CULTURAL PERSPECTIVES IN SCIENCE EDUCATION

Science Education Research and Practice in Europe
Retrospective and Prospective

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Each volume in the 7-volume series The World of Science Education reviews research in a key region of the world. These regions include North America, South and Latin America, Asia, Australia and New Zealand, Europe, Arab States, and Sub-Saharan Africa.

The focus of this Handbook is on science education in Europe. In producing this volume the editors have invited a range of authors to describe their research in the context of developments in the continent and further afield. In reading this book you are invited to consider the historical, social and political contexts that have driven developments in science education research over the years. A unique feature of science education in Europe is the impact of the European Union on research and development over many years. A growing number of multi-national projects have contributed to the establishment of a community of researchers increasingly accepting of methodological diversity.
Science Education Research and Practice in Europe
CULTURAL PERSPECTIVES IN SCIENCE EDUCATION
Volume 5

DISTINGUISHED CONTRIBUTORS

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Cultural Perspectives in Science Education consists of handbooks and books that employ sociocultural theory and related methods to explicate key issues in science education. The series embraces diverse perspectives, endeavoring to learn from difference, polysemia and polyphonia, and resisting a tendency to emphasize one preferred form of scholarship. The series presents cutting edge theory and research, historical perspectives, biographies and syntheses of research that are germane to different geographical regions. The strength deriving from differences in science education is evident in the works of scholars from the expanding international community in which science education is practiced. Through research in science education, each volume in the series seeks to make a difference to critical issues that face humanity, examining scientific literacies and their role in sustaining life in a diverse, dynamic ecosystem.
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SENSE PUBLISHERS
ROTTERDAM/BOSTON/TAIPEI
ACKNOWLEDGEMENTS

We would like to thank colleagues at Sense Publishers, in particular Michel Lokhorst, for their support throughout the production of this volume. We are also grateful to our series editors, Ken Tobin and Catherine Milne who provided the necessary stimulus, patience and motivation throughout what turned out to be a long process.

We would especially like to thank all the authors who so generously gave of their time in contributing their chapters in a spirit of collegiality and scholarly excellence. Our friend and colleague, Phil Scott from the University of Leeds, who together with Asma Almahrouqi, contributed Chapter 12 on classroom discourse and science learning, sadly and suddenly passed away in July 2011. His contribution to science education in Europe and beyond is immeasurable as is our sense of loss.
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INTRODUCTION

In editing this volume of *The World of Science Education* devoted to Europe, we have invited a range of authors to describe their research in the context of developments in the continent and further afield. In this chapter, we begin by considering what we mean by Europe and then look at the historical, social and political contexts that have driven developments in science education research over the years. We finish with a look forward to where science education in Europe might be going in the years to come.

WHAT COUNTS AS EUROPE?

Europe is generally defined as one of the seven continents bordered by the Atlantic Ocean to the west, the Arctic Ocean to the north, the Mediterranean Sea to the south and the Black Sea to the southeast. The border to Asia is usually considered as being the Urals and the Caspian Sea. There are 50 countries within Europe with at least as many languages and cultures.

The creation of the European Union has given us an additional way to think of Europe. At the end of 1945 much of the continent lay in disarray and yet by 1950 a group of six countries (Belgium, France, Germany, Italy, Luxembourg and the Netherlands) had united to form a European coal and steel community so that a peaceful future might be secured. Subsequent unifying events included the signing of the Treaty of Rome in 1957 and the establishment of the European Economic Community (EEC).

Denmark, Ireland and the United Kingdom joined the European Union (EU) in 1973, raising the number of member states to nine. Greece joined in 1981 followed by Spain and Portugal in 1986 making a total of 12 member states. Communism collapsed across Europe in the 1990’s and in 1993 the EU introduced the idea of four basic ‘freedoms’: movement of goods, services, people and money. Three more countries joined the EU in 1995: Austria, Finland and Sweden. Borders between countries were opened and students were encouraged to study in other EU countries. Eight new countries were added in 2004: the Czech Republic, Estonia, Latvia, Lithuania, Hungary, Poland, Slovenia and Slovakia. Cyprus and Malta were added soon afterwards. Bulgaria and Romania became members in 2007.
taking the total to 27 member states. There are three candidate countries: Croatia, the former Yugoslav Republic of Macedonia and Turkey.

Today there are nearly half a billion people living within the European Union – the world’s third largest population after China and India. The EU is less than half the size of the United States, but its population is over 50% larger. Norway, Iceland and Switzerland are outside the official EU but they have a special agreement allowing many of the same opportunities that exist between member countries.

It is no secret that the EU has ambitions of becoming the world’s most dynamic knowledge-based economy, a status which will require substantial investments in research and education. The Bologna Declaration of 1999 (www.ehea.info) established compatibility and comparability between institutions in Europe on the way towards international competitiveness. The declaration has objectives to establish the European area of higher education and to promote the European system of higher education world-wide through the following measures:

1. The adoption of a system of easily readable and comparable degrees
2. The adoption of a system based on two main cycles, the undergraduate (3 year BA) and graduate (2 year MA followed by a 3 year Ph.D.)
3. The establishment of a system of credits (European Credit Transfer and accumulation System)
4. The promotion of mobility for students, teachers, researchers and administrative staff
5. The promotion of European co-operation in quality assurance
6. The promotion of the necessary European dimensions in higher education (curricular development, inter-institutional co-operation, mobility schemes and integrated programmes of study, training and research.

Today over 47 countries (from within and outside of the EU) have signed the Bologna Declaration, committing to the goals of the European Higher Education Area. Comparability and compatibility are important for European countries as higher education and research are transcending country boundaries on the way to common goals of excellence in the knowledge society.

The impact of the EU on education in Europe is seen most within higher education as most educational systems have comparable structures for degree programmes (3 year BA + 2 year MA + 3 year Ph.D.), common grading systems (A-F), and financial schemes to encourage student exchange. Degrees are more easily accepted across country borders, also encouraging movement of academics within Europe. And, finally, financial schemes for research are in place for the advancement of international comparisons in education.

Becoming a more integrated Europe in search of a common identity also brings with it the challenges of cultural diversity. As science educators we want to think that the content of science is and should be broadly the same regardless of where it is taught in the world. However, cultural diversity means that the delivery of the science curriculum happens in many different ways, thus producing very different learning outcomes. Some countries differentiate early, others not at all. Some
countries include science in a core curriculum while others only include language and mathematics. Some countries follow what we could call a “student-centered” ideology for teaching whereas others continue to be “teacher-centered”. Some countries have resources to include Information and Communications Technology (ICT) throughout the curriculum whereas others have little to no funding for such resources. Some countries are able to provide teacher professional development courses for teachers, thus encouraging life-long learning; others have almost no opportunities for teachers.

The issues of language diversity are also overwhelming in Europe. In the EU alone there are 23 official languages into which documents are translated. Many European countries have multiple languages into which all documents, including school textbooks, are translated. Switzerland has three official languages: German, French and Italian; Spain has Spanish as its official language yet includes Catalan, Basque, Galician and Aranese as Co-official languages; Belgium has three official languages: Dutch, French and German, and so on. Now add to this the challenges of immigration from other regions of the world and consider the impact of language on a school system.

An interesting language issue within the science education community in Europe arose over the translation of the German tradition of “bildung” and “didaktik”. It has been argued that an appropriate English translation was difficult to achieve (See Duit, Gropengießer, Kattmann, Komorek and Parchmann as well as Wickman, Liberg and Östman in this volume). (The term didaktik in German is not to be confused with the English word didactic since they have very different meanings.) Today it is not uncommon to use the German words within an English text since a broader understanding of their meaning has been accepted by the English-speaking community.

A RETROSPECTIVE LOOK AT SCIENCE EDUCATION IN EUROPE

The history of science education in parts of Europe has many similarities to the development of the field across the Atlantic. As the United States was reacting to the post-Sputnik shock in the 1960’s and developing new types of curriculum for science, similar types of developments were going on in Europe. For example, Jean Piaget’s Centre d’Épistémologie Génétique, established in 1955 in Geneva, had tremendous impacts on educational thinking in Europe. In the following section, we use England as an example of European development in science education.

England: An Example of the Development of Science Education in Europe

Since the 1960s, science education in European schools has been through a process of almost continual change. In England, for example, the most significant changes include the introduction of Nuffield Science; the move towards ‘balanced science’ (that is, the teaching of biology, chemistry and physics for all students); the rise of ‘process science’ (as opposed to focusing on ‘the facts’) and, more recently, the
introduction of a National Curriculum and the associated assessment procedures. Each innovation has challenged existing science teacher pedagogy in some way or another and, in turn, has had consequences for teacher development. The complexity of the relationship between pedagogic change and changes in the representation of science in the curriculum is indicated by this comment from Monk and Dillon:

Shifting pedagogic perspectives have been the major surface feature of the changes in discourse of science education in the metropolitan countries of the old imperial powers. Generally we have moved from transmission views to more constructivist views. Older views of science as an empirical, inductivist enterprise with access to a knowledge base of an independent reality have been gradually eroded and replaced by newer constructivist views. These are not unitary (Solomon 1994), but multiple. However they all share a concern for the student’s knowledge base as being idiosyncratic and biographical. (Monk and Dillon, 1995: 317).

This gradual erosion of older views of science have come about through curriculum change, the introduction of new courses and through changes to the nature of pre-service and in-service courses for science teachers. The process of change in science education, since the 1960s, though gradual, has not been one of seamless transition, rather it has involved reconstruction, reversal and high levels of political engagement (Donnelly and Jenkins, 2001).

Dissatisfaction with school science education was evident in the USA and in the UK before the launch of the Sputnik satellite in 1957 (Klainin, 1988: 172). The Nuffield Science projects, mentioned above, owe at least some of their success to what is sometimes termed the post-Sputnik angst (Waring, 1979). However, despite the innovations of the Nuffield era in science education, successive government reports and political commentary have continued to focus on the inadequacy of science education in both primary and secondary schools. The criticisms, which, in part, continue today, were partially responsible for the changes in the science curriculum.

In Beyond 2000, a critique of science education at the turn of the 21st century, Millar and Osborne (1998) picked out what they considered to be the major developments in education, and particularly in science education in England since 1960. First, they identified ‘the major curriculum innovation, undertaken by the Nuffield Foundation which ... gave greater emphasis to the role and use of experimental work’ (p. 2002–3). Nuffield Science involved a more experimental, investigative approach to science education pedagogy than had previously been the case (Jenkins, 2004).

The Nuffield approach involved an emphasis on practical activities, supported by worksheets, teachers’ guides, a network of teachers, examiners, academics and publishers. Nuffield Combined Science, first published in 1970, was probably the most influential course and was common in schools in the late 1970s. Indeed, Keohane (1986: vi) remarked: ‘by 1979 (as the survey by her Majesty’s Science...
Inspectorate showed) over half the schools in England were using the course wholly or in part’.

The 1986 revision of the *Nuffield Combined Science* materials, published as *Nuffield 11 to 13*, took into account various changes that had taken place since the first version was published in 1970:

... in that period, school children, schools, science, technology, and society at large have undergone great change. And that is not to mention the great changes in children’s expectations of schools and science lessons, in teachers’ expectations of children and resources for learning, and in society’s expectations of teachers. (Nuffield Science 11 to 13, 1986: 2)

Second, Millar and Osborne noted another significant development in science education as the introduction of the comprehensive school system in the mid-1960s which led, *inter alia*, to the development of courses ‘for the less academic pupil’ (1998: 2003). This change had enormous implications for science pedagogy. Third, they noted that courses developed during the 1980s aimed to increase the emphasis placed on the processes of science (that is, the skills necessary to undertake science experiments) (Jenkins, 2004). Fourth, they noted the influence of the Department of Education and Science policy statement, *Science 5–16* (DES, 1985) which argued that all young people should have a ‘broad and balanced’ science education (that is, a curriculum containing biology, chemistry and physics throughout the school system) and occupying (for most pupils) 20% of curriculum time from age 14 to 16 (Jenkins, 2004). Fifth, Millar and Osborne noted the impact of the introduction, in 1986, of the General Certificate of Secondary Education (GCSE) which resulted in a variety of science courses that included all three main sciences intended for all students. Sixth, they highlighted the introduction of the National Curriculum in 1989, which made science a ‘core’ subject in the curriculum for students aged 5 to 16 (Millar and Osborne, 1998: 2002–3).

Millar and Osborne (1998: 2003) also argued that since science had become one of the three core subjects of the National Curriculum in England, the nature of science education had changed and that ‘there has been a general acceptance that learning science involves more than simply knowing some facts and ideas about the natural world’ and that ‘a significant component of science curriculum time should be devoted to providing opportunities for personal inquiry [that is, doing experiments]’ (for a counter view, see Hodson, 1990, 1992).

Since *Beyond 2000* was published, science education in England has continued to evolve. A growing number of schools offer students the possibility of studying biology, chemistry and physics as separate subjects (Triple Science). A national network of science learning centres has been set up and continues to attract interest from policy makers from other countries. A growing number of science centres and museums offer educational events and activities aimed at school students and provide opportunities to meet real scientists.

Debate about the quantity and quality of practical work continues to be an issue, just as it was in the 1960s and 1970s. Support for teaching science outside the
classroom has grown over the years although its provision is very variable across the country with some teachers still reluctant to take their students outside.

In general, science education in English schools has made some progress since the 1960s. There is more gender equity and more focus on teaching about the nature of science. Students can experience a range of scientific ideas inside and outside the classroom. The overall quality of science teaching is probably better now that it was some years ago. However, many of the curriculum, assessment and pedagogical issues that challenged teachers in the post-war era can still be found in today’s schools.

**RESEARCH IN SCIENCE EDUCATION IN EUROPE**

As science education in Europe has developed through policy reform and through curriculum development, so too has the quality and quantity of research. Many countries have their own associations promoting research in science education generally or in the separate sciences. Increasing collaboration between countries led to the setting up of pan European organisations such as ERIDOB – European Researchers in the Didactics of Biology - which meets every two years.

Early collaborations between European science educators led to summer schools for Ph.D. students in Zeist in the Netherlands in 1993 and Thessaloniki, Greece, in 1994. As more European researchers attended conferences in the US organised by the National Association for Research in Science Teaching (NARST) and Australasia (Australasian Science Education Research Association (ASERA) so the desire to create a European equivalent grew. In 1995, a group of science educators including Rosalind Driver, organised a science education conference in Leeds. One key purpose of the conference was to create a European association of science educators. It is to the credit of a large number of European science educators, assisted by colleagues from Australia and the USA, that the association was born. Few people who were present at the final plenary discussion, orchestrated by John Gilbert from Reading University, will ever forget the challenges of language, culture and regional loyalties that helped to create the organisation that ESERA (www.esera.org) is now.

ESERA’s first President was Dimitris Psillos from Greece and the Secretary was Philip Adey from the UK. Piet Lijnse (Netherlands), Reinders Duit (Germany); Maria Pilar Jiménez Aleixandre (Spain); Martine Méheut (France) and Helene Sørensen (Denmark) made up the rest of the Executive. Subsequent ESERA Presidents have included Robin Millar and the two editors of this volume. ESERA has grown from strength to strength and has held biennial conferences in Rome, Kiel (Germany), Thessaloniki, Noordwijkerhout (Netherlands), Barcelona, Malmö, Istanbul and Lyon. In the intervening years it has organised Ph.D. summer schools in Barcelona (Spain), Marly-le-Roi (France), Gilleleje (Denmark), Radovljica (Slovenia), Mülheim (Germany), Braga (Portugal), York (UK), Udine (Italy) and Bad Honnef (Germany).
In recent years, several documents have been published in Europe that more or less described a crisis situation for the recruitment of Science, Technology, Engineering and Mathematics (STEM) students to higher education and eventually the workforce. The first was the report published in 2004: *Europe Needs More Scientists* (EC, 2004) chaired by the former Portuguese Science and Technology Minister Professor José Mariano Gago. The focus of this report was not only that Europe needed to promote more students to careers in STEM areas, but also that the focus needed to be on educational systems for improving school science. The importance of stressing hands-on science based on experiences was suggested to increase motivation. The focus shifted from science for future scientists to a science education that promoted science for all and scientific literacy.

In 2006, the Nuffield Foundation convened two seminars involving science educators from nine European countries. The seminars investigated the extent to which the issue of poor attitudes towards science was common across Europe, the similarities and differences between countries, and some attempted solutions and remedies. The idea behind these two Nuffield-funded London seminars was to draw together a group of leading science educators, from across the continent, to consider the state of science education in the EU. Invitations were extended to those engaged in science education, albeit principally academic science educators, from a range of European countries that were felt to represent the diversity of countries within the EU. The first seminar was held at the Nuffield Foundation headquarters, on June 1–2, 2006 and the second was held, in the same year, on December 7–8. In addition, an initial draft of the main findings was presented and discussed at ESERA’s biennial conference in Malmö, Sweden in August 2007. The focus of the first seminar was very much on exploring the current state of science education across Europe, the issues that are confronting it, and the evidence for those views. The seminars sought to explore what were felt to be the four key issues that are central to the nature of the teaching and learning experience offered by school science. That is: curriculum; pedagogy; assessment and teacher supply, professional development and retention. Introducing the subsequent report, *Science Education in Europe: Critical Reflections* (Osborne and Dillon, 2008), the Director of the Nuffield Foundation, Dr Anthony Tomei wrote:

Its message is clear. There are shortcomings in curriculum, pedagogy and assessment, but the deeper problem is one of fundamental purpose. School science education, the authors argue, has never provided a satisfactory education for the majority. Now the evidence is that it is failing in its original purpose, to provide a route into science for future scientists. The challenge therefore, is to re-imagine science education: to consider how it can be made fit for the modern world and how it can meet the needs of all students; those who will go on to work in scientific and technical subjects, and those who will not. The report suggests how this re-imagining might be achieved.
The authors of *Science Education in Europe* examined the concern about science education, expressed in reports such as *Europe Needs More Scientists* which, they argued ‘concentrates solely on the supply of future scientists and engineers and rarely examines the demand.’ Their critique noted that:

There is, for instance, a failure to recognise that science is a global activity where the evidence would suggest that there is no overall shortage at the doctoral level [2] although there may be local shortages of particular types of scientists and engineers, for example, pharmacologists in the UK. There may also be shortages at the technician and intermediate levels of scientific and technological work but better data is needed before making major policy decisions on science education. In such a context, encouraging or persuading young people to pursue careers in science without the evidence of demand would be morally questionable. (p. 7)

Osborne and Dillon argued that framing the discussion about school science in terms of the supply of the next generation of scientists is problematic because it defines the primary goal of science education as a pipeline, albeit leaky.

In so doing, it places a responsibility on school science education that no other curriculum subject shares. Our view is that a science education for all can only be justified if it offers something of universal value for all rather than the minority who will become future scientists. For these reasons, the goal of science education must be, first and foremost, to offer an education that develops students’ understanding both of the canon of scientific knowledge and of how science functions. In short that school science offers an *education in science* and not a form of pre-professional training. (p. 7)

The report, which has been cited almost 200 times, according to Google Scholar, makes a series of seven recommendations including:

- More attempts at innovative curricula and ways of organising the teaching of science that address the issue of low student motivation are required. These innovations need to be evaluated. In particular, a physical science curriculum that specifically focuses on developing an understanding of science in contexts that are known to interest girls should be developed and trialled within the EU. (p. 8)

and

- EU governments should invest significantly in research and development in assessment in science education. The aim should be to develop items and methods that assess the skills, knowledge and competencies expected of a scientifically literate citizen. (p. 8)

A report published by the OECD titled: *Encouraging Student Interest in Science and Technology Studies* (OECD, 2008) looked at the overall trends in higher education compared with other disciplines. The report suggested that whereas absolute numbers of science and technology students have been rising in
accordance with increased access to higher education in OECD countries, the relative share of science and technology students in the overall population has been falling. Of particular importance is that female students also continue to lag behind. Recommendations from this report are similar to others which call for curriculum reforms, improved science teacher education and in-service and particular attention to ideas to increase the number of females studying science and technology subjects.

SCIENCE EDUCATION RESEARCH AND DEVELOPMENT IN THE EU

In response to the situation found in Europe for recruitment into the STEM areas, the European Commission established a research programme in Science in Society (SIS) with a broad perspective on marking the importance of Science in Europe (http://cordis.europa.eu/fp7/sis). The SIS programme in the Seventh Framework Programme (FP7) has a budget of EUR 330 million, reflecting a strong commitment to the significance of science in Europe. The SIS Program has been charged with the responsibility of supporting the following specific research activities: the connection between science, democracy and law; ethics in science and technology; the reciprocal influence of science and culture; the role and image of scientists; gender aspects; science education methods; and science communication. Science educators and researchers have been particularly active in research calls dealing with science education methods, science communication, gender aspects and the role and image of scientists.

In 2006 an expert group under the leadership of Michel Rocard, former prime minister of France and member of the European Parliament, was established to look more closely at on-going initiatives funded by SiS in Europe to identify the necessary conditions for bringing about change in young people’s interest in science. The timing of the report, published in 2007, was important for France, since they were to assume the EU Presidency in 2008. The expert group looked particularly at successful projects that worked with the way science is taught in schools, concluding with an appeal to promote inquiry based science teaching and learning as a basis for improving the way science is taught in schools. The report, Science Education NOW: A Renewed Pedagogy for the Future of Europe (EC, 2007) came with recommendations for politicians in member states for how to go about making changes in how science is taught. The most important impact of the report was the release of additional research funding in this area.

Two initiatives were described in the Science Education NOW report, serving as examples of successful projects having had an impact on science teaching through inquiry in Europe. The first was the Pollen project (www.pollen-europa.net), launched in 2006, in which inquiry based science education (IBSE) at the primary level was implemented within 12 seed cities throughout Europe. The major goal of Pollen was “to provide an empirical illustration of how science teaching can be reformed on a local level within schools whilst involving the whole community, in order to demonstrate the sustainability and efficiency of the Seed City approach to stakeholders and national education authorities, and to seek leverage effects”
(www.pollen-europa.net). It should be noted that the Pollen project was supported by the French Academy of Sciences, also responsible for the La main à la pâte programme, launched in 1996. The more recent EU supported Fibonacci Project (www.fibonacci-project.eu) continued from this line of prestigious predecessors by increasing the number of participating countries and also including mathematics. The project is based on the idea that local and regional initiatives are appropriate for the reform of science education in Europe.

The second project described by the Science Education NOW report was the German SINUS-Transfer project (http://sinus-transfer.eu) based on years of experience working with discussion between teachers on their pedagogical practices in teaching science and mathematics in German schools. The Mind the Gap and the S-TEAM (www.s-teamproject.eu) projects described by Stadler and Jorde (in this volume) are supported through EU funding under the SiS funding scheme for science education methods in inquiry based science education. It is an important point to make that the individual countries in the EU have responsibility for their own curriculum (what is to be taught). However, it is possible to establish norms about matters concerning the pedagogy of teaching and thus create international networks of researchers concerned with teaching.

Coordinating the many projects supported within the 7th Framework Programme is a task taken on by the newly established SCIENTIX (The community for science education in Europe) project and website (www.scientix.eu). Even a quick look at this site shows the tremendous amount of supported activity in Europe in STEM areas. The searchable website is in itself a challenge for Europe, as language and culture need to be considered in all types of search engines.

Europe is definitely talking about STEM issues. The question remains, are we able to coordinate our efforts to make the impact desired for general scientific literacy as well as for Europe’s need to compete within the worldwide knowledge society? The many STEM projects launched in the past few years are based on solid science education research, going on in Europe since the 1960’s. Much of this research has been done locally – within national boundaries. The trend towards large-scale inquiry based science projects in Europe is influenced by European funding within the 7th framework for SIS. Whereas this is a very positive movement for bringing ideas, researchers and teachers together throughout Europe, it is not the type of funding that allows basic types of research. What is drastically needed now and in the future is funding to work comparatively with educational research in science education so that we can begin to develop a better understanding of what actually works and whether ideas are transferable to other cultures and contexts.

REFERENCES


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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.
ON THE INTERDISCIPLINARY NATURE OF SCIENCE EDUCATION

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

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; Tiberghien, 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.
THE MODEL OF EDUCATIONAL RECONSTRUCTION

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.

<table>
<thead>
<tr>
<th>Intentions (aims and objectives)</th>
<th>Topic of instruction (content)</th>
<th>Methods of instruction</th>
<th>Media used in instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Why</td>
<td>What</td>
<td>How</td>
<td>By What</td>
</tr>
</tbody>
</table>

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 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. More recently, in a subsequent project teacher professional development based on the MER is given particular attention. 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.
The model concerns the analytical process of transposing (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 Riemer 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).
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 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. *Conceptual 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).

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)?
THE MODEL OF EDUCATIONAL RECONSTRUCTION

(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?

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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 Lijne’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).

REFERENCES


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