Developing teacher subject knowledge through historical and philosophical perspectives

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This paper contains much of the theoretical background prepared in the first instance by Dietmar Höttecke, the project scientific leader, and this is acknowledged here.

Introduction

The Relevance of Science Education project (ROSE, 2009 and 2004) has indicated a lack of motivation towards schools science. Unfortunately, the questionnaire ROSE used did not include questions on History and Philosophy of Science (HPS). The History and Philosophy in Science Teaching (HIPST) project is dedicated to inserting that perspective into science teaching in schools, museums and other non-formal centres. The paper gives the theoretical background and some material from the UK Case Study. The project runs from February 2008 to July 2010, when all the materials will be publicly available. The UK section has the following structure:

Theme and concepts	Commentary
Measuring and instruments in the context of temperature and heat	The effect of being able to measure a phenomenon when instruments became available is an important feature in establishing a physical science discipline.
Paradigm shifts in the context of acidity	Paradigm shifts are well known and obvious in sciences other than chemistry. This theme seeks to explore whether acidity has embedded paradigm shifts, as an investigation into theories of acidity and an exemplar of theory making.
Modelling and representation in the context of chemical equations and symbols	Representation is a fundamental aspect of scientific development, not least theory development. This theme takes a problematic area of symbolism, seeing it in the light of developing chemistry as a recognized scientific discipline as opposed to craft work at the bench. It also notes multi-level modeling, and using models to grasp intangible thinking at the sub-microscopic level.

The example provided later is based on measuring instruments in the context of heat and temperature.

Theoretical Background of HIPST

As HIPST fosters teaching and learning of science with history and philosophy of science (HPS) several clarifications have been made in order to set up a theoretical foundation for the project:

- What is meant by history, what is meant by philosophy of science regarding science teaching?

- How can we legitimate teaching and learning with HPS?

What is meant by history, what is meant by philosophy of science regarding science teaching?

The meaning of history: The word history expresses the past as it was on the one hand. On the other hand every history has to be told in a narrative form and is best characterized as a story. History is exposed to a dialectical tension of being PAST as it was and being STORY as being told. History as a reconstruction of this object can start from very different perspectives depending on political, social or economical views and believes.

Conclusions for historical research, teaching and learning: Important didactical conclusions for teaching and learning with and about HPS emerge from the distinction of the meanings of history as being past and as being reconstructed.

- The meaning of history as true past is unhelpful because we have nothing else but reconstructions which historians and developers of case studies have developed. They performed historical research on the basis of their specific perspectives, interests, research questions, choices of historical sources and interpretational frameworks.
- History in the meaning of reconstruction is open for revision, subject to change, but also vulnerable to distorted interpretations.
- Historical reconstructions should avoid teleological methodologies, which means that our current understanding of an object should not guide the process of its reconstruction. This approach is often criticized as whiggish (e.g. Butterfield, 1931, Klein, 1972, Cunningham, 1988, Allchin, 2004), because an understanding of the past is shaped and guided by the present understanding of the object of study. As a result, historical objects are detached from all the circumstances under which they once were developed (Cunningham, 1988).
- “History proceeds by the interpretation of evidence [...] historians will agree that historical procedure, or method, consists essentially of interpreting evidence” (Collingwood, 1946: 9f). What counts as history (of science) is a product of a mental process (Droysen, 1868) and not based on a straight forward analysis of facts.
- We understand science not in isolation, but as embedded in the culture, society and their development as a whole. We also understand science as both a process and a product.
- The epistemological status of a historical source is best described as a sign of the past in a semiotic sense. We do not understand sources as authorities or testimony (Wilson, 1993). Nevertheless, this does not mean that supposition of the past is meaningless (Charpa, 1995).
- The semiotic character of historical sources has to be extended to scientific terms as well. Terms gain their meanings within historical contexts in which they once were used (Höttecke, 2001).

- The meaning of history of science as a reconstruction of scientific ideas, processes and objects may disappoint students' and science teachers' expectations of science as something hard, clear cut and unquestionable. Thus, history may also revive and increase the interests in science of those who hitherto put off by traditional ways of teaching science.
- The integration of history of science into science teaching contradicts traditional approaches of science teaching as the complexity of the content increases, not decreases. Developers of historical case studies for teaching and learning have to take pedagogical issues into account (Matthews, 1994). The pedagogical task is to simplify history without distorting it. Moreover, history of science has to convey adequate views about history, the nature of science as well as scientific terms, concepts and central ideas.

Philosophy of Science: Philosophical and historical considerations differ. This aspect concerns a principle distinction of two fields of research as well as their role for teaching and learning science. While science teaching and learning may be separated from history, they never can be separated from philosophy. Even if teachers follow traditional approaches of teaching science they represent and convey ontological and epistemological beliefs. Philosophy also supplies a meta-language to talk about science. Terms like theory, experiment, data, evidence, hypotheses, test, model or analogy enable to talk about science beyond its content.

History, Philosophy and the making of meaning: According to our view learning (science) is a process of making meaning about the world and the self. A role for HPS is to help and guide students' meaning making. According to this perspective an important objective of HPS is to encounter the learners with their own culture and society (Höttecke, 2007).

How can we legitimate teaching and learning with HPS?

Contextualized Learning: Curriculum developers all over Europe have stressed the role of **context for science learning**. From a student perspective a context enriches science learning with meaning and shows how science is inextricable merged with society, economy, ecology and culture. A historical perspective on science comprises all these different relations of science in order to highlight its general relevance for human life in the past, presence and future and contribute to an **understanding of the interaction of science and society** in general.

Advancement of problem solving skills: International comparative studies like PISA have shown that competences of **problem solving** are deficient in many European countries. Students on the other hand have to develop a motivation for their own. They need contexts which sustain their problem solving activity and which have to appear meaningful and authentic from their own layperson perspective. History and philosophy of science highlight the process of science in a rich cultural context and open up ways to science teaching and learning which is jointly oriented to the process of science as well as to the process of learning. The history of science is full of opportunities to study the problem solving activity of real scientist in authentic situations. In contrast, problems and their solutions of contemporary scientist often appear too complex for students.

Inquiry learning within historical settings: Inquiry learning fosters the learning of scientific concepts. Inquiry learning encourages students to develop their own **strategies of problem solving**, but the problems have to be cognitively inspiring. Research recently has indicated that inquiry learning does not support knowledge generation necessarily (Hopf, 2007). Students do experiments more willingly and develop better strategies for learning if they are involved in problem solving activities. Milne and Taylor (1995) accordingly call inquiry learning for being more **active and creative**. The history of science provides a wide range of resources for inquiry learning in this sense.

Reconstruction of historical experiments: If students work with reconstructions of historical experiments they may be engaged with authentic problems, build small scientific communities, which share their knowledge and skills or demarcate themselves from those of other student-communities. They (re-)search for evidence which they use in argumentation in the struggle of different theories.

Promotion of a better comprehension of scientific concepts: This argument recognizes that **scientific concepts** can be formulated more intelligibly in their historical context of discovery than in a schematic and systematised way of modern interpretations. In discovery contexts scientific concepts do not yet belong to an accepted and settled inventory of knowledge. Instead, they appear questionable and variable. Thus, they can help students to develop their own thinking and conceptual growth when their science learning struggles with conceptual discrepancies and alternatives as many studies have shown (Duit, 2007). This argument is the more important as large scale assessments like PISA have shown that less than a half of the students (longitudinal study comparing science classes 9 and 10) profit from traditional science teaching courses (Prenzel et al.).

Supporting conceptual growth: Research indicates that the study of **historical concepts can help students to develop their own concepts towards a scientific comprehension** (Bar et al. 1998, Benseghir 1996, Höttecke 2001, Sequeira et al. 1991, Seroglou et al. 1999, Wandersee 1986). History allows students to **situate and assess their own understanding of scientific concepts** on the background of historical concepts and ideas. Therefore, history supports the process of **conceptual growth** on the learners' side.

Showing science as European cultural heritage: Students become aware of the **different national contributions to science**. Therefore, learning about the history of science strengthens the transnational dialogue within Europe and helps to develop a self-conception of European citizens as a part of a society which is strongly influenced by developments in science and technology.

Learning about the nature of science: In a Delphi study (Osborne et al., 2003) have shown experts of science education, science, history, philosophy, and sociology of science to generally agree that **learning about the nature of science** belongs to the central objectives of science education. Against the background of their study the authors challenge the relation of learning science content and learning about the nature of science for the benefit of the latter. Bybee (1997) has developed a quaternary model of scientific literacy as a major goal of science education. Students on the highest level have developed an understanding about "the essential conceptual structures of science and technology as well as the features that make that understanding more complete, for example, the history and nature of science". On this highest level students understand the relationship between science, technology, and society and acknowledge science as a cultural achievement. HIPST will contribute to the advancement of science education in order to prepare students to reach the **highest level of scientific literacy**.

Explicit reflection on the nature of science: Research has shown that even inquiry-oriented teaching does not necessarily lead to a better comprehension of the nature of science. Several studies recommend **explicit reflection on the nature of science** (Akerson et al. 2000, Bianchini et al. 2000, Khishfe et al. 2002, Schwartz et al. 2004,) which is an integral part of teaching the history and philosophy of science in our view. History and philosophy of science offer many opportunities to ask questions about the "hows" and "whys" of science.

Developing citizenship in a science and knowledge society: The nature-of-science-argument promotes the view that **active citizenship in democratic decision-making processes** requires knowledge about what science means as political decision-making increasingly depends on scientific expertise. Therefore, students have to learn more about the relation of science, technology and society on the one hand. Historical case studies exemplify this relation in depth.

History as a tool for teaching about the nature of science: Several studies indicate that epistemological beliefs about knowledge and knowledge acquisition affect attitudes and processes of learning (Baumert et al., 2000, Edmondson et al., 1993, Halloun, 2001, Hogan, 2000, Lising et al., 2005, Songer et al., 1991, Tsai, 1999, Urhahne et al., 2004). Research and case studies of teaching practice have shown the **effectiveness of history-oriented teaching** in order to learn about the nature of science (Barth, 1999, Galili et al., 2001, Heering, 2000, Höttecke, 2003, Irwin, 2000, Lin et al., 2002, Seker et al., 2005, Solbes et al., 2003, Solomon et al., 1992).

Science as a human endeavour: Science appears less abstract and gets the **character of a human endeavour**. This argument touches the problem of public recognition of science as systematic and inhuman. This view is one of the reasons for a decline of interest of many students in science as a Eurobarometer survey recently has shown (Hodge, 2006) in accordance with other studies (Häußler et al. 1996). Most alarming seems to be that students do not feel normal science classes appealing.

Supporting authentic images of science and scientists: The inclusion of historical case studies in science teaching provides realistic **images of science** as process and **images of scientists** themselves. It offers many opportunities to balance distorted views about scientists many children tend to held as curious male people, wearing white lab coats, long beards and thick glasses who work in isolation on dangerous things shouting out "I have got it!" as they have a sudden success. Many draw-a-scientist-tests (Chambers, 1983, Rahm & Charbonneau, 1997, Sjöberg, 2000) have shown that these images urgently need to be balanced. Historical case studies show science as an authentic endeavour. They are suited for showing that scientist solve problems instead of inventing dangerous things, that they work in wider communities instead of working in an isolated basement lab, that scientific success does not have to depend on gender, and that scientists and their work are interwoven in socio-scientific issues.

Promoting girls' attitudes towards science: Research (Heering, 2000) indicates that especially **female students benefit** from the changing character of science as an open inquiry and from the appearance of scientific knowledge as progressive and changeable. This aspect has not yet been investigated thoroughly.

What is our theoretical backing of an effective implementation strategy within HIPST?

Teachers and the nature of science: Abd-El-Khalick et al. (1998) point out that **teachers do not expect cognitive learning outcomes in the realm of nature of science**. They tend to the opinion that learning about the nature of science occurs without focusing on the nature of science explicitly. Research indicates that even if teachers themselves possess adequate concepts about the nature of science they dismiss strategies of their pedagogical implementation (Abd-El-Khalick et al., 1998, Akerson et al., 2003, Brickhouse, 1990; Hodson, 1993; Lederman, 1992; Lederman & Zeidler, 1987). Acceptance or denial of new teaching techniques heavily depend on teachers general assumptions about education and their educational practice. Therefore, teachers would acquire confidence in new teaching techniques, if resonance will be established between their ideas about how to teach, their general educational beliefs, and their views on the nature of science (Waters-Adam, 2006).

Teachers need to develop skills for open inquiry teaching: Learning history and philosophy of science in our view encompasses the re-enactment of historical disputes, experiments and discussions. Role play would be a convenient method for re-enactment, if it will be accompanied by reflections on the nature of science. It exemplifies how science works, sheds some light on the powers promoting its progress, shows that scientific knowledge is tentative and not fixed and that scientific theories need the support of empirical evidence. The openness of teaching and learning situations acquires teaching skills like moderating discussions, collecting and structuring student's contributions, guiding open inquiry and developing support and help systems for students' learning. On the other hand international survey studies like PISA and TIMSS-video have shown that science teaching is overwhelmingly teacher oriented. Obviously, science teachers need further teacher-training to acquire **specific pedagogical content knowledge** (Shulman, 1986, Loughran, Berry, & Mulhall, 2006) **for the moderation of open inquiry teaching and teaching about the nature of science** (Abd-El-Khalick & Lederman, 2000).

Lack of teaching material: A survey of school-books shows a lack of history and philosophy of science in these materials and in the practice of teaching, respectively. Even if HPS is addressed it often leads to whiggish demonstrations of what science is (Silva, 2007). Hence, teachers who intend to teach about these aspects have **little access to materials** helping them to learn about the history and philosophy of science themselves and to prepare and structure their science lessons. This is the more important since we know that teachers prepare their lessons primarily with the aid of textbooks for school science teaching or collections of worksheets. Teaching material for HPS will be effective, if students as well as teachers benefit from it for their own learning.

Lack of networking educational strategies and institutions: Learning science with the aid of its history and philosophy for the benefit of an adequate understanding of science and its nature affords the **coordination of all relevant educational resources**. Though the development of scientific literacy is an important objective of school science teaching, other institutions like science museums strive for the same goal. We are certain, that expertise of school science teachers and experts from science museums would profit very much from each other, if they shared their methodologies, practices, skills, and experiences. Moreover, experts in teacher-training and extended vocational training also have much to contribute: they have experiences with the development of teaching materials, their evaluation and the development of new teaching techniques and their implementation.

Crossing boundaries: As Monk and Osborne (1997) have indicated the **world of teachers and the world of researchers and curriculum developers are quite separated** from each other. This aspect may explain the lack of effective implementation of HPS in school science teaching. History and philosophy of science have to be adapted to the framework of school science. This means that the development of case studies has to take constraints of school science teaching into account. During the developmental process the perspectives of history and philosophy of science, science education research and school science teaching have to be balanced. The same holds for the development of case studies for teaching and learning in science museums. The methodologies of action research (Altrichter et al. 1998) or its interpretation as participative action research (Eilks et al., 2004) offer fruitful and proven frameworks for a cooperation of all actors involved.

Example from the UK

The context chosen for this paper is temperature and heat because these concepts are challenging for both teachers and learners; because historical information is readily available, especially in early published papers; because it is possible to replicate easily some historical experiments; because the topic excellently demonstrates the impact of measurement on historical scientific thinking; and because many philosophical processes relevant to novice learners such as induction and deduction, simplifying, paradigm shift, modelling, and questioning the status of evidence can be demonstrated in this theme.

Structure:
Home Page: Welcomes visitors and provides explicit links to other pages.
Teachers' Page: The focus of this page is to provide self-study scholarly reading. It derives from a strongly held view by the author that when teachers own their need to develop their subject knowledge, and value it in terms of characterising their approach to teaching, it becomes an essential part of the knowledge structure they bring to teaching. It has a section on science education research on learners' knowledge and alternative conceptions. I provide direct electronic links to papers and abstracts where possible. A second section provides details about the historical search for making sense about temperature and heat, and the distinction between them. A third section focuses on a very long term experiment started by Joule on glass thermometers reading differently, even when correctly calibrated. This is followed by a section on the Ideal Temperature scale. Finally, a section on explaining the difference between temperature and heat completes this page. There are two facets of this section that make it innovative. The first is the use of optional links when a specialist term is encountered. Teachers who wish to know more or access a dictionary can easily do so by clicking on the term, while others can simply pass over. The second facet is to make available optional excursions to specific issues, personalising learning. A major aim of the project is to develop that facet by encouraging teachers to create their own excursions, within the wiki structure.
Scheme of Work: although this page provides a Scheme of Work overview, it is characterised by setting in four columns an overview, concepts to be developed, history

background and philosophical background. The concepts are further subdivided into macroscopic, sub-microscopic and children's ideas. This page is rich in links to other internet sites, e.g. for scientific biographies and historical experiments.

UK Scheme of Work: to be able to show how the topic meshes with the normal curriculum, details of the UK Scheme of Work are provided.

Learners' pages: there are two of these, one on temperature and one on heat. The format is similar to that on the teachers' page, with details of the activities in the overview column. As far as possible, material is written in intermediate language accessible to learners. When the project is running, further intermediate language translations of adult information will be provided in this section, some of this created by the young learners. As with the teachers' section, optional access to explanations of new terms, and excursions will be part of the wiki development phase. This is part of my approach of engaging novice learners in creating the resource.

Contexts pages: I have already noted the absence of appropriate material in textbooks, especially for teachers. These pages, divided into century sections, provide timelines for scientific discoveries on temperature and heat, for discoveries in other sciences, for cultural changes, and for political events. I have also prepared a more discursive account of this information.

Challenges:

Synthesising: although there is a wealth of information available, finding it, making selections and constructing detailed but accessible web pages has been a major challenge and very time-consuming. The availability of a Virtual Learning Environment has facilitated making links to appropriate sites, leading users directly to information sources.

A world-centred approach: I have found it a great challenge to avoid a European-centred approach to the history of science, and possibly even to an Anglo-centred approach. I intend to use the international nature of the HIPST team to make their contributions to the contexts pages to redress the balance.

Pedagogy: working with historical material may be something new for teachers which will become more apparent with the trials. Collecting data during trials should include data on teacher change as much as on learner change.

Philosophy: including major philosophical approaches has been both exciting and challenging. Reflecting on how science really works, as opposed to being applied, is an essential component of work with young people.

The future

The next step is to trial the work in schools and collect data on its effect. I expect the project to yield worksheets, videos, and further pedagogical examples as it progresses, and that the web sites will become dynamic through the project.

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