that is, for the development of the personality of the learner. The meaning of *Didaktik* is based on the notion of *Bildung*. It concerns the analytical process of transposing (or transforming) human knowledge (the cultural heritage) like domain specific knowledge into knowledge for schooling that contributes to the above formation (Bildung) of young people. Didaktik should not be interpreted from the perspective of the English expression *didactical* which denotes a rather restricted instructional method (Hopmann & Riquarts, 1995; Fensham, 2001).

Two major conceptions of German Didaktik are presented in the following. The first conception is Klafki's *Didaktische Analyse* (Educational Analysis) published in 1969. His ideas rest upon the principle of primacy of the aims and intentions of instruction. They frame the educational analysis, at the heart of which are the five questions in Table 1.

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?*

The other significant figure of thought within the German *Didaktik* tradition is the fundamental interplay of all variables determining instruction proposed by Heimann, Otto, and Schulz also in 1969 (Figure 2). In this model students' learning processes are of key interest and not the contribution to *Bildung* as is the case in Klafki's *Educational Analysis* approach. The aims and intentions of instruction form the most significant frame for the process of designing instruction; however, they are given the role of primus inter pares (the first among equal partners). The *interaction* of intentions and the other variables shown in the first line of figure 2 is given particular attention. Students' intellectual and attitudinal as well as socio-cultural preconditions significantly influence the interplay of these components. They allow asking the four key questions that shape the process of instructional planning: Why – What – How – By What.

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

Figure 2. On the fundamental interplay of instructional variables.

The most important issues of the German Didaktik tradition as outlined are the following. In planning instruction (by the teacher or curriculum developers) the science content to be learned and students' cognitive and affective variables linked to learning the content have to be given equal attention. The science content is not viewed as “given” but has to undergo certain reconstruction processes. The science content structure (e.g. for the force concept) has to be transformed into a content structure *for* instruction. The two structures are fundamentally different. In the first step the *elementary ideas* with regard to the aims of instruction have to be *detected* by seriously taking into account student perspectives (e.g. their pre-instructional conceptions). Hence, it becomes, obvious that key ideas of the later constructivist perspectives of teaching and learning science were already part of the German *Didaktik* tradition.

An additional key figure of thought within the German Didaktik tradition is called “Elementarisierung” (see Nipkow, 1986, for the use of this term in German pedagogy). The literal English translation *elementarization* is not commonly used in pedagogy and science education literature. It includes three major facets (Bleichroth, 1991; Reinhold, 2006). Educational analysis according to Klafki’s (1969) first question in Table 1 aims at identifying the *elements*, i.e. the elementary features (basic phenomena, basic principles, general laws), of a certain content to be taught. The search for the elements has to be guided by the aims and objectives of instruction in such a way that students may understand them. The term *element* as used in considerations on *elementarization* clearly has a metaphorical meaning. It is a search for the entities of a complex content domain (e.g., a complex science theory) that may be viewed as *elements* in a similar way as the elements that allow explaining the composition of all substances. For the science concept of *energy* the following elementary features have proven fruitful: Energy transformation, conservation, degradation, and transfer (Duit & Häußler, 1994). Energy degradation is among the elementary features as understanding this feature is essential for allowing students to understand energy conservation. All processes in the real world display primarily energy degradation. Energy conservation usually may be “observed” (illustrated) only in particularly designed experiments not in daily life processes.

The second facet included in the use of the term *elementarization* is the process of reducing the complexity of a particular science content in such a way that it becomes accessible to the learners. This facet should not be interpreted in terms of merely “simplifying” science content because the purpose is not necessarily to make science simpler but to find a way to introduce students to the elementary features of a content that have been constructed in the search for the elements as outlined above. The process of elementarization often is a delicate task of finding a balance between correctness from the science point of view and accessibility for students. Frequently, it turns out to be a course between Scylla and Charybdis.

There is an additional facet included in the term elementarization, namely to plan student learning processes as a series of elements of instructional methods that allow to guide students from their pre-instructional conceptions towards the science concepts (Bleichroth, 1981).

THE MODEL OF EDUCATIONAL RECONSTRUCTION

The Model of Educational Reconstruction (MER) draws on the German Didaktik tradition outlined above. In particular, it addresses the need to bring science related issues and educationally oriented issues into balance when teaching and learning sequences are designed that deliberately support understanding and learning science. It also addresses the above gap between science education research and science instruction practice by explicitly linking research and development – in much the same way as, for instance, Design Based Research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003).

Introductory Remarks

The model has been developed as a theoretical framework for studies as to whether it is worthwhile and possible to teach particular content areas of science. Clarification of science subject matter is a key issue if instruction of particular science contents (such as evolution, photosynthesis, or energy) is to be developed. Often issues coming from the structure of the referring science content primarily or solely inform this clarification process. Educational issues then are regarded only after the science subject matter structure has been clarified. Initially, the focus was on studies on educational reconstruction of *science content*. More recently, it became clear that also *science processes* and *views of the nature of science* need to undergo this process in order to allow efficient learning and teaching of issues *about* science.

The MER closely links research on the science content structure[3] and the educational significance of parts of it, and also includes empirical studies on students' understanding as well as preliminary trials of pilot instructional modules in classroom practice. It is, for instance, a key assumption of the model that the curriculum developers' awareness of the students' point of view may substantially influence the reconstruction of the particular science content. The results of the research already conducted within the framework of Educational Reconstruction clearly show that intimate knowledge of students' conceptions may provide a more adequate understanding of the referring science content by the curriculum developers. The MER has been designed primarily as a frame for science education research and development. However, it also provides significant guidance for planning science instruction in school practice.

The model has been developed in close cooperation of members of research groups on biology education in Oldenburg and physics education at the IPN in Kiel (Kattmann, Duit, Gropengießer, & Komorek, 1995, 1997). The model provided the framework for a project on the "*Educational Reconstruction of key features of non-linear systems*" (Duit, Komorek, & Wilbers, 1997; Komorek & Duit, 2004; Stavrou, Duit, & Komorek, 2008). It was also used as a key facet of the theoretical framework for instructional planning within the quality development projects "*Physics in Context*" (Duit & Mikelskis-Seifert, 2010) and "*Chemistry in Context*" (Parchmann & Schmidt, 2003; Schmidt, Rebentisch & Parchmann, 2003).

Colleagues at the University of Oldenburg initiated a large series of studies on educational reconstruction of key biology concepts like evolution, vision, cell and the like in German biology education in general (Frerichs, 1999; Gropengießer, 1998; Kattmann, 2001; Hilge, 2001; Brinschwitz & Gropengießer, 2003; Baalmann, Frerichs, Weizel, Gropengießer, & Kattmann, 2004; Lewis & Kattmann, 2004). They also started a "*Graduate School Educational Reconstruction*" that allowed investigating the power of MER not only in science but also in various additional school topics.[4] More recently, in a subsequent project teacher professional development based on the MER is given particular attention.[5] In general the model became a key figure of thought in German science education. It has also been adopted by science educators elsewhere – especially in Europe, i.e. in countries with a deliberate Didaktik-tradition.

Epistemological Orientation

The model is based on a constructivist epistemological position (Phillips, 2000). This epistemological orientation concerns the understanding of students' perspectives as well as the interpretation of the scientific content (Gerstenmaier & Mandl, 1996). We stress the point of view that the conceptions the learners develop are not regarded as obstacles for learning but as points to start from and mental instruments to work with in further learning (Driver & Easley, 1978; Duit & Treagust, 2003; Treagust & Duit, 2008). We further assume that there is no such thing as the "true" content structure of a particular content area (Abd-El-Khalik & Lederman, 2000). What is commonly called the science content structure is seen as the consensus of a particular science community. Every presentation of this consensus, including the presentations in the leading textbooks, is viewed as an idiosyncratic reconstruction of the authors informed by the specific aims they explicitly or implicitly hold. Thus academic textbooks are regarded as descriptions of concepts, principles and theories and not as accounts of reality itself. Certainly in most cases the scientific knowledge is of higher inter-subjective validity than everyday knowledge but – like the latter – it is still a system of mental constructs. Clearly, these considerations also hold for issues of science processes and the nature of science (i.e. issue *about* science). However, it has to be taken into account that the consensus about the particular features of science processes and the nature of science is far less well established as with regard to science content (Lederman, 2008).

Overview of the Model

Figure 3 illustrates that the MER consists of three closely interrelated components; figure 4 provides details of the process of educational reconstruction.

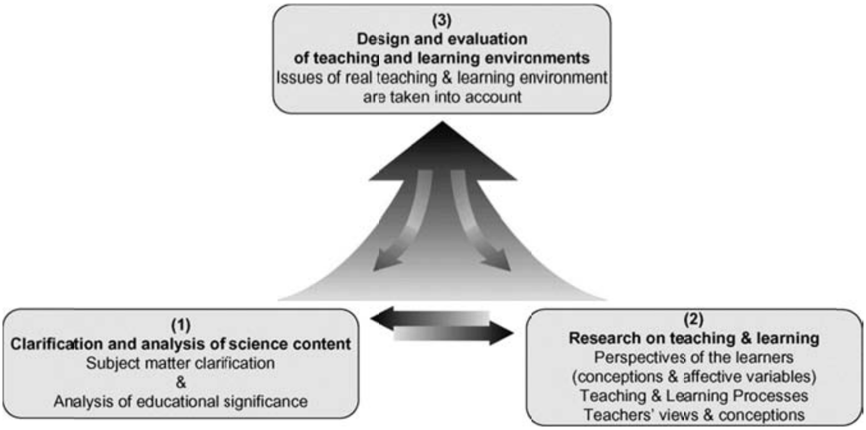

Figure 3. The three components of the Model of Educational Reconstruction.

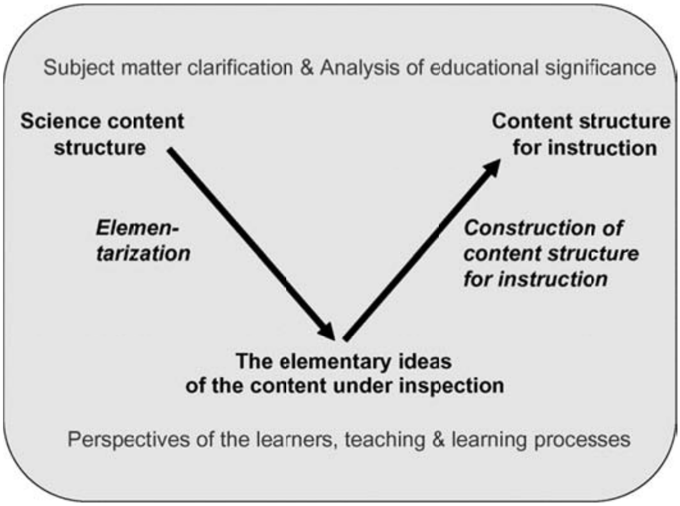

Figure 4. Steps towards a content structure for instruction.

The model concerns the analytical process of transposing[6] (or transforming) human knowledge (the cultural heritage) like domain specific knowledge into knowledge for schooling that contributes to student scientific literacy. Briefly put, the content structure of a certain domain has to be transformed into a content structure *for* instruction (see figure 4). The two structures are substantially different. The science content structure for a certain topic may not be directly transferred into a content structure for instruction. It has to be *elementarized* to make it accessible for students but also enriched by putting it into contexts that make sense for the learners.

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, therefore, necessary to embed the abstract science knowledge into various contexts in order to address learning potentialities and difficulties of the learners.

Component (1): Clarification and Analysis of Science Content

The aim of this component is to clarify the specific science conceptions and the content structure from an educational point of view. Two processes closely linked are included, *clarification of subject matter* and *analysis of educational significance*. Clarification of subject matter draws on qualitative content analysis of leading textbooks and key publications on the topic under inspection but also may take into account its historical development. A critical analysis of a particular science content from the standpoint of science education is necessary, because academic textbooks address experts (e.g. scientist and students to become scientists). Scientific knowledge is often presented in an abstract and condensed manner. Usually, neither preconceptions nor circumstances of the research process, the research questions and the methods employed are given. We even find linguistic expressions of old and outdated thought in academic textbooks. In a scientific community this may not hamper understanding too much. To learners at schools and informal learning sites this kind of science content is not accessible and sometimes misleading. We also attend to science terms that might be misleading to learners, especially words of different meaning in science and everyday-life.

Interestingly, 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) also contributes to more adequately understanding the science content in the process of subject matter clarification. Experiences show that surprising and seemingly “strange” conceptions students own may provide a new view of science content and hence allows another, deeper, understanding of the content clarified (Kattmann, 2001; Duit, Komorek, & Wilbers, 1997; Scheffel, Brockmeier, & Parchmann, 2009).

As mentioned previously, the key idea of educational reconstruction includes the idea that a certain *science content structure* has to be transformed into the *content structure for instruction*. According to Figure 4 two processes are included: *elementarization* which lead to the elementary ideas of the content under inspection (see additional remarks on this process above) and *construction of content structure for instruction*. In both processes science content issues and issues of students’ perspectives (their conceptions and views about the content as well as affective variables like their interests and science learning self-concepts) have to be taken into account. Figure 4 provides a somewhat simplified impression of these processes. Usually, the procedure is not as linear as depicted but a somewhat complicated recursive procedure is needed to re-construct an appropriate content structure for instruction (see Figure 5 below).

As mentioned already, traditionally, science content primarily denotes science concepts and principles. However, recent views of science processes (science inquiry), the nature of science and also the relevance of science in daily life and society should be given substantial attention in science instruction (Osborne, Ratcliffe, Millar, & Duschl, 2003; McComas, 1998; Lederman, 2008). All these additional issues need to be included in the process of educational reconstruction, i.e. also they need to be educationally reconstructed.

Component (2): Research on Teaching and Learning

Figure 3 indicates that the process of clarification and analysis of science content on the one hand and the process of construction of content structure for instruction on the other need to be based on empirical research on teaching and learning. Empirical studies on various features of the particular learning setting need to be regarded. Research on students' perspectives investigates their pre-instructional conceptions and affective variables like interests, self-concepts, and attitudes. But many more studies on teaching and learning processes and the particular role of instructional methods, experiments and other instructional tools need to be taken into account. Furthermore, research on teachers' views and beliefs of the science concepts, students' learning and their role in initiating and supporting learning processes are essential.

The research literature on teaching and learning science is extensive (Abell & Lederman, 2008; Duit, 2009). This is by far the largest research domain in science education. A wide spectrum of methods is employed ranging from qualitative to quantitative nature, including questionnaires, interviews and learning process studies in natural settings.

However, for a number of new and also traditional topics little to no research at all is available. In these cases, research on teaching and learning and the process of educational reconstruction are closely interrelated (Baalmann et al., 2004; Duit, Komorek, & Wilbers, 1997). Here qualitative methods like interviews or small scale learning process studies prevail (Komorek & Duit, 2004).

Component (3): Design and Evaluation of Teaching and Learning Environments

The third component comprises 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. Hence, the design is, first of all, structured by the specific needs and learning capabilities of the students to achieve the goals set. Key resources of the design activities are research findings on students' perspectives (e.g., their potentialities, learning difficulties as well as their interests, self-concepts and attitudes) on the one hand and the (preliminary) results of subject matter clarification on the other hand. Both resources are regarded as equally important for designing instruction.

Various empirical methods are used to evaluate the materials and activities designed, such as interviews with students and teachers, e.g. on their views of the value of the desired items, questionnaires on the development of students' cognitive and affective variables, and also analyses of video-documented instructional practice. Development of instructional material and activities as well as research on various issues of teaching and learning science is intimately linked.

Interview studies primarily provide guidelines for the rearrangement of learning sequences and design of learning environments (Baalmann, Frerichs, & Kattmann, 1999; Frerichs, 1999; Gropengießer, 1998, 2001; Hilge, 2001; Komorek, Vogt, & Duit, 2003; Osewold, 2003; Baalmann et al., 2004; Schwanewedel, Hößle, & Kattmann, 2007; Fach & Parchmann, 2007). In teaching experiments (Steffe & D'Ambrosio, 1996; Komorek & Duit, 2004; Scheffel, Brockmann, & Parchmann, 2009) carried out with a few students each, learning processes are investigated. The learners' "pathways of thinking" are inferred and linked to the learning activities. The effect of carefully designed learning environments on the students' conceptions is investigated (Komorek, Stavrou, & Duit, 2003; Komorek & Duit, 2004; Schmidt, 2011). In the studies by Brinschwitz and Gropengießer (2003), Weitzel and Gropengießer (2003), Groß and Gropengießer (2003), Riemeier (2005) as well as Niebert and Gropengießer and Riemeier and Gropengießer (2008) the interpretation was framed by experiential realism and a cognitive linguistic theory of understanding (Lakoff, 1990). Further studies in natural settings of science classrooms are conducted (Duit, Roth, Komorek, & Wilbers, 1998). Limitations and the particular shaping of learning processes within the conditions of real classroom settings are to be taken into account in theses studies (compare Brown's, 1992, approach of *design experiments;* for a similar approach: Knippels, 2003; Verhoeff, 2004).

The Recursive Process of Educational Reconstruction

Figure 3 points out that there is a fundamental interaction between the three components of the Model of Educational Reconstruction. However, the three components do not follow strictly upon one another but influence each other mutually. Consequently the procedure must be conducted step by step recursively. In practice, a complex step by step process occurs. Figure 5 presents this process in a project on educational reconstruction of limited predictability of chaotic systems (Duit, Komorek, & Wilbers, 1997).

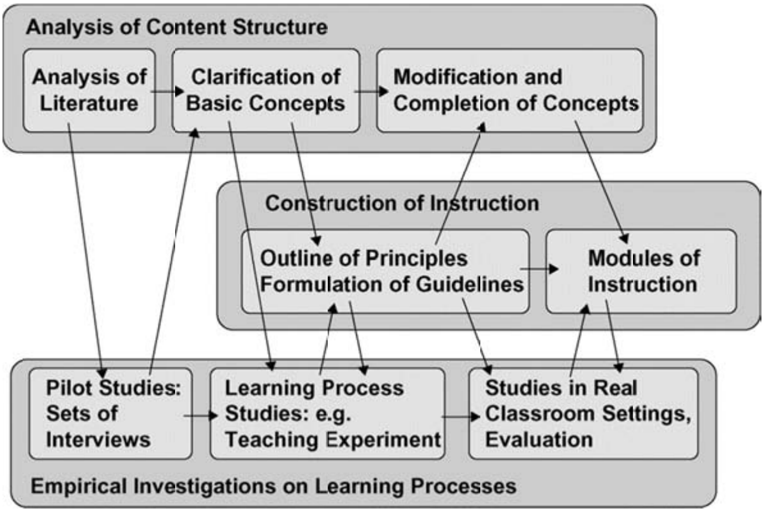

Figure 5. An example for the recursive process of Educational Reconstruction (Kattmann et al., 1995).

The Model of Educational Reconstruction and Other Models of Instructional Design

The MER presented here shares major features with other models of instructional design that aim at improving practice. First of all, the model is explicitly based on constructivist oriented views of efficient teaching and learning environments. In this regard, the model meets the mainstream of the wide spectrum of contemporary attempts towards constructivist oriented instructional design (Vosniadou, 2008; Tytler, 2007; Widodo, 2004). However, the model does not favour a particular variant of this kind of design. Actually, in the many studies explicitly based on the model partly substantially different epistemological variants are used and varying constructivist oriented instructional methods employed depending on the aims of the particular learning settings.

The cyclical (recursive) 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*[7] presented by Lijnse (1995).

As mentioned, 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, i.e., to bridge the deep gap between research and practice (see above). *Design Experiments* (Cobb et al., 2003) and other design based research approaches have been developed as a means to address this problem. They intimately link research and development, and also take instructional practice explicitly into account. Further, they may lead to the development of content-oriented theories (Andersson & Wallin, 2006) – in much the same way as the MER.

It seems that this model also shares some major features with the approach of *Learning Progressions* that has been developed the past decade, primarily in the USA (Duncan & Hmelo-Silver, 2009). Learning progressions describe "*successively more sophisticated ways of reasoning within a content domain that follow one another as students learn*" (Smith, Wiser, Anderson, & Krajcik, 2006). The major shared issues of the approaches concern that science content structure features and students learning pathways in a long term perspective both are given significant attention.

Clearly, the MER shares a significant number of features with other frameworks for science education research and development, e.g. constructivist orientation, development of content-oriented theories, recursive process of research and development, and aiming at improving instructional practice. The particular contribution to the international state of discussion seems to be the idea that science content structure has to be reconstructed on the grounds of educational issues, namely the aims of instruction and student perspectives. The processes depicted in Figure 4, namely the *elementarization* leading to the key basic ideas of a certain content domain and the adjacent *construction of the content structure for instruction* indicate the special contribution of the model. The more general contribution of the MER can be seen in providing a framework of relevant components for science education research and development and thereby shaping its trilateral relations. The three components are mutually related to each other in a systematic way.

CONCLUSIONS – ON THE ROLE OF THE MODEL OF EDUCATIONAL RECONSTRUCTION IN SCIENCE EDUCATION RESEARCH AND DEVELOPMENT

The MER presented above initially was developed as a model for instructional planning – in school practice and in curriculum development groups. In the following we attempt to illustrate that the model has been also proven fruitful beyond the initial focus.

The Model of Educational Reconstruction as a Framework for Science Education Research

The model integrates three significant lines of science education research: (1) The clarification and analysis of science content, (2) research on teaching and learning with a particular emphasis on the role of student pre-instructional conceptions in the learning process, and (3) the design and evaluation of learning environments (Figure 3). Briefly summarized (for more details see Duit, 2007) there are the following characteristics of these three lines:

(1) *Clarification and analysis of science content.* As outlined more fully above there are two processes closely linked, *subject matter clarification* and *analysis of educational significance*. Not only science content but also science processes and views of the nature of science are included. Research methods for subject matter clarification are analytical (hermeneutical) in nature, and methods of content and text analysis prevail. History and philosophy of science issues are also taken into account. Analysis of educational significance is analytical in nature as well, drawing on pedagogical norms and goals. However, in a number of projects also empirical studies on the educational significance were included, e.g. by employing questionnaires to investigate the views of experts (Komorek, Wendorf, & Duit, 2003).

(2) *Research on teaching and learning.* This is by far the largest research domain in science education (Duit, 2009). The major sub-domains comprise: Student learning (cognitive and affective variables); teaching; teacher professional development; instructional media and methods; student assessment. A large spectrum of methods on empirical research has been employed ranging from qualitative to quantitative and including studies in natural settings. Various epistemological perspectives have been used with variants of constructivist views predominating (see above).

(3) *Design and evaluation of learning environments.* There is no doubt that much development work (e.g., regarding new experiments, new multi-media tools) still is not linked with research but draws on beliefs and "experiences" of the developers. The position underlying the MER 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 carrying out research studies. Third, improving practice is likely only if development and research are closely linked.

The MER provides a model in which primarily features of the particular teaching and learning situation are addressed. The wider context of the learning environment, comprising features of the educational system however, are not taken explicitly into account. *Research on curricular issues and science education policies* which is an additional major science education research field therefore is given only rather limited attention.

As argued above (Figure 1) science education should be seen as a fundamentally interdisciplinary scholarly discipline. The MER is based on this position and paradigmatically takes into account that science education research integrates research traditions from various disciplines, namely the sciences, philosophy and history of science, pedagogy, psychology, and additional disciplines like linguistics, ethics, and sociology.

Conceptual Reconstruction

Student learning processes are taken carefully in account in the MER. The major term to theoretically frame learning processes within constructivist oriented approaches has been *conceptual change* (Duit, Treagust, & Widodo, 2008). Unfortunately, the term invites several misunderstandings as the daily life meaning of change also includes exchange. However, research has clearly shown that a simple exchange of the new science conception for the old student conception usually does not happen in actual learning processes. In order to avoid misunderstandings of the term conceptual change several terms like *conceptual growth* or *conceptual enrichment* have been proposed (e.g., Strike & Posner, 1992; Vosniadou, 1996). Kattmann (2007) argued for using the term *conceptual reconstruction* in analogy to the processes of educational reconstruction (Figure 4). This term indicates that students need to *reconstruct* their pre-instructional conceptions. Mental processes are included that may be described as revolutionary (discontinuous) if conceptions are fundamentally re-organized, or as developmental (continuous) if conceptions are modified or linked in a new way. Furthermore, *conceptual reconstruction* also theoretically frames learning processes in which learners develop their mental structures by forming new conceptions on the grounds of their own imagination and experience. C*onceptual reconstruction* shares major features with the term "*reconstruction of model knowledge*" as introduced by Dole and Sinatra (1998).

The Model of Educational Reconstruction as a Model for Teacher Professional Development

The MER presented in Figure 3 provides a theoretical frame for instructional planning. A significant number of competencies of the science educators using the model to develop instruction are essential. In principle the same set of competencies is needed if a teacher uses the model for instructional planning or intends to enact an instructional unit designed, e.g., by a curriculum development group. Hence, the MER also provides a theoretical frame for teacher education (van Dijk & Kattmann, 2007; Komorek & Kattmann, 2009) as will be briefly outlined in the following.

The way teachers think about key characteristics of instruction has proven an essential part of their PCK – their Pedagogical Content Knowledge (Shulman, 1987). As van Dijk and Kattmann (2007) thoroughly argue, the Model of Educational Reconstruction allows identifying these characteristics. PCK is seen as a unique knowledge domain denoting the blending of content and pedagogy into an understanding of how particular topics, problems, or issues may be organised, represented, and adjusted to the diverse interests and abilities of learners. Teacher thinking in terms of the PCK in this sense seems to be basically in accordance with teacher thinking in terms of the German Didaktik tradition as outlined above and therefore also with the key features of teacher thinking in terms of the MER.

Duit, Komorek and Müller (2004), drawing on the MER, developed a set of key features of teacher thinking on planning and analysing instruction. They distinguish three key domains of teacher thinking:

(A) *Constructivist views of teaching and learning*. Teacher thinking about science teaching and learning is based on constructivist views. Teachers are aware that students interpret everything presented to them from their private perspective. They also take into account that knowledge may not be simply passed to students but that their role is to sustainably support students in constructing their knowledge themselves. Further, teachers should embed science topics in contexts that make sense to students.

(B) *Fundamental interplay of instructional variables.* Teachers should be aware of the interplay of the variables composing instruction, namely *Aims & Objectives*, *Content*, *Methods*, and *Media* (Figure 2), i.e. take into account that for instance the choice of a particular method is also a choice for emphasising certain aims. They should further be aware that a rich spectrum of aims, contents, methods, and media needs to be applied in instruction. With regard to Content they should consider not to restrict themselves to science concepts and principles but to take into account also science processes, views of the nature of science and issues of the significance of science in technology and society. Finally, they should provide learning opportunities that allow students to construct the knowledge intended themselves.

(C) *Thinking in terms of the processes of educational reconstruction.* This kind of thinking concerns the features provided by the MER (Figure 3). Significant features included in the model are already taken into account in the above two domains. Here the process of clarification science content as outlined in Figure 4 is in the foreground. Teachers need to be aware that science content knowledge may not be taught in a somewhat simplified version of the content structure of science. The content structure for instruction has to be adjusted to student pre-instructional conceptions and needs to be embedded into contexts that make sense for students.

Komorek and Kattmann (2009, 179) provide the following set of questions based on the MER that allow reflection on teaching and learning in school lessons:

(1) What were the most important student conceptions occurring during the lesson?
(2) Did the science conceptions provided support understanding of the subject?
(3) Did the students have opportunities to acknowledge and reflect about their conceptions as well as their learning progress?
(4) Were the teaching methods and student activities suitable for learning and understanding the subject?
(5) What conceptions (concepts, notions and principles) were used by the students in the scientific context offered?
(6) What correspondence between student alternative conceptions and the offered science conceptions can be identified?

(7) Were the students aware of inherent scientific and epistemological positions concerning the subject?
(8) Did the students apply the acquired knowledge in other fields and did they reflect on it critically?

The Model of Educational Reconstruction for Teacher Education

In analogy to the MER (Figure 3) a model for designing teacher education settings may be constructed as shown in Figure 6 (Komorek & Kattmann, 2009).

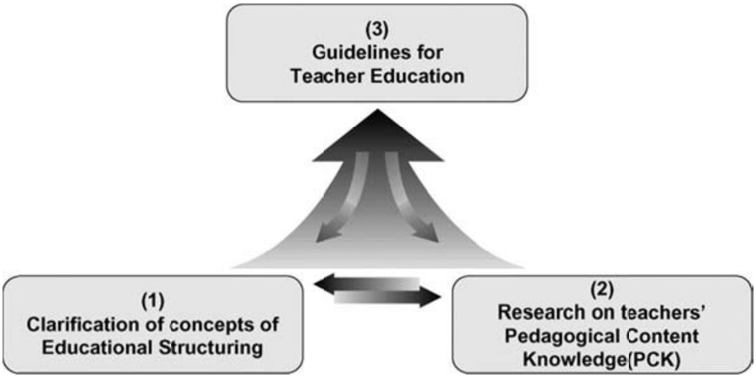

Figure 6. Educational Reconstruction for Teacher Education (ERTE).

Van Dijk and Kattmann (2007) developed this model. Figure 6 shows a slightly modified version. The basic idea of the ERTE Model is that teachers usually (Borko, 2004; Abell, 2008) hold idiosyncratic views about teaching and learning that are only partly in accordance with the position included in the MER. Component (1) in Figure 6 comprises the major ideas of the MER. In order to design efficient settings for teacher education addressing the kind of thinking in terms of the model it is necessary to investigate teachers' views (their PCK). Further, it is essential to critically clarify and analyse the conceptions of teacher education in the literature. As is also the case for the MER, the process of developing the guidelines (component 3) is recursive. The following set of questions may guide this process (Komorek & Kattmann, 2009, 181f):

(1) What subject matter knowledge for teaching do teachers have at their disposal?
(2) What do teachers know about students' pre-instructional conceptions on the subject matter and about their learning processes?
(3) What conceptions do teachers have of educational structuring (design of instruction, subject matter representation)?

(4) What conceptions do teachers have about the interrelation of subject matter knowledge for teaching, students' pre-instructional conceptions, and the influence of this interrelation on the process of educational structuring?

CODA

The Model of Educational Reconstruction is a theoretical frame for research and development in science education. It draws on the German Didaktik tradition. The key message of the model is that science subject matter content (including concepts and principles as well as conceptions about science and the scientific inquiry processes) may not be presented in a somewhat reduced or simplified manner in science instruction. The science content structure for instruction is somewhat more elementary (from the science point of view) on the one hand but richer, on the other hand, as the elements of science content of a certain topic need to be put into contexts that make sense to the students and may be understood by them. The tendency of many approaches towards more efficient science instruction to put the major emphasis on efficient instructional methods falls short. It is also necessary to change the traditional content structure for science instruction. Also science content and not only instructional methods should be seen as problematic (Fensham, 2001).

A model like the MER may not be tested empirically in a strong sense. Such a model needs to be based on sound theoretical foundations. In addition the consequences drawn on the grounds of these foundations need to be sound. We think (or at least hope) that this is the case for the arguments we presented above. Experiences gained in the many studies carried out within the framework of educational reconstruction have shown the usefulness of the model and appear convincing to us. The MER has become the major theoretical perspective in science education research in the German speaking area. It has also been adopted in various science education groups in Europe. This seems to be due to a certain general agreement on key issues of the Didaktik tradition which is a common way of thinking about instruction in – at least – continental Europe. It is, however, still a challenge to convince science educators from different traditions in thinking about science instruction that the model has much to offer. Further, the application of the model for theoretically framing and designing teacher professional development settings still needs serious additional work.

Clearly, the model and surely also the kind of consequences we draw need to be critically analyzed in order to further develop our perspective. This holds, especially, for the application of the model in designing learning settings explicitly addressing issues of science processes and views of the nature of science and in teacher education. To incite a discussion on the significance of the model is what this chapter intends.

NOTES

[1] This chapter draws on previous overviews of key features of the Model of Educational Reconstruction, especially on the following publications: Kattmann, Duit, Gropengießer, & Komorek (1995), Duit, Gropengießer, & Kattmann (2005), Duit (2007), Parchmann & Komorek (2008), and Komorek & Kattmann (2009).

[2] s. Duit (2007) for a more elaborate overview.

[3] The term “science content structure” may need clarification. *Structure* points to the fact that the content elements of a certain content domain (like energy) are intimately linked and that this structure is essential in the process of educational reconstruction.

[4] http://www.diz.uni-oldenburg.de/20512.html (June 2012)

[5] http://www.diz.uni-oldenburg.de/44743.html (June 2012)

[6] In French science and mathematics education the concept of *transposition didactique* (Chevallard, 1994; Perrenoud, 1998) is used. It seems that major ideas of the MER are included in this concept.

[7] The term, developmental research“ as used in Lijnse’s (1995) approach concerns the intimate link between instructional development and research in basically the same way as in “design experiments” (Cobb et al., 2003). It should be taken into account that in the field of educational design the term “developmental research” may also denote research in a developmental perspective, i.e. research investigating long term progression of instructional interventions (Richey, Klein, & Nelson, 2004).

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