Chapter 3
Didaktik—An Appropriate Framework for the Professional Work of Science Teachers?

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Didaktik and Current Developments in Science Education

Three factors can be identified that contribute to a marginalization of content, particularly in the perception of teachers but also in the activities of researchers in science education. Each of the three comes from a different aspect of science education:

The first factor derives from the Anglo-American curriculum tradition. In this curriculum tradition a division of labour takes place in which curriculum experts formulate content standards independently of the practitioners responsible for teaching and learning the content. Teachers are to implement effectively a curriculum of content "as an agency for the institutionalized teaching of a 'content', seen unproblematically in terms of this or that view of and selection from a subject matter" (Westbury 1998, p. 62).

The second factor contributing to a marginalization of content comes from developments in science education research—the shift to give priority to essential ideas of cognitive psychology in research on teaching and learning has reinforced this marginalization process. The role of subject matter became more and more underestimated in empirical studies on teaching and learning. "Such neglect is surprising given the needs to be specific about issues of knowledge when we address the curriculum of 'knowledge societies': *What should we teach* is subsequently pushed into the background" (Klette 2008, p. 4; emphasis in original).

The third factor is the currently very strong presence of large-scale assessment studies such as TIMSS and PISA. These have supported a process of standardization in the many countries participating in these studies (see Waddington et al. 2007, for an overview). The development of knowledge tasks for these assessments is restricted to small groups of determiners, and takes place in the absence of broad discussions about fundamental aspects of general education and about subject-related instructional goals. Educational policy makers, school administrators, teachers, and

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students in the participating countries are only very minor players in the design processes that lead to a standardization of the knowledge content of these tests.

In this situation Didaktik can be a corrective, bridging content-related issues on the one hand and pedagogical aspects on the other. Didaktik provides a teacher with a language and intellectual scaffolding with which he/she becomes able to scrutinize the content topics of the curriculum mandated by the state in terms of their contributions to a value-oriented education of students. The teacher as a professional practitioner has to embed the topics into an educational context. Didaktik "seeks to model forms of teacher thinking that might direct the teacher to systematic hermeneutic reflection about the ways in which classroom environments might support a personal subjective encounter, or relationship, with the educative 'content' represented in the curriculum, the ultimate forms of social life, and the like" (Westbury 1998, p. 57).

The spelling of "Didaktik" is deliberately distinguished from *didactic* because of the very different connotation of these different words. The latter, *didactic,* describes a methodological conception that has pejorative vibes. "Someone who is *didactic* tells people things rather than letting them find things out or discussing things" (Collins COBUILD English Dictionary 1995). *Didaktik*, on the other hand, has no linkage with this description of a particular form of teacher/teaching.

Didaktik offers a response to many critics who claim that improvement of science teaching and learning is not only a matter of teaching methods but also an issue of science content. Fensham (2001) reminded the science education community "that the disciplinary knowledge of the sciences is not automatically appropriate for school science" (p. 38). Criteria are needed for the processes of selection of topics, their elementarization and their construction for instruction, including as a later part of this process the students' cognitive and affective preconditions (as an example see Duit et al. 1997, also Duit et al. 2007).

It is not suggested that the continental European concept of Didaktik is to replace the Anglo-American tradition of curriculum. But it can supplement the curriculum tradition by emphasizing content-related aspects at the level of daily teaching. Thus, Shirley (2008) saw opportunities to combine positive results within curriculum-oriented developments on the one hand and Didaktik-oriented principles on the other. The standards and accountability movements, together with the tendency to embed investigations on teaching and learning oriented to cognitive psychology and disregarding issues of content into research designs, have generated several different consequences. They have caused discussions among teachers on how to meet these standards and therefore contributed to a deeper awareness of learning efficiency problems; in some cases this has resulted in positive practitioner collaboration. On the other hand the "division of labour" mentioned above has been strengthened. Shirley (2008) calls for a "post-standardization" phase in which these aspects are both taken into account: "The challenge in a new era of post-standardization, then, will be to sustain the momentum that reformers have made enabling teachers to collaborate and to innovate, but to do so in such a way that befits the full human dignity of learners who aspire towards autonomy (*Mündigkeit*) and self-activity (*Selbsttätigkeit*) as free and sovereign beings" (Shirley 2008, p. 38).

Bildung as an Essential Element of Didaktik

Bildung and Didaktik

In the German-speaking countries, and to some extent also in the Northern European countries, "Bildung" is the central notion describing the process of personal development and the result of this development process. Bildung is more than education; therefore no English term denotes the concept of Bildung appropriately. Some scholars translate Bildung as "formation", covering the forming of a personality and the product of this formation. It may be helpful for readers who come from the Anglo-American curriculum tradition to read what an American educational researcher proposes as a valid description after having struggled with numerous attempts to clarify the meaning of Bildung:

> *Bildung* is a noun meaning something like "being educated, educatedness". It also carries the connotations of the word *bilden*, "to form, to shape". *Bildung* is thus best translated as "formation", implying both the forming of the personality into a unity as well as the product of this formation and the particular "formedness" that is represented *by* the person. (Westbury 2000, p. 24; see also the descriptions by Nordenbo 2002 and Wimmer 2003, Wimmer is quoted by Ogawa, in Chap. 8)

Even in the German language it is not possible to find a clear and brief definition of Bildung. Among other reasons this is due to the fact that the concept of Bildung has undergone various changes of its meaning over recent history. Wolfgang Klafki, the most prominent exponent of a modern conception of Bildung, drafted the most significant indicators of this development in some decades around 1800, by absorbing stimuli from the European Enlightenment, "a few fundamental points in common emerged, not least the idea of the self-responsible, cosmopolitan person, contributing to his own destiny and capable of knowing, feeling and acting" (Klafki 1998, p. 313).

For Klafki, the terms "*self-determination, freedom, emancipation, autonomy, responsibility, reason,* and *independence*" are crucial notions denoting Bildung (Klafki 2000a, p. 87). This set of concepts describing qualities individuals should strive for could be misinterpreted as a portrayal of Bildung as an individualistic conception, but Klafki goes on to say: "…the basic concept of subject- or self-determination is anything but subjective!" (Klafki 2000a, p. 88). Bildung is also characterized by a second group of determinants: "*humanity, humankind* and *humaneness, world, objectivity, the general*" (Klafki 2000a, p. 88). Bildung, therefore, develops in the interplay between individual attributes, achievements and expectations on the one hand and the conditions a person has to cope with on the other. These conditions are results of societal processes and comprise different kinds of social life as well as systems of norms and beliefs that pertain to the fields of politics, arts, science and other domains.

Although Bildung refers to an individual's community, Klafki perceived a lack of an in-depth analysis of an individual's environment: "…the economic, social, and political conditions needed for the realization of this general demand for Bildung" was not examined consistently by those who strove for a widely accepted conception of Bildung (Klafki 2000a, p. 89). He proposed a further development that takes account of contemporary approaches to "a more differentiated and critical determination of the relationship between Bildung and society" (Klafki 1998, p. 313). Three abilities were, in this way, to be promoted by Bildung (Klafki 1998, p. 314):

- Self-determination
- Co-determination (all people are invited to take part in the development of the society)
- Solidarity (with those "whose opportunities for self-determination and co-determination are limited")

Bildung and Scientific Literacy

The generally accepted understanding of Bildung becomes more clear when compared with and contrasted to the way scientific literacy has often been used in the last two decades. For example, in the context of the OECD PISA project, scientific literacy stresses the application of knowledge and therefore has a more functional connotation than Bildung has. The cognitive aspects of students' scientific literacy "include students' knowledge and their capacity to use this knowledge effectively…" (OECD 2006, p. 22, see also Fensham 2007). Another characteristic feature of the PISA program is its claim to test whether or not students are well prepared for the demands imposed on them during their whole life: "PISA 2006 covers the domains of *reading, mathematical* and *scientific literacy* not so much in terms of mastery of the school curriculum, but in terms of important knowledge and skills needed in adult life" (OECD 2006, p. 8). Bildung also claims to help students withstand the challenges of their future life but by a *general* preparedness that is not simply acquired knowledge and skills.

The dominant position of the term "scientific competency" in the description of the PISA program (OECD 2006) signals additional differences between Bildung and scientific literacy. The focus on functionalist aspects of students' knowledge (competencies and skills) contrasts with the concept and *process* of Bildung; this concept and process are not primarily aimed at gaining specific qualifications that result in substantial benefits, but at helping a learner to acquire a characteristic individuality that allows one to successfully approach the above mentioned attributes of a person with Bildung. Therefore, a phrase such as "We teach children to be competent in a special domain" is not in line with this perception of Bildung. Knowledge is a part of Bildung, but the knowledge is embedded into a holistic view of the personality of an individual. Within this view both aspects of education—to help students to achieve a considerable state of Bildung as well as to prepare them to meet the requirements of private and vocational life—are two sides of the same coin. One of the most distinguished contemporary German pedagogues, Hartmut von Hentig, well known as an author of fundamental reflections on Bildung and as a school and university teacher, has used a pictorial metaphor to illustrate this situation. Bildung describes the tension or the bridge between ideals passed on and current needs of competence, between philosophical self-assurance and practice-oriented self-preservation of the society. According to Plato's great Cave Allegory: Bildung is both, the rise towards sunlight and the descent towards the cave. The one side without the other is senseless (v. Hentig 1996, p. 58).

Teachers Within the Concept of Didaktik

More than 50 years ago Klafki presented reflections on a possible transformation of a subject matter into an educational content. A series of five questions was proposed as a guidance for a teacher's reflections when preparing lessons, reflections leading to designing "one or several opportunities for children to make fruitful encounters with certain contents of education (Bildungsinhalte)" (Klafki 2000b, p. 143). This early version of a content analysis in Didaktik ("Didaktik analysis") was based on Klafki's first approach to a connection between the classical conception of Bildung and its significance for teachers' daily work. Under the perspective of the more modern interpretation of Bildung, Klafki expanded his comments on the five main questions towards the integration of social conditions and the processes of interaction. The starting question for the Didaktik analysis refers to a teacher's situation at the beginning of his/her lesson planning: "What questions, therefore, should a teacher ask in the preliminary phase of instructional preparation….?" (Klafki 2000b, p. 151). The five questions mirror the wide range of reflections teachers are requested to make:

I. What wider or general sense or reality does this content exemplify and open up to the learner? What basic phenomenon or fundamental principal, what law, criterion, problem, method, technique or attitude can be grasped by dealing with this content as an "example"?
II. What significance does the content in question, or the experience, knowledge, ability, or skill to be acquired through this topic already possess in the minds of the children in my class? What significance should it have from a pedagogical point of view?
III. What constitutes the topic's significance for the children's future?
IV. How is the content structured (which has been placed in a specifically pedagogical perspective by Questions I, II and III)?
V. What are the special cases, phenomena, situations, experiments, persons, elements of aesthetic experience, and so forth, in terms of which the structure of the content in question can become interesting, stimulating, approachable, conceivable, or vivid for children of the stage of development of this class? (Klafki 2000b, pp. 151–155).

In Germany and some other countries, generations of teacher students were introduced to the procedure of Didaktik analysis which helps teachers to reflect on the school contents' contributions to develop students' Bildung and to make content-related decisions about their teaching grounded on this analysis (Hopmann 2000). Student teachers learn that reflections on these questions do not deliver definite responses, but they open a discourse—preferably with colleagues—in which aims of instruction, students' cognitive, social, and affective perspectives, and the scientific structure of a topic under question are linked to each other, so that at the end of an iterative process an appropriate content structure for instruction becomes visible ("educational reconstruction", Duit et al. 1997, p. 602, Kattmann et al. 1995). In many cases a consensus on broader domains of content is achieved quite easily, but it is basically more difficult to scrutinize details. There is no doubt that the principles of quantum physics are a significant example of modern physics. The photo-electric effect and the Franck-Hertz-Experiment are widely accepted as parts of a syllabus at the upper secondary level and most teachers agree that these effects can be learned by students without serious learning problems. But there would be less agreement about the Compton Effect. How "fundamental" is this effect for understanding the principles of quantum physics?

Some aspects of Klafki's questions have been taken on and further developed by educationalists who, from various perspectives, have contributed to efforts to improve science education. For example, Klafki's II comprises students' prior knowledge and conceptions, but also includes their emotions connected with a topic. In a proposal that received wide attention Klafki suggested a way to achieving general education (Allgemeinbildung) by orientation at "key issues" (Schlüsselprobleme) that are to be defined as typical and topical for a given time period. For our cultural existence, topics such as peace, environment, impact of technology on the society, human rights, and others are to be considered. The "science-technology-society" (STS) movement in science education can be interpreted as a part of this idea. The attempt to derive concrete themes from these overarching frames necessarily fails, taking into account Klafki's criteria as a whole. Klafki's Didaktik analysis does not offer a means for a detailed determination of topics in science education, but it helps teachers to reflect on criteria that are oriented at students' cognitive and emotional preconditions, as well as at the significance of topics for students' current and future lives, and at requirements demanded by the society.

Referring to Didaktik analysis Shirley (2009) complains about the absence of a theoretical basis like Didaktik in the American tradition: "The loss of a living link to the Didaktik tradition is especially unfortunate because the moral values at the center of Didaktik are unavailable to contemporary American educators—at least through this venue" (p. 199).

Bildung Within Natural Sciences

Among other scholars, Martin Wagenschein (2000a) has been particularly prominent. He has written numerous basic articles, and with many and varied examples described how students' Bildung in natural sciences can be achieved. His central ideas are known by nearly all science teachers in the German-speaking countries and many teachers have read at least one of his publications.

For Wagenschein, the main goal of science education is to help students understand phenomena of the natural world. To "understand" means to have gained insight into the essence of scientific relationships, it does not mean just to know the formula or to be able to apply it to a concrete problem. According to Wagenschein, there are three characteristic teaching–learning situations in which Bildung in this sense is developing:

- *Exemplary teaching:* In order to gain a deep understanding of a piece of content it is necessary to invest a sufficient amount of time. Therefore, "we need the courage to leave gaps, in other words to be thorough and to deal intensively with selected examples" (Wagenschein 2000a, p. 116).
- *Genetic teaching:* If the knowledge is to become an integral part of a student's Bildung it is important that he/she has the opportunity to search productively for the solution of a problem, to find it, and to check it critically. With this position Wagenschein, already at the beginning of the 1950s, of the last century, introduced elements of an idea that later, in its cognitive dimension, was portrayed as the constructivist view of learning. Wagenschein emphasized the development of knowledge much more than the result of the process of acquiring knowledge.
- *Socratic teaching:* A teaching–learning process which focuses on the development of knowledge is best arranged in a Socratic conversation. The teacher has to talk with his/her students not in a lecturing and dogmatic way but, like Socrates in his dialogues, focussing on their ideas and moderating their learning processes.

According to Wagenschein, teaching environments with this triad of principles are particularly suitable (and often necessary!) for learning phases in which a basic understanding of central notions and processes in natural sciences are to be acquired. This is especially the case in the upper grades of elementary school and lower grades of secondary school. However, Wagenschein's triad is meant to be effective at all levels, since the process of Bildung does not come to an end. But weightings shift priorities: at higher levels the preparation for vocational or academic studies is dominant.

In order to substantiate the idea of an exemplary, genetic, and Socratic way of teaching, an example described by Wagenschein and translated into English (Wagenschein 2000b) is now given to clarify this conception:

The starting point for this example is Wagenschein's observation that after having been a student at school most people remember the term $g/2 \times t^2$ when asked for the characteristics of a free fall, even though they are not able to describe what this term really means. In his example Wagenschein pleads for teachers to ask the students to begin a series of investigations starting with Galileo's inclined plane experiments that give them the chance to refine their measurements from very simple methods, i.e. weighing the amount of water that flows into a bucket while the rolling ball covers a definite distance (as Galileo describes it), using a ruler and a metronome or a stopwatch, up to the application of electronic devices. At the end of such an extended investigation of reflections, deliberations, and experimental improvements the sequence of the numbers 1, 3, 5, 7,… may result. This denotes the distances between the points passed by a constantly accelerated (e.g. a falling) body in fixed time intervals. Wagenschein argues that if the teaching goal is not simply to be able to apply a formula, but to understand the characteristic feature of the free fall, the odd-numbered sequence is a much more appropriate description than the term mentioned above.

A comparison of this example with Matthews' (2000) proposal for teaching pendulum motion reveals both similarities and fundamental differences. The similarities are related to the historical and philosophical references that are emphasized by both authors as important parts of a science curriculum. A basic difference is revealed by the authors' conceptions about learning physics. For Wagenschein, the often strenuous and sometimes long-lasting work of students who follow their own suggestions to find approaches to solving problems could lead to a concept or a theory in the final stage of their work. Such a process contributes to students' Bildung even in those cases where their endeavours do not lead to a result they are comfortable with. In Matthews' transmission view these activities of students would be a waste of time: "…at the heart of science are concepts, and these need to be understood first" (Matthews 2000, p. 280). He goes on to argue that teachers have to provide their students with the correct scientific view before any observation begins: "…the theoretical structure that precedes observation is something that students need to receive from teachers" (p. 279).

A chemical example is now given to demonstrate how students can approach basic ideas in chemistry on their own. Under the perspective of Bildung, a central appeal to science teaching emphasizes the significance of phenomena which should have the priority over their explanation by means of models, at least in a first phase of a course. In chemistry teaching, chemical reactions are often described too early by chemical equations that mirror an interpretation which is not easily understood by students: The symbols in a chemical equation reflect the existence of atoms which remain unchanged in a reaction. In the view of many teachers, the idea of "conservation" matters a great deal, and atoms are appropriate entities to meet this principle. However, students cannot perceive conservation but they do observe changes and transformations in chemical reactions.

Buck and Mackensen (2006) describe a chemistry-related teaching–learning example that is, as they state, inspired by Wagenschein. They report on ideas of de Vos (2002) who proposed presenting a chemical reaction to students which dispenses with all effects that could students distract from the main point, namely from the conversion of one substance into another one (therefore a chemical; reaction with no fire, no detonation, no "fizzling", no electricity, etc.). A simple and beautiful reaction happens when solutions of lead nitrate and potassium iodide are mixed. A magnificent yellow precipitate is formed which slowly sediments from the solution. Chemists regard the chemical equation as the optimal form for describing the process:

$$Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$$

Many teachers try to reach this equation quite early with their students without asking whether the students have understood the basic assumptions connected with this equation. A genetic approach aims at just such an understanding of assumptions.

The series of experiments begins with mixing the two substances without any solvent but using a pestle and a mortar. Rather quickly a bright yellow colour appears. The colour becomes visible during the process of rubbing and is restricted to this area. The teacher does not need to ask the students, this phenomenon raises its own questions. Many students believe in the conservation of substances, at least in the conservation of their characteristics in any process. Therefore, the following statement is one consistently given by students: "The yellow substance has already been in the grains (like yolk of an egg), the rubbing has opened the grains and freed the yellow colour." The rubbing of the pure substances and of the mixture can contribute to test this hypothesis. The influence of the rubbing can be qualified by putting the two substances together so that they have an area of contacting each other. A weak yellow line becomes visible. The pestle is only a mechanical instrument to intensify the contact.

Another characteristic of students' questions and statements is their refusal to speak of a yellow substance; they mostly mention a yellow colour. It is hard for students to accept that, in a reaction, substances disappear and new ones are created. Therefore, subsequent investigations are used to reinforce this aspect. In a Petri dish a layer of distilled water covers the base and small portions of the two substances are placed into two sectors of the dish opposite to each other. Both substances dissolve and after a while a thin yellow line emerges that grows in length and breadth: a dune of gold. The separation of manipulation and reaction is a central feature of this process; dissolution, transport and chemical reaction take place in different areas of the Petri dish at different times and each phenomenon can be thus observed separately.

The discussions about these de-accelerated phenomena of "lapsing" and "emerging" of substances can lead to a deep understanding of the fundamental characteristics of chemical reactions if a teacher gives students enough time to reflect on questions that, almost inevitably, appear: How can a yellow substance emerge from colourless stuff?—obviously two special substances are necessary. Do the substances disappear while the yellow is emerging?—the yellow was not there before, therefore it is new. But nothing was added or removed. Is it possible the yellow was already there?

Wagenschein's idea of genetic and Socratic teaching and learning is in evidence with this example. The described way of knowledge growing leads to an "enrooting" that is different from knowledge that can be assessed by means of questionnaires. Unfortunately, in Germany students are not allowed to work with lead nitrate, but good chemistry teachers need to find a way to keep up the principles of genetic and Socratic teaching with a similar instructive example.

There are some preconditions for teaching and learning situations aiming at Bildung: concentration on selected topics which have the power to serve as examples to achieve Bildung; reference to historical examples if suitable (because often these developments are similar to students' ways of thinking); sufficient time for the students to try out in experiments what they have conceptualized in order to solve a problem; and phases of metacognitive reflections on the status of one's own learning and knowledge (Gunstone 2001). Knowing that the everyday situation in classrooms and schools very often hinders the realization of such teaching–learning processes, Wagenschein proposed some rules teachers should take into account when striving for the improvement of their teaching:

- *Not always:* First, the simple, elementary (and often boring) topic, then step by step the more difficult topic,
  but often: First, an astonishing, complicated, and problematic case, then the challenge to discover comprehensible and familiar topics.
- First, the phenomenon in nature, then the phenomenon in laboratory.
- First "qualitative", then "quantitative".
- First the phenomenon, then the theory and the models.

Teacher Education that Facilitates Students' Bildung

Questions

What are the consequences of these reflections on students' Bildung for teacher education programs? Which knowledge base is necessary to become a teacher capable of fostering the development of students' Bildung? What other attributes of a teacher besides his/her knowledge are characteristic features of a teacher with high professional expertise? What are the main indicators of different phases of teacher education?

In a profound analysis of the literature on attempts to systematize the various components of a teacher's professional expertise, and as a basis of a research project on mathematical teachers, Kunter et al. (2007) propose a model that describes components seen as being at the core of a mathematical teacher's professional competence. As psychologists the researchers concentrate on variables that can be recorded by questionnaires, and they regard the notion "competence" as being appropriate in this context.

The main aspects of teacher competence Kunter et al. (2007) propose are represented by the following concepts:

- *Knowledge*. For knowledge, the authors adopt a part of Shulman's differentiation between different facets of a teacher's knowledge (Shulman 1986): general pedagogical knowledge, subject-matter content knowledge, and pedagogical content knowledge.
- *Beliefs*. Teachers' beliefs indicate how they think about different conceptions of teaching and learning, about the nature of knowledge, and about their instructional goals.
- *Psychological functioning*. A combination of high engagement and a high capacity to deal with the pressures of school life is crucial for teachers' psychological

functioning. Different motivational variables are defined in order to have instruments to measure these aspects.

In science teacher education, among these aspects it is mainly the knowledge-related components that are subject to efforts to help students develop a basic qualification for their profession. This is so despite the fact that knowledge is not a sufficient (and sometimes not even a necessary) precondition for excellence in teaching. In a later section of this chapter the relationship between knowledge and ability to teach is discussed in more detail. The development of student-teachers' subject matter content knowledge (CK) and pedagogical content knowledge (PCK) are the goals of science teacher education, although aspects of general pedagogical knowledge (PK) are effective within every teaching situation. At least two basic questions need to be carefully considered when designing a study program:

(a) Which topics within science and which themes within science-related pedagogy are necessary parts of a teacher education program?
(b) What are the expectations concerning the influence of teachers' content knowledge (CK) and pedagogical content knowledge (PCK) on their teaching competence?

These two questions cannot be discussed separately. But for analytical reasons, some aspects of each particular question are now considered individually; after this is done the two questions are referred to each other.

Answers: Subject Matter Knowledge

In 1999 the vast majority of the European countries agreed upon a declaration in which they promise to introduce, among other things, a system "of easily readable and comparable degrees", adopting a "system essentially based on two main cycles, undergraduate and graduate" (Bologna 1999).

In the context of subsequent intensive discussions about whether and how to introduce the Bachelor-/Master-System for teacher education studies, two opposing positions were put. The first position advocated a more consecutive model where the dominant idea is that a broad basis of subject matter knowledge—acquired in a first study phase resulting in a bachelor's degree—is a good foundation of various professions. In this case a bachelor's degree is a polyvalent certificate. The second position advocates a model stressing studies oriented towards an integrative design in which subject matter CK studies and PCK studies are referred to each other from the beginning. The goal of this integrative model is to lay the foundation stone for a successful process of professionalization as early as possible.

In Germany, the second model became accepted. For the time being this situation marks the end of an area of many decades in which the following phrase guided the science studies of prospective teachers working at a Gymnasium (high school): "The more excellent a teacher's subject knowledge is the more efficient is his/her teaching." After much questioning of this dictum, the guiding principle is now an optimal interconnection of subject matter and pedagogical (content-related) topics. This means that in teacher education content-related as well as organisational elements of teaching and learning settings are to be integrated, so that they offer alternatives to the traditional modes of teacher training. Self-determined studies, long-term projects, historical references to scientific topics, and a presentation of science that starts from phenomena and holistic approaches then moves to systematic and analytical considerations are some of the elements necessary to prepare teachers for activities with which they foster students' Bildung in schools. The principles of Didaktik applied in teacher education require a study program for prospective teachers that is different from the programs for bachelors or masters students who are to become science researchers. These changes require a longer period of time to develop but more and more changes become visible which can support the claim that teacher education programs are study program "sui generis".

In a study for the German Physics Society (DPG 2006) physicists together with physics educators called for changes of methods and topics in physics teacher education studies. The starting point of the physicists' reflections on appropriate physics studies for student-teachers was the demanding tasks teachers are confronted with in schools.

> The young prospective teachers have to be provided with an optimal instruction and with optimal tools for their performing of the tasks. Practice has shown that teacher training which is—to a considerable amount—just an appendix to subject matter studies in physics, does not meet these requirements. Therefore, student-teachers' studies in physics have to be optimized especially for the demands on teachers. That means student-teachers' studies have to be studies sui generis. (DPG 2006, p. 4, translation: author)

- Methods in Physics courses should be designed in a way that students experience teaching–learning situations which they later as teachers can apply as models of their own lessons in which they teach captivatingly, with enthusiasm, and oriented at students' interests.
- The topics should not be determined by the system of physics, but assigned to themes across different complex areas, e.g. swimming–streaming–flying or earth–weather–environment.

Obviously, these proposals by German physicists do not explicitly define a program to prepare student-teachers for processes of Bildung in physics education in schools. But some elements point to this direction, for example, the focus on students' active participation in lessons and the concentration on topics which are challenging students' engagement (See the quote from Wagenschein given above, at the end of the section Bildung Within Natural Sciences: "…but often: First an astonishing, complicated, and problematic case…"). Physicists at universities have begun accepting that the knowledge standards they expect from future physicists have to be different from the standards they demand of student-teachers. With knowledge about the Lagrange formalism in mechanics, or the Dirac equation in quantum physics, teachers are definitely overqualified. In Germany, prospective teachers have to study (and later on teach) two subjects. During their studies the professionally oriented components (general and subject-related pedagogy, teaching internships) of their qualification cover a third of their whole study program.

There are no empirical investigations about the effectiveness of different teacher education systems, for instance comparing the consecutive Anglo-American system with the integrative system in Germany, but the results of large-scale surveys show that German teachers at all school levels believe they are sufficiently knowledgeable about the science content of their subjects and that they appreciate the early connection of science contents with instructional aspects since it helps them to realize early the pedagogical potential of the science topics to be taught and learnt (Merzyn 2003).

Answers: Pedagogical Content Knowledge

To carry out a lesson according to Wagenschein's example of the inclined plane requires more than subject matter knowledge and pedagogical knowledge. For instance, it is necessary to know something about students' preconceptions concerning motion and acceleration, to know how familiar students are with methods of measurement and how to help students organize group work in physics. There is no doubt that science teachers need content-related pedagogical knowledge. For many decades prior to Shulman's introduction of the notion pedagogical content knowledge, "Fachdidaktik" has been a part of student-teachers' study programs at the Universities of Education in Germany. "Fachdidaktik" combines "Fach"—subject matter—with Didaktik and is closely connected with the conception of Didaktik. One single definition of Fachdidaktik does not exist (as is also the case with PCK) but during a long tradition an understanding developed that became visible in study programs and examination regulations.

The somehow diffuse character of Fachdidaktik needs, however, to be sharpened in investigations where Fachdidaktik (or PCK) is a variable in a research design. In a broad quantitative study a research group in Germany investigated the impact of mathematics teachers' PCK on particular aspects of their mathematics instruction, e.g. on students' cognitive activation. The processes of conceptualization resulted in items forming subtests which covered subfacets of PCK. "Square" is an item of the subfacet "Tasks": "How does the surface area of a square change when the side length is tripled? Show your reasoning." (Kunter 2007, p. 47; see also Krauss et al. 2008)

The researchers' basic assumption is that tasks with multiple solutions are best suited to support students' learning processes. As a consequence, teachers' competence is seen to be reflected in the largest possible number of solutions they are able to depict. In the "Square" item teachers are prompted to show their competence: "Please note down as many different ways of solving this problem (and different reasonings) as possible."

With this example, the problem of a more precise description of PCK becomes evident. How near to a teacher's subject matter knowledge is PCK to be defined? Should the elements of PCK not be closer to a teacher's decision making in the classroom?

The conceptualization of PCK revealed in the above item can be described as overemphasizing the intellectual aspects of teaching because, with this understanding of PCK, acting in classroom is not imaginable without acts of intellectual planning and applying. For the development of students' Bildung, this restricted conception of PCK is lacking aspects which need to be taken into account when reflecting on the relationship between thinking and acting.

Bildung and Technical Rationality

Why is the conception of PCK apparent in the item described above not an appropriate one in order to be a guideline for science teacher education aiming at the development of students' Bildung?

Schön, taking on and developing Michel Polanyi's phrase "tacit knowing" ("we can know more than we can tell", Polanyi 1966, p. 4), has described professionals' "thinking in action". He argued against the idea of a successive progression of thoughts and acts: "Once we put aside the model of Technical Rationality, which leads us to think of intelligent practice as an *application* of knowledge to instrumental decisions, there is nothing strange about the idea that a kind of knowing is inherent in intelligent action" (Schön 1983, p. 50). We often carry out actions without any need "to think about them prior or during their performance" and "we are usually unable to describe the knowing which our action reveals" (Schön 1983, p. 54). Knowing-in-action, therefore, is "the characteristic mode of ordinary practical knowledge" (p. 54). Accordingly, Schön holds that, as a rule, experienced practitioners do not act according to a consecutive model—first the theory, then the practice—but perform in an intuitive-improvisational manner using their knowing-in-action (Schön) or tacit knowing (Polanyi), knowing which is often not accessible either to an observer or to the actor himself/herself.

Under this perspective, pedagogical content knowledge in Shulman's and many other authors' conception focusing on "knowledge" and "understanding" misses some facets out and takes too narrow a view. From experts in general and teachers in particular we expect to have "not mentally stored knowledge, but the ability to perceive, to think, and to act skilfully, to *do* certain things in an expert-like way. We are interested in *knowledge in use* rather than *knowledge as a state*" (Neuweg 2004, p. 2). Similar ideas are expressed by Jones and Cowie in their conclusion to their chapter in this volume (Chap. 4): "The knowledge, skills and practices that teachers describe provide one, and we would suggest, a rather restricted insight into the knowledge an accomplished teacher brings into play in the moment of interaction. Potentially more useful in the long term, but much more demanding in the short term, is the depiction of how and why teachers interact with students and their ideas in particular ways."

In the cases of pre-service teachers and novice teachers, another problem reinforces the separation of stored knowledge on the one hand and orientations of acting on the other. In many studies discrepancies between teachers' intentions to act—based on their knowledge—and their actions in classrooms have been found (Fischler 1994). The interpretation of this dilemma refers to the special demands on teachers' work: "Teachers must learn to weigh difficult dilemmas and to make and implement decisions on the fly; to put their plans into action effectively as well as to alter plans for unforeseen circumstances while they are in the midst of teaching; to respond to children and to represent well the material they are teaching" (Hammerness et al. 2005, p. 370).

In the current mainstream of research projects on teachers' professional development under a cognitive psychological perspective, the ideas of Polanyi, Schön, and of Neuweg (described below) play only a marginal role.

From the perspective of a tacit knowing Neuweg (2004, 2005) portrays the way to help student teachers to make explicit progress in the processes of professionalization. Neuweg specifies four preconditions for the emergence of pedagogical expertise: (1) Experience, (2) Knowledge, (3) Reflection, and (4) Personality.

Neuweg's First Precondition—Experience

In the light of the tacit knowing view, the phrase "knowledge informs action" is not tenable. Intuitive-improvisational acting is not primarily determined by plans but, above all, by a sensitive engagement in a "situation of uncertainty, instability, uniqueness, and value conflict" (Schön 1983, p. 49). Because implicit knowledge (knowing-in-action) cannot be made explicit, a novice is dependent on processes of learning through experience (learning by doing). Modes of apprenticeships presumably are appropriate means to meet these demands. Of course, these modes have to be connected to deep reflections on the relationships between the observed actions and the actor's underlying planning, knowledge, beliefs about teaching and learning, and pedagogical principles. Otherwise student teachers' "apprenticeship of observation" (Lortie 1975, p. 61) in the long period of being students themselves would prevent them from changing their preconceptions about teaching which they have developed through their numerous experiences.

Under this precondition, the following statement is fully justified: "…what we need is not so much theories, articles, books, and other conceptual matters, but, first and foremost, concrete situations to be perceived, experiences to be had, persons to be met, plans to be exerted, and their consequences to be reflected upon" (Kessels and Korthagen 1996, p. 21). Under the perspective of Schön, it is self-evident that he emphasizes the significance of a "reflective practicum" in which a novice has the chance to get to know practitioners with "their conventions, constraints, languages, and appreciative systems, their repertoire of exemplars, systematic knowledge, and patterns of knowing-in-action" (Schön 1987, pp. 36–37). The interactions with practitioners serving as coaches and, sometimes more importantly, with fellow students lead to reflections and learning processes that go "beyond statable rules… by constructing and testing new categories of understanding, strategies of actions, and ways of framing problems" (Schön 1987, p. 39).

Neuweg's Second Precondition—Knowledge

Besides the problematic nature of knowledge that is assumed to guide actions, another category of knowledge is significant for teachers: It is knowledge that prepares their actions in classroom, leads their perceptions in classroom situations, and helps them to justify their classroom decisions. Even though scientific knowledge on its own cannot produce excellent practice, a professional has to be able to show that his/her decisions have been reasonable under a scientific perspective.

Neuweg's Third Precondition—Reflection

In the above mentioned investigation with mathematics teachers one of the results referred to the question of whether or not experienced teachers are more competent in activating students cognitively. No correlation was found. Experience *per se* does not contribute to pedagogical expertise. In order to enable student-teachers to gain experience of high quality it is necessary to offer to them interplay between engagement in practice, reflection on their practice, and again acting and experiencing. In this way a reflective habitus can be developed.

Neuweg's Fourth Precondition—Personality

The personality paradigm does not play a significant role in contemporary research projects on teachers. The variables within the category "psychological functioning" are near to the dimension of personality but not completely in line with it. In teacher training it is important to inform students about the relevance of individual personal characteristics for their professional career and to offer to them possibilities of self-experience.

Consequences

Which consequences should be drawn from the statements, positions, and judgements unfolded above? There does not exist a master plan leading to science teachers' competence to foster their students' Bildung. But on different levels and in various contexts there are elements, facets, and hints about how to approach situations in which student-teachers grasp the idea of Bildung.

Congruence Between Goals and Experience

One of the basic requirements is that student-teachers experience themselves situations they intend to create as teachers in classroom. Instructors and student-teachers have to be aware that they need to not only talk about Didaktik but to permanently generate Didaktik. In a kind of a "pedagogical double-decker" (Wahl 2001, p. 163), the instructor has to demonstrate professional behaviour when talking about it. In Wagenschein's example, it is not sufficient just to inform student-teachers about possible relationships between intervals of lengths and times investigating an accelerated motion and to tell them how to measure these intervals. Student-teachers have to get the chance to explore the experimental problems on their own, to be confronted with ideas they cannot comprehend quickly (as this is the normal case with students in school) and to reflect on the task's potential to contribute to processes towards Bildung.

Subject Matter Studies

The aspect of acting independently in study-phases in which this is a reasonable mode of work applies also to subject matter studies. The statements by the DPG in Germany, discussed above, are not much more than a program at the moment but are more or less a revolution in physicists' minds.

Knowledge

As discussed in previous paragraphs, content knowledge as well as pedagogical content knowledge is not dispensable, because very often it is a necessary precondition for instructional processes that a teacher can justify his/her decisions by means of evidences from the educational sciences. It is generally accepted that both types of knowledge (CK and PCK) are not sufficient for a good teaching practice. But the function of knowledge for teachers' actions has to be considered more cautiously. In most domains, university studies are predominantly shaped by a conception of technical rationality. Experts tell us that this conception has to be generally questioned, and especially in teacher training. Tacit knowing or knowing-in-action requires more careful attention concerning the question how to support its development.

Reflection

Thinking about and working with Didaktik and Bildung permanently necessitates reflections on the goals of science education, on appropriate selections of topics for science instruction, on methods supporting processes of Bildung, and on questions about what the essential features of Bildung are and what relevance Bildung in science still has in the present. Following the ideas of Didaktik a teacher needs to become aware of being constantly challenged to reflect on his/her decision making prior to, during, and after classroom situations. This is an essential precondition for good teaching practice.

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