PHYSICS EDUCATION RESEARCH – INDISPENSABLE FOR IMPROVING TEACHING AND LEARNING

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1 ON THE SITUATION OF PHYSICS TEACHING

Research has shown that the situation of physics teaching in school is deficient (Duit, Niedderer, & Schecker, 2007). It seems that the following issues are the most significant ones:

(1) Limited achievement gains in school (and also in universities);
(2) Students' interests in learning physics decrease – especially girls' interests;
(3) The enrolment in physics and physics oriented studies has declined in many countries – partly dramatically.

Hence, the contribution of physics instruction to scientific literacy and to sufficient enrolment in physics oriented studies and vocations are deficient. A significant reason seems to be that learning physics includes difficulties that are due to the particular nature of physics such as the abstract and highly idealized kind of physics (mathematical) modelling. Research on students' conceptions has shown that most pre-instructional ideas students bring to physics instruction are in stark contrast to the physics principles to be achieved – from kindergarten to the tertiary level (Duit, 2007). Accordingly, students, especially girls, perceive physics not only as very abstract, complicated, and difficult, but also as counterintuitive and incomprehensible. Further, *what* is taught and *how* it is taught in instructional practice seem to be additional major reasons for the actual deplorable state of physics teaching and learning in many classes.

Sjöberg (2001) argued that the predominant focus of physics instruction is the physics of the (late) 19th century. Modern physics is nearly totally missing for lower secondary. That means most students leave school without any idea of the more recent views of the world. Maybe the hope is that popular science books and TV shows will jump in and provide a certain (often rather limited) picture. Sjöberg also claims that in most physics classes a certain myth about *the* scientific method prevails as well as inadequate views how science is made. So far, science processes (i.e. views on the manifold methods science employs to generate new knowledge) play a somewhat minor role in instructional practice. The same holds for views of the "Nature of Science" (NOS; Abd-El-Khalik, & Lederman, 2000).

Regarding the way physics is taught, worldwide limited strictly teacher controlled instructional strategies prevail. Most teachers are not (well) informed about the actual state of research on efficient teaching and learning. Their way of thinking about good instruction is limited to model the physics content adequately

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but often does not include modelling of students' abilities, motivation and interests (Duit & Treagust, 2008).

It should be added that the above briefly summarized deficiencies of physics instruction basically hold for science instruction in general (Tytler, 2007). There are many attempts worldwide to improve the situation. Quite recently, the European Commission, for instance, issued a proposal by an expert group: "Science Education NOW: A renewed pedagogy for the future of Europe" (European Commission, 2007). The attempts developed deliberately address the deficits outlined. First, science content is not restricted to science concepts and principles; second, content is embedded in contexts that make sense to the students (Nentwig, & Waddington, 2005), and, third, constructivist oriented instructional strategies are employed fostering students' responsibility for their own learning (Beeth et al., 2001).

2 SCIENTIFIC LITERACY

In the 1990s an intensive debate on "scientific literacy" needed for the 21st century occurred (Gräber & Bolte, 1997). Major goals of science instruction aiming at "scientific literacy" were (a) recruiting students for science and technology related careers, and (b) providing skills for understanding the world and for civic responsibility in an increasingly technological world. Two basic viewpoints are essential, namely developing understanding of science, and contribution to general school education (i.e. cross-curricular competencies) as pointed out within the scientific literacy conception of the international monitoring study PISA (OECD, 2005). Based on a nation wide project Millar and Osborne (1998) presented four arguments why scientific literacy is essential:

(1) ***The economic argument:*** Modern industrialized societies need scientifically literate workforces;
(2) ***The utility argument:*** Individuals need some basic understanding of science and technologies to function effectively as individuals and consumers;
(3) ***The cultural argument:*** Science is a great human achievement and it is a major contributor to our culture;
(4) ***The democratic argument:*** Citizens need to be able to reach an informed view on matters of science related public policies in order to participate in discussions and decisions.

Scientific literacy includes various content issues:

(i) The concepts and principles of science (which are usually predominating)
(ii) Scientific methods (processes)
(iii) Views about the nature of science
(iv) Views about the relevance of science in society and technology including advantages and risks.

It appears that the view of scientific literacy briefly outlined above is widely accepted as aim of teaching science in school. It will be briefly discussed in the following that physics education research should play a major role in attempts to improve science teaching and learning in such a way that scientific literacy as outlined may result.

3 ON THE INTERDISCIPLINARY NATURE OF PHYSICS EDUCATION

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

Philosophy of science and history of science provide thinking patterns to critically analyze the nature of science, and the particular contribution of science to understand the "world", i.e. nature and technology. Pedagogy and psychology provide competencies to consider whether a certain topic is worth teaching and to carry out empirical studies whether this topic may be understood by the students. There are further reference disciplines that come into play also, like linguistics which may provide frameworks for analyzing classroom discourse or conceptualizing learning science as introduction into a new language or ethics for framing instruction on moral issues.

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

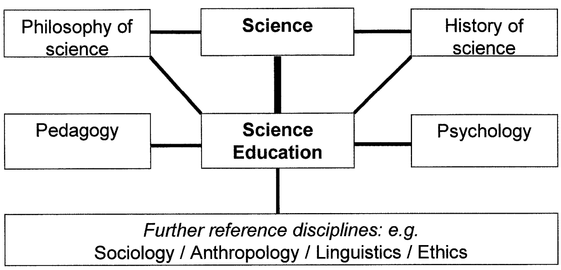

Figure 1 Reference disciplines for science education.

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

4 THE MODEL OF EDUCATIONAL RECONSTRUCTION

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

The model is based on the German educational tradition of "Bildung" and "Didaktik" (Westbury, Hopmann, & Riquarts, 2000). Both terms are difficult to translate into English properly. A literal translation of "Bildung" is formation. In fact Bildung is viewed as a process. Bildung stands for the formation of the learner as a whole person, i.e. for the development of the personality of the learner. The meaning of Didaktik[b)] is based on the conception of Bildung. It concerns the analytical process of transposing (or transforming) human knowledge (the cultural heritage) like domain specific knowledge into knowledge for schooling which contributes to the above formation (Bildung) of young people. Briefly put, the content structure of a certain domain (e.g. physics) has to be transformed into a content structure *for* instruction. The two structures are substantially different. The science content structure for a certain topic (like the force concept) may not be directly transferred into the content structure for instruction. It has not only to be simplified (in order to make it accessible for students) but also enriched by putting it into contexts that make sense for the learners. Two phases of this process may be differentiated. The first may be called "elementarization". On the basis of this set of elementary ideas the content structure for instruction is constructed. It is a key claim of the Didaktik tradition that both processes "elementarization" and "construction of the content structure for instruction" (see Figure 2) are intimately interrelated to decisions on the aims of teaching the content and the students' affective and cognitive perspectives.

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

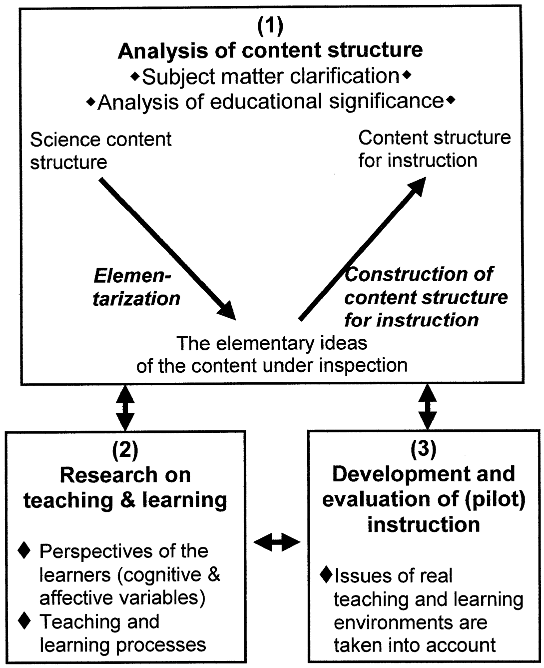

Figure 2 The Model of Educational Reconstruction

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

5 DOMAINS OF SCIENCE EDUCATION RESEARCH[c)]

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

5.1 Analysis of Content Structure

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

Research methods for subject matter clarification (concerning the above set of content issues) are analytical (or hermeneutical) in nature, and certain methods of content and text analyses prevail. History and philosophy of science issues come into play here.

Analysis of educational significance will be usually also analytical in nature, i.e. drawing on certain pedagogical norms and goals. However, in projects on educational reconstruction of large domains empirical studies on the educational significance may be also empirical, e.g. by employing questionnaires to investigate the views of experts (cf. Komorek, Wendorf, & Duit, 2003) or variants of Delphi studies (Osborne, Ratcliffe, Millar, & Duschl, 2003).

5.2 Research on Teaching and Learning

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

A large spectrum of methods of empirical research is employed ranging from qualitative to quantitative nature, including questionnaires, interviews and learning process studies. Drawing on methods developed in social sciences (like

[c)] For an overview of research on teaching and learning physics see Duit, Niedderer, and Schecker (2007).

psychology) and close cooperation with social scientists in developing methods that address science education research needs has proven essential.

5.3 Development and Evaluation of Instruction / Instructional Design

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

5.4 Research on Curricular Issues and Science Education Policies

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

This domain concerns features of the educational system in which science instruction is embedded. Research here concerns decisions on the curriculum, on aims and contents of science instruction as well as on implementation, evaluation and dissemination of innovations introduced into the school system. Research on scientific literacy, standards, systemic reforms (quality development) and teacher professional development have become much researched sub-domains in science education the past years. Also international monitoring studies like TIMSS (Third International Science and Mathematics Study; Beaton et al., 1996) and PISA (Programme for International Student Assessment; OECD-PISA, 2005) have to be mentioned here. On the one hand they provide a large set of data that have been interpreted also from science education perspectives. On the other hand these studies have revealed serious deficits of science instruction in many countries and incited various large scale attempts worldwide to improve science teaching and learning (Beeth, et al., 2003) as is outlined also in Figure 3.

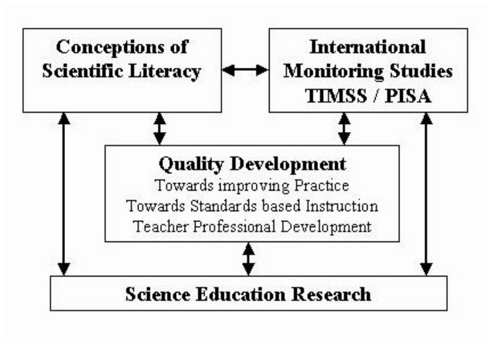

Figure 3 Present large scale attempts to improve science instructional practice.

Figure 3 also displays that science education research is one of many "players" in attempts to improve science instruction. A close cooperation with the other players is absolutely essential. This also concerns cooperation with the reference disciplines pedagogy and psychology in Figure 1. To carry out science education research not only requires drawing on theoretical frameworks and research methods of these reference domains. It has proven also rather fruitful to carry out joint research projects where mutual interests exist. Research on teaching and learning a particular content, for instance, may only inform improvement of practice if the above content specific considerations are taken into account – that also holds for research carried out by educational psychology.

6 PHYSICS EDUCATION RESEARCH – INDISPENSABLE FOR IMPROVING TEACHING AND LEARNING

Improving teaching and learning physics is far from being an easy venture. Improvement of teacher competencies *and* quality of instruction is always due to an intimate interplay of many variables. Improvement of student achievement may, for instance, not be expected if chiefly one variable is changed, e.g. new experiments or computer simulations are introduced. Such simple actions usually do not work. It is always necessary, that physics subject matter issues and pedagogical/psychological issues are taken into account. Physics educators who attempt to improve practice need various competencies beyond intimate familiarity with physics concepts and principles (see Figure 1 above). For improving practice there are no simple recipes. We are trying to investigate or steering highly complex non-linear systems.

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