Preface

Improving the quality of science and mathematics education at universities has been a task to which governments and tertiary education institutions have committed. This was the case in Denmark at the end of the 1990s when the Danish Government, its Ministry of Research, and a network of Universities gathered efforts around the construction and functioning of the Centre for Educational Development in University Science. The centre established collaboration between seven Danish universities around the teaching and learning of science: Aalborg University, Copenhagen University, the Danish University of Education, the Pharmaceutical University, Roskilde University Centre, the Royal Veterinarian and Agricultural University, and the University of Southern Denmark. The centre operated during the period 1998-2001, thanks to the generous funding of 35 millions of Danish Kroner in total.

The Centre for Educational Development in University Science embraced a wide range of educational research and development actives through which the practice of university science education was addressed and improved. Areas such as mathematics, physics and chemistry education were central. The centre ran a Ph.D. programme, which enrolled 12 students who addressed a variety of educational issues in the subject areas of relevance for the centre. The centre also organised a series of conferences and seminars aiming at the professional development of teaching staff in the institutions associated. The centre financed a number of teaching development projects run by university staff in their own institutions and classrooms. Many leading scholars from around the world made important contributions to the work of the centre.

The present book emerged from the wide-ranging network of research and researchers, established through the Centre for Educational Development in University Science. The intention of the book, however, is not to provide any report of the research or developmental activities of the centre, but rather to contribute to the worldwide concern for analysing both challenges and possibilities for university science and mathematics education. Even if the book collects a majority of papers by Danish authors working in Danish contexts, the issues addressed by the different sections and chapters are of a general relevance for tertiary educational environments around the world. Furthermore, the dialogue between the Danish authors and leading international researchers in the field contributes reinforcing the broadness of the book for an international audience, in a changing world were transitions in what is considered to be the core of science and mathematics education in universities are taking place.

We want to thank all the people who have contributed to the completion of this volume. Thanks to the Danish Ministry of Research and to Aalborg University for providing the necessary funding for editing the book. Thanks to Patricia Perry for a careful typographical editing of the manuscript, to Anette Larsen for editorial support, and to Anne Kepple for a language revision of several of the chapters. And thanks to Marie Sheldon and Kristina Wiggings and other members of the staff at Springer for their support and guidance during the edition process.

Finally, we would like to dedicate this collection to the memory of Leone Burton, a remarkable colleague and friend who during very many years supported our work participating in some of the activities of the Centre for Educational Development in University Science, conducting sessions with research students and staff in Denmark, and being a critical partner in our previous work and in an early stage of production of this collection. We are honoured to publish her paper, probably the last printed record of her proliferous and pathbreaking academic carreer.

Aalborg, May 2008

Ole Skovsmose
Paola Valero
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Chapter 2
A Reflective Science Education Practice

Why, What, and How?

Kathrine Krageskov Eriksen

2.1 Reflectivity: A Key Concept

When the Danish University Law (Videnskabsministeriet, 2003) was reformed, a component was added stating that Danish universities should not only do research and offer education that meet the highest international standards, but that they should, moreover, convey to society research and educational results for the further prosperity of the latter. In the legal text it is further explained that universities shall be obliged to actively exchange knowledge and competence with society, and that this includes an obligation to engage in public debate about important social issues. Apparently, something has changed – a change that seems to include a closer entanglement of academic science and society. In the context of science education at least two questions are thus raised: How is the social role of science changing? And what (if any) implication does this bear for science education?

The argument made here is that a change is indeed taking place; from traditional (academic) science which celebrates disinterestedness and unblemished quest for objective knowledge to contemporary science infused with socio-cultural and political-capitalist interests and influencing societal development profoundly. A change, which makes the scientific community a much-needed participant in social reflectivity. However, studies encountered below suggest that contemporarily the scientific community tends to cling to the old celebrated virtues and it only reluctantly enters its new role as participant in societal development and debate. The problem is not only that science apparently "chooses" not to participate in the social reflective processes, but more significantly that this choice is grounded in the traditional academic ethos according to which scientists of today have been trained. Science education, the entry point of the scientists of tomorrow, hence becomes extremely important as a place for inducing changes to the institution of science and the scientific self-perception.

I suggest that as a response to this, tertiary science education must focus on the development of students' scientific reflectivity, and that this concept includes the

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development of contextualized awareness and professional humility, as well as gap sensitive interactive skills. Further, I launch and develop a teaching method, anchored ethical dialogue, through which one may stimulate the development of all three notions. Hence, anchored ethical dialogues could become fix points for the development of scientific reflectivity and thus, ultimately, for raising the level of social reflectivity. I have attempted to depict this in Fig. 2.1.

However, before considering the various concepts and notions included in Fig. 2.1 in more detail, I will take a closer look at the development postulated above.

2.1.1 Science and Risk Society

Modernity can be seen as an era in which modern scientific thinking and technological development created a profound belief in progress – a belief that was inevitably linked to a trust in the ability of science and technology to further free and enlighten humankind. However, since these heydays of the modern breakthrough the role of science within society has changed.

> In developed civilisation, which had set out to remove ascriptions, to evolve privacy, and to free people from the constraints of nature and tradition, there is thus emerging a new global ascription of risks, against which individual decisions hardly exist for the simple reason that the toxins and pollutants are interwoven with the natural basis and the elementary life processes of the industrial world.
>
> (Beck, 1992, p. 41)

As the quote illustrates, to Ulrich Beck the central concept for describing this change is *risk*. It is the production of risks and the attention subsequently ascribed to these risks by society that constitutes the driving force in societal transformation.

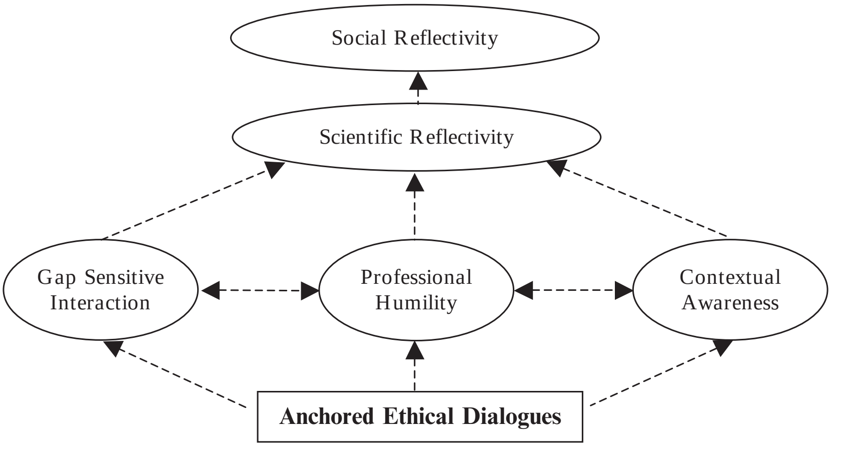

Fig. 2.1 A reflective educational practice

Beck understands risks as something potentially concrete. Risks are the potential results of the activities of humankind. The main difference between the risks Beck describes and the risks of preceding societal orders is thus their relation to modernity. Whereas the risks of previous ages were stemming from nature (or from the scarcity of resources), the risks marking present society are somehow related to the modernization processes that had the liberation of humankind from these restraints of nature as their goal. More precisely, they are the results of the very same modernization processes: The notion "risk society" refers to "a stage of radicalized modernity" (Beck, 1997, p. 20), where it is the success of modernity, the liberation of humankind from poverty, hunger and so forth that produces a new social order.[1] The unintended consequences or "hazardous side effects" (Beck, 1992, p. 20) of modernity, that is of the scientific and technological development constituting its hallmark, the production of risks, become central to the development and the focus of our attention. Thus according to Beck what we are experiencing is a break inside modernity where society removes itself from traditional industrial society and assumes a new constitution, but where the break is a result of the processes of the very same modernity: "Modernization has consumed and lost its other" (Beck, 1992, p. 10), that is nature and tradition, and now turns toward itself – hence the designation reflexive modernity.

It is exactly this attention given to the observed and potential effects of our own endeavours that characterizes risk society and becomes a new social driving force. The concept of risk does not (only) refer to damage or destruction of nature in itself, it refers to potential destruction, the potential time bomb against our health and reproduction that may and may not have been created: "The concept of risk thus characterizes a peculiar, intermediate state between security and destruction, where the *perception* of threatening risks determines thought and action" (Beck, 1999, p. 135).

Beck's analysis thus points to important differences between the emerging and the preceding social orders in relation to the perceived risks/hazards. One of the most important points is the involvement of science and it is exactly Beck's pinpointing of the intimate relationship between science, technology and social development which makes the risk society perspective a useful one to apply in the present context. Thus, the central trait of risk society, the characteristic differentiating it from pre-risk societies, Beck stresses, is not the occupation with risk, nor is it the increased extent of these risks. The crucial feature is the scientific constitution and the society-changing scope of the risks (e.g., Beck, 1992, pp. 153ff).

However, the role of science in risk society is not merely that of an enfant terrible, producing all the risks we are encountering. The situation is far more complex. It is not the failure of science but its success that constitutes the basis for the up-growth of risk society. Scientific and technological development is not simply the background for the very improved conditions for humankind of today, for we are also dependent on science for detecting and dealing with the risks of this risk

[1] Again, we are talking about the Western world.

society. Thus, science takes at least three social roles, that is the role of risk creator, risk detector, and risk analyser (Beck, 1992, Chap. 7).

The role of science as risk creator of course refers to the crucial involvement of science and scientific thinking in all aspects of modern society and specifically in the creation of solutions to the problems of humankind. Solutions, the unintended consequences of which, we are now facing in risk society. This, the societal transforming role of science has become visible. Further, we are absolutely dependent on science for the process of detecting and analysing risks. The risks of risk society are intangible; the human sensory apparatus often cannot directly experience them. Moreover, there is an enormous gap in time and space between impact and the manifestation of a risk. Risks instead come to life only in the form of scientized probabilities, which speak in "the language of chemical formulas, biological contexts and medical, diagnostic concepts" (Beck, 1992, p. 52). The extent of endangerment of the individual cannot be estimated by the individual him – or herself. Essentially, we all have to rely on external, scientific knowledge and thus we are becoming "*incompetent* in matters of [our] own affliction" (Beck, 1992, p. 53). This development leaves science in a vital social position and it exposes exactly how crucial it is for society that the scientific sphere is aware of its own position, abilities, and limitations.

2.2 Scientization

This development has of course affected science and the view on the scientized approach to life in the modernity. Beck describes this development by employing the notion of *reflexive scientization*. Initially man's relations to the surrounding, given world was scientized (*simple scientization*). However, as scientization has gradually changed this world, science is being confronted with itself, that is its own products and defects, and as a result our relation to science becomes scientized (reflexive scientization) (Beck, 1992, p. 155).

Beck goes on to say that reflexive scientization also results in the dogmatization of science being abolished, in that science has turned towards itself and scientized the scrutiny of its own foundations, products, and effects. It may be argued, however, that Beck's use of the term reflexive scientization in the latter sense becomes somewhat confusing. Who exactly is reflecting on whose foundations, products, and effects? If the answer, as indicated by Beck (1992, p. 156), is that the study (sociology, philosophy etc.) of science is scrutinizing the foundations of science scientifically, then the problem is that the concept of science is employed too broadly. This is not science scrutinizing its own foundations. Rather, it is one sphere of science scrutinizing the foundations of another sphere of science, for example natural science. So, seen in this light it is indeed *reflexive* scientization in that scientization is being reflected scientifically – but more so in the sense of a mirror being held up by others than in the sense of self-reflection. And crucially, it does not mean that (natural) science cares to look into that mirror: it may carry on its endeavours unaffected! So, at least in this interpretation, I see some problems in Beck's line of argument.

Instead, I suggest the introduction of an additional notion that is *reflective scientization*. I suggest replacing the use of reflexive scientization in the meaning outlined above (in the mirror sense), and instead use it to designate scientific self-reflection, that is the (natural) scientific sphere reflecting on its own foundations, limitations and so forth and working actively to change these (and in this process the insight gained from for instance science studies is of course vital). I believe this separation of notions (and of scientific spheres) makes the analysis from Beck more clear and fruitful to employ in the present context. And actually, according to Beck, it is exactly such a reflective science that is needed:

> To be sure, risk cannot be banned from modern life, but what we can and indeed should achieve is the development of new institutional arrangements that can better cope with the risks we are presently facing; not with the idea in mind that we might be able to regain full control, but much more with the idea in mind that we have to find ways to deal democratically with the ambivalences of modern life and decide democratically which risks we want to take.
>
> (Beck, 1999, p. 108)

The point is not merely that science should raise its voice in the political debate about the application of its results. Rather, Beck implies a changed approach to doing science, in which science is capable of self-criticism concerning all aspects of its own endeavours, including "what it considers noteworthy or not, how it asks questions and casts the "nets" of its causal hypotheses, how it decides on the validity of its conjectures [...]" (Beck, 1992, p. 180). Only in this way can we try to discover and thus avoid the unintended consequences, which are adding to the risks of risk society. In short we can say: To deal with reflexive modernisation (in the shape of a risk society), we need reflectivity within the institutional setting of science!

This realization provides us with a link to the overall topic of the present study, science education. Development of science education could provide one way of promoting reflectivity. To add to our understanding of the development needed, I will briefly turn to a number of other scholars and their interpretation of the relationship between science and society in the emerging social order.

2.2.1 Post-Academic and Mode II Science

Traditionally, science, or maybe rather the scientific archetype or "the stereotype of science in its purest form" (Ziman, 2000, p. 28), has been academic science, that is the social institution of science as one has been able to find it within academic institutions for the last century or so. It is John Ziman's claim that although the term academic science by no means covers all scientific work going on[2]; in many respects

[2] Science within the setting of industry accounts for up to 90% of all research taking place (Ziman, 2000, p. 16).

it does, however, epitomize the traditional scientific self-understanding. Academic science of course includes many disciplines with separate sets of rules and epistemic values. However, "the sub-tribes of academia span a common culture" (Ziman, 2000, p. 31) and to describe this culture in terms of its ideal values Ziman refers to the set of norms defined by the sociologist Robert Merton (1968). The norms include communalism, universality, disinterestedness, and organized scepticism and together they describe an ideal scientific endeavour that shares knowledge publicly, is culturally unbiased and free of material interests, and in which critical examination of published findings through peer-review provides the framework for systematic testing of claims and thus the basis for the reliability of scientific findings. Put together, the initial letters of the Mertonian norms spell out the acronym CUDOS meaning acclaim or prestige, and ideally it is by performing and contributing to science according to these norms, the scientific ethos, that academic scientists earn recognition among their colleagues in the form of citations, titles, and employment (Ziman, 2000, Chap. 3). The extent to which science has, and possibly can, actually be carried out in compliance with this ethos has been much debated, nevertheless the ethos influences scientists' behaviour and general attitude. For example, the norm of disinterestedness has been supportive of the view that the sphere of science can been seen as separated from "real life" (Ziman, 2000, pp. 53ff).

A crucial point made by Ziman is, however, that academic science is changing and giving way to a new *post-academic* science governed by a different ethos and occupying a different social role. The main characteristic of post-academic science is that it is turned outwards to a degree unknown to academic science. This is not only with reference to a growing openness between various disciplines inside science. The focus of scientific attention is becoming increasingly influenced by outside forces. Post-academic science is to a large degree oriented towards complex conglomerates of problems that require multi-disciplinary approaches and thus force scientists to work together across disciplinary boundaries. Financial limits to growth of the scientific sector paired with an increasing instrumental sophistication and costliness in many scientific disciplines also force scientists to work together. Moreover, the limited financial sources have precipitated a hitherto unknown competition for research funding. This development in turn influences scientists' choice of research objects, since the funding bodies give away money according to priorities influenced by current political and economic interests. Consequently, the scientific focus shifts from the general quest of knowledge towards potential applications and exploitation of the knowledge generated according to current, and therefore necessarily limited, vision (Ziman, 2000, pp. 66ff).

However, the traditional academic scientific ethos is not compatible with this development and the changed requirements. Thus, the emergence of post-academic science signals the beginning of a novel scientific culture. In the new culture, for instance, the commitment of making public the knowledge acquired is likely to often conflict with commercial interests. The focus on specific problem solving may link research and technological development even more closely than is presently the case. In evaluating research results peer review will thus be supplied or replaced by quality control of people, projects, and performance. Consequently, post-academic science will be infused with social values and interests. This may have consequences for the reliability of scientific knowledge – negative as feared by Ziman (1996) or positive as postulated by Nowotny et al. (2001).

Gibbons et al. (1994), and Nowotny et al. (2001) provide related accounts of contemporary changes to science. They propose that the "closer interaction of science and society signals the emergence of a new kind of science: contextualized, or context-sensitive, science" (Nowotny et al., 2001, p. vii) in which the value of science becomes more connected to its concrete use and the social impact of this use. The critique of scientific results is hence no longer primarily an internal scientific matter; various social actors with various social interests now join in. The authors suggest that a broad discussion of novel scientific development will test more aspects of this development than did traditional scientific discussions and therefore in a sense make it more reliable or *socially robust* (Nowotny et al. 2001, Chap. 11). Ziman, on the other hand, points out that this means that society loses science as *the* impartial expert.

In all circumstances it means that future demands put on scientists will be revolutionarily different to the demands put on scientists in the traditional academic setting. Scientists must be aware of aspects of their research that are very different from the aspects relevant in the academic scientific culture. Instead of praising detachment from outside interests and the remoteness to practical utility of research results, scientists must become capable of anticipating potential applications and consequences, whether environmental, social, ethical and so forth, of their work. And they must become capable of discussing potential future scenarios with actors from outside the scientific sphere. Or, using the terminology developed above, they must become able to act reflectively.

2.3 Reflectivity as an Educational Concept

A next question arises: May education actually influence individual scientists and, crucially, science as an institution to act reflectively? In exploring an answer it is difficult to avoid the concept of *Bildung* from the German educational tradition.

2.3.1 Science Education in a Bildung Perspective

Bildung has classically been interpreted as education or maybe, rather, formation of the individual to become able to reflect upon and act to change the common conditions. I will not go into a further presentation of the Bildung idea here, but focus specifically on the distinction adaptation/Bildung launched by the Norwegian philosopher Jon Hellesnes (1976). As already noted, in the classical Bildung tradition Bildung is formation to become able to better the common conditions, not merely to become able to enter a community. Nevertheless, the former necessitates the latter! Thus, the formation processes undertaken by the individual, and in the present context this equals education, will always be a form of socialization. As Hellesnes accentuates, the crucial issue is what kind of socialization is taking place. Hellesnes sees Bildung as the antithesis to adaptation and hence as a *reflective* socialization in which “the rules of the game” are uncovered and critically evaluated – and talking general Bildung this game is society at large.

However, if we transfer this interpretation of Bildung to the tertiary science education context, some fundamental questions arise: Which game and rules are we talking about? On the face of it, the answer is of course straightforward. We are talking about science education, thus the game is surely science and the rules are obviously scientific ways of dealing with reality. However, what we learned from the analysis of the relation between science and society is that the answer is *not* straightforward! Science can no longer (if ever) be seen as an isolated entity. Rather, science is to a hitherto unknown degree interwoven in the societal development and in pending social problems, both so in the form of risk creator, risk detector, and risk analyzer and in relation to the structures determining the focus of scientific research. Moreover, it was suggested that science and the conventional scientific self-perception is inadequate for dealing with this changed role of science. It is against this background that the answer is clearly not merely science. The answer is to be found in the connection of science as a knowledge generator and as a social actor. The game new scientists are to become socialized into is thus this complex social institution of science, and the rules they are to learn concern scientific research as such but also the relationship between science and society. Further, if this socialization is to amount to Bildung and not merely adaptation, this complex setting has to be somehow unveiled to the students *and* the students must become capable of critically reflecting upon it. The next question is of course, how can this be done? If education is socialization and what is desired is reflective socialization, then how is this acquired?

2.3.2 Science Education as Socialization

One proposed link between education, the socialization/Bildung of coming scientists, and in turn societal development may be extracted from a Danish study of higher education by Bo Jacobsen (1981). Jacobsen hypothesizes a relationship between educational structure and personality types. Employing Jacobsen’s study, it may be proposed that socialization processes in higher education depend on at least two structural levels: An upper level of organization and general content of the education in question and an intermediate level of the concrete pedagogical interaction taking place at the educational institution. Further, that it is the “tightness” or “looseness” of these different structural levels of the educational system that influence the socialization of students, so that tight systems tend to produce more tight-minded individuals than loosely structured ones do.

However, to claim that these structural levels determine the socialization of students is a simplification. First, students are not empty jars upon their arrival; they have already been socialized through their previous experiences, educational and others. Second, throughout their higher education students will receive inputs from sources other than the educational system per se; inputs that will also influence their socialization. And third, students are not simple mechanisms that can be expected to react in a certain way to a given stimulus.

Thus, I believe that Jacobensen's approach, which may be read as being solely structuralistic, needs modification. In doing this, I will lean on Anthony Giddens' theory of structuration.[3] The theory of structuration is Giddens' contribution to resolving the agent-structure dualism. He views the relationship between agent and structure as a coherent relation or duality where structures are seen as both the means for and the results of the actions of individual agents (Fig. 2.2). In Giddens' optics, structures do not exist per se; rather they are constantly created and re-created through our actions. Since we base our actions on structures, we continuously reproduce them. The link between agent and structure is thus the social practice (Kaspersen, 1996, pp. 398–400).

Employing Giddens' theory of structuration, socialization can be comprehended not merely as the product of structures but also as the basis for the reproduction of structures and thus ultimately for the structures themselves. Therefore, the adoption of this perspective can help us see beyond the existing structures and highlight the potential for change. Giddens gives part of "the responsibility" back to the individual agents since structures in his point of view cannot be comprehended as something that *is* but only as something that *becomes* through reproduction (by agents). Thus, in contrast to a one-sided structure perspective Giddens' theory provides a link between changes to the socialization of agents and changes to overlying structures, in turn society – or in the present context between science education and the role of science in society. In other words, in Giddens' perspective working with the lower structural levels (as we in educational work do most of the time) or trying to "do something" as an individual agent, does posses potential for change.

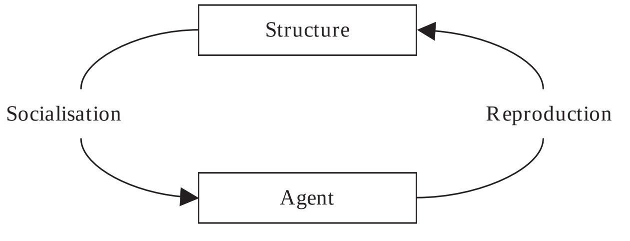

Fig. 2.2 Giddens's structuration theory – the social practice[4]

[3] Giddens' structuration theory can be found in an elaborated version in Giddens (1984). However, I base my description on Kaspersen (1996).

[4] The figure is based on the description of Giddens's theory of structuration from Kaspersen (1996).

If we apply Hellesnes' distinction between two forms of socialization, Bildung and adaptation, to Giddens' theory of structuration then, depending on the socialization type, the actions of the agents, that is the reproduction of structures, becomes not merely reproduction but either a "blind" reproduction (simply following the game and the rules) or a reflective reproduction (questioning the game and the rules and if necessary working actively to change them). To illustrate this point I have elaborated Fig. 2.2 into Fig. 2.3.[5]

At this point, I will again consider the concept of reflectivity and use the term to designate both a reflection (cognitive action) and the action for change of the practices (active transformation). Against the background of the preceding analysis of education as socialization, a higher science education that matches the social challenges identified earlier may thus be conceptualized as a socialization process allowing for reflectivity.

Thus, this analysis suggests that science education could be one place to initiate changes to the scientific self-perception. And further, that an educational practice which acknowledges the social need for a scientific community prepared to confront the problems and risks connected to scientific and technological development (and is thus developed as a response to the social challenges analyzed above) may be characterized as an educational setting in which the socialization of students is considered explicitly and measures are taken to ensure that the socialization processes are open for reflectivity.

But what does this imply in more concrete educational terms? On a very general level it implies that scientists need to develop additional abilities, sensitivities or competences. In addition to traditional academic scientific virtues (e.g., possess a broad professional base; skilled in laboratory techniques; the ability to find necessary information, and the ability to make new discoveries), students must develop

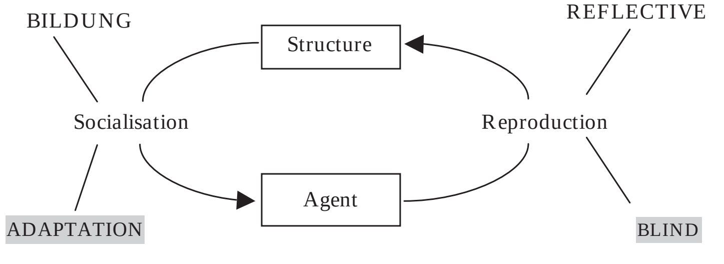

Fig. 2.3 Giddens' structuration theory in a Bildung perspective

[5] Giddens works with a related distinction when differentiating between practical and discursive consciousnesses. Our practical consciousness guides our actions – provides the background for "playing the game" – but most of the time we do not make explicit our knowledge. In contrast, our discursive consciousness enables us to present explanations for our actions and thus it also provides the basis for changing these actions (Kaspersen, 1996, pp. 400–404).

a reflective approach to the scientific endeavour. The final questions that this study aspires to answer hence become the following: What does development of reflectivity imply? And how may we change higher science education as to put more focus on development thereof?

2.4 Reflectivity and Pedagogical Interaction[6]

In Bo Jacobsen's study (1981) two structural levels influencing students' socialization are identified: The upper level of organization of the studies and the level of pedagogical interaction. Concerning the upper level, one may tentatively say that organizational structures that endorse an integrative approach and the development of own structures must be promoted if the socialization process of students is to be open to reflectivity. I will, however, not engage in further analysis of this structural level – but focus instead on the second level of pedagogical interaction, which is of particular relevance in the present context.

2.4.1 Reflectivity and Content

In relation to the level of pedagogical interaction at least the content, the format, and the social relations of teaching and exam situations need to be considered. Concerning content let me start by introducing an example: teaching university chemistry students about halogenated organic compounds usually involves an introduction to the spatial structure of the compounds, ways of synthesizing the compounds and concrete examples of compounds from the group, DDT being one. This type of knowledge relates to chemistry as a product and it includes knowledge about chemical compounds, concepts, and laws. Borrowing from Leif Östman (1999), for the present purpose I will refer to this type of knowledge as *ontological* chemical knowledge. However, further aspects of chemical knowledge exist. First, in the teaching of halogenated compounds the historical background to the synthesis of these compounds or perhaps a discussion of the synthesis and testing procedures linked to the development of new chemical compounds could be included. All these aspects are linked to another sphere of the subject of chemistry, which I will refer to as the *epistemological* sphere (Östman, 1999) or the understanding of chemistry as an activity and as a scientific community. Second, the subject of chemistry also consists of a third sphere. This could be referred to as the social or ethical sphere (Östman, 1999) and it contains knowledge of chemistry in a social context,

[6] This interpretation of scientific reflectivity is partially based on experience from an experimental ethics teaching sequence and subsequent interviews with chemistry students at the University of Copenhagen (see Eriksen, 2003).

including questions of how chemistry is part of society and which considerations (ethical) could be made in this regard. In the case of halogenated hydrocarbons a discussion of the use of DDT as an insecticide and the consequences now being linked to this use could be a way to include this third sphere of the subject of chemistry in the actual teaching.

The explicit incorporation of all three spheres of chemical knowledge into tertiary chemical education could help ensure reflectivity at the subject content level – the constant reflection on this content knowledge: What is chemical knowledge? How is it produced? Is it true? How is it used? What are its limitations? What are the benefits and dangers connected to this use? Do we as chemists have a responsibility for this use? Traditionally, much chemistry teaching at university level has primarily been linked to the ontological knowledge sphere of chemistry, carrying with it a tendency to treat the subject of chemistry as a collection of factual information that should be learned as well as possible (Eriksen, 2003). But as discussed above this is not an adequate approach; all three spheres of chemical knowledge must be included in the teaching in order to explicate and open the rules of the chemistry game for reflection and debate. Paraphrasing Kant we can say: reflectivity without content is empty, content without reflectivity is blind!

2.4.2 Reflectivity and Format

In the interpretation launched here, reflectivity is connected to both the understanding of rules and of the development of abilities to reflect upon and actively change these rules. This accentuates the role of the actual teaching, and it seems obvious that forms of teaching where the teacher presents accepted knowledge to the students who are then supposed to internalize this knowledge is not compatible with this aim. Wolfgang Klafki (2001, pp. 162–184) as the teaching basis for his *categorial Bildung* suggests *exemplary learning*. Exemplary learning, basically, employs the idea that working with the particular case as starting point, students can gradually develop more or less generally applicable insights. By means of these general insights students should become able to comprehend structurally related phenomena; that is to develop categorial insight, and thus ultimately to critically evaluate and act upon future categorically related challenges. Employing an exemplary learning approach, the teaching process is therefore not seen as the presentation of pre-determined knowledge and skills for the students to acquire, rather it is focused on pedagogical assistance of the students' own active learning. Central formats for exemplary learning are hence experimental work and project work in which the acquisition of basic, categorical insights and abilities are prioritized. However, students cannot acquire all the knowledge they need through time-consuming exemplary learning. It must be supplemented with orientation-like teaching. In Klafki's point of view exemplary learning provides precisely the necessary ballast for extracting meaningful messages from a more informative (fact-presenting) teaching. Thus, exemplary absorption and the acquisition of broad orientation-like knowledge are not merely supplementary; they actually provide the necessary basis for each other to occur.

Accepting Klafki's analysis of exemplary learning we can now undertake a more nuanced discussion of teaching formats and socialization of students. If the aim is opening for reflectivity, the teaching can of course not be carried out solely in transfer-oriented settings. However, from Klafki's analysis it becomes clear that the crucial factor is not that all teaching activities are based on project work and room for students' own discovery and categorization of reality. Rather, the idea must be to secure anchorage points in the subject matter. At crucial "points of impact" in the content of a given course students must be given the opportunity to work independently and in depth and thus to develop their own categories or structures for comprehending this particular exemplary piece of knowledge.

2.4.3 Reflectivity and Social Relations

According to Jacobsen's (1981) subdivision of the intermediate pedagogical structural level, a third dimension has to be taken into account when the influence of this level on the students' socialization is discussed: the social relations. And it seems obvious that adaptive socialization and socialization as Bildung are correlated with very different forms of social interaction between both teachers and students and in-between students. If students are to develop the ability to criticize the rules of the game they cannot solely find themselves in situations where someone else has the authority to determine right from wrong. Instead, at least some of the time they must become engaged in situations where their own interpretations and opinions are recognized and valued. In other words, the teaching situations must sometimes be based on dialogue – a dialogue in which students and teachers engage on (to the extent possible) equal terms.

2.4.4 Reflectivity and a Note on Exams

My reflections on the structural level of pedagogical interaction have primarily been concerned with the teaching setting. However, as Jacobsen also stresses in his study, the settings of teaching and exams act in concert. Parallel to the above argued effects of the explicit and implicit messages sent to students through the teaching, the organization of exams can be said to profoundly influence the students' enculturation into accepted attitudes and priorities and thus ultimately their socialization. To exemplify, the teaching may very well be based on project work and aimed at the development of insight into the underlying principles. If exams test and reward only the acquisition or rote learning of facts and figures students will of course adjust to this and focus on these aspects in their studies, despite the intentions behind the teaching.

I will not, however, more explicitly consider the various exam formats. The reflections on exam content, format and social relations do not differ significantly from the reflections on the teaching setting already encountered and I will leave the transfer of arguments to the reader.

2.5 Reflectivity Operationalized

As already revealed the present study suggests that education into a reflective scientific practice may be operationalized through the concepts of *contextual awareness, gap sensitive interaction*, and *professional humility*. These concepts grew from experimental teaching of ethics at the University of Copenhagen and subsequent evaluation in collaboration with students and teachers (Eriksen, 2003).

2.5.1 Contextual Awareness

As discussed above the concept of reflectivity entails an aspect of *contextual awareness*. If scientists are to contribute to the social reflectivity they must be(come) aware of the contextualized nature of science. That is, they must develop an understanding of the cultural and philosophical context in which science is embedded. I suggest that the development of this contextual awareness requires that the curriculum as a whole reflects the contextualized nature of science. Otherwise the discrepancy between for example one course in philosophy of science and the "hidden curriculum" behind the composition of the rest of the courses may lead (some) students to, at best, view philosophical reflections on science merely as a spice on the "science dish" or, at worst, as a waste of time. Exemplary case based projects could act as possible anchorage points for unfolding of the contextualized nature of science.

Taking chemistry education as an example, this idea of contextual awareness and a case based development thereof can be illustrated. Developing contextual awareness in relation to organic chemistry means that students must develop an appreciation not only of different types of organic compounds, typical reactions, and synthetic pathways but also of the contextual embedding of organic chemistry. In other words the need to develop knowledge from all of the three spheres presented above, that is the ontological, the epistemological, and the ethical spheres. The field of organic chemistry is embedded in a historical, disciplinary and societal context. Developing an awareness of the two former contexts means that students must gain insight into the historical development of the chemical subfield of organic chemistry: what is the basis for the emergence of such a field? Why is it called organic chemistry? How has it developed? What are its aims? What are its constraints? How is it connected to other chemical disciplines? And developing an awareness of the latter context means that students must learn about the applications of organic chemistry; about the panoply of societal contexts dependent on organic chemistry (food industry, medicine, agriculture to mention a few) and about the enormous impact which the explosive development of our ability to synthesize new organic compounds has had on society.

Exemplary learning based on a case centred on one organic compound like DDT may easily exemplify many of these aspects (Simon, 1999). Working with a DDT case along different lines could for example illustrate the emergence of an organic chemical subfield (based on the growing understanding of the structure of organic compounds, chemists in the last part of the nineteenth century became able to analyze compounds and to suggest methods for their synthesis and DDT was first synthesized in this exciting time). Furthermore, the DDT story illustrates a growing application oriented and commercial interest in organic synthesis (the insecticidal properties of DDT were discovered during a large screening project for potential insecticides); the widespread use of organic compounds in society (DDT has been used as an insecticide in private homes, the military, and in agriculture); environmental effects (the story of DDT in nature illustrates food chain accumulation, degradation, or lack thereof, spreading from the point of impact, effects on living organisms etc.); as well as social effects (the development of a large industry-like agriculture in the West has been dependent on fertilisers and insecticides and it has transformed many aspects of society, environmental issues influence a wide range of societal actions from political decision making to grocery shopping). Thus, by working with a case like the DDT story students' contextual awareness of organic chemistry could be developed. The idea is not to turn science students into historians or sociologists but to develop their awareness of the contextual embedding of their own discipline in order to develop their ability to co-create social reflectivity in their role as scientists.

2.5.2 Gap Sensitive Interaction

As outlined above much more than good rhetorical skill is an issue when developing an interactive competence suited to partaking in social reflectivity. Students must become able to interact in what we might refer to as "a gap sensitive way." That is, students must become able not only to present research results in an easily comprehensible way, but also to engage in discussions of the implications, at several levels, of these research results, and, in doing this, being sensitive to several potential gaps. Previously in this study, we have identified at least one gap, which can now be considered, that is the gap between contemporary contextualized science and the conventional, academic scientific self-understanding. Furthermore, awareness of the gaps between science and ethics; between different ways of perceiving the world, nature, and man's right to "fiddle" therewith; and between a scientific and a "lay" interpretation of central concepts such as risk are central for gap sensitive interaction.

Again referring to the DDT story, we may exemplify some of these gaps: To decide whether the use of DDT should be prohibited when currently many developing countries have no realistic alternative in their fight against malaria is a question that spans the gap between science and ethics. We need science to estimate the risks connected to the use of DDT as a preventive measure in the fight against malaria and we need science in order to develop safer alternatives. However, deciding whether to continue the use of DDT in this relation is not a scientific question and science cannot provide an answer, only necessary background information. It is possibly less obvious that the issue of risk estimation spans the same gap. As discussed by Beck, the use of science to analyze risks and the use of scientific language when risks are described can make us blind to their real nature. So when discussing the risks connected to the use of DDT and thus parameters such as "acceptable values" and "average exposure," we do not always realize that we are really allowing "a permanent ration of collective standardized poisoning" (Beck, 1992, p. 65). When employed in a gap insensitive way, the use of science and of scientific language can be a way to obscure that risk estimation is also a matter of ethics, not merely chemistry – we should not poison each other (completely…).

2.5.3 Professional Humility

Closely connected to interacting in a gap sensitive way is the development of what we may label professional humility. In this concept I include the idea that in order to communicate genuinely with critics of their research scientists must develop a humble attitude towards their own professional knowledge. I do not mean to indicate that scientists should abandon their understanding of science as an outstanding knowledge generator, but merely that they must develop the awareness that nothing is certain, that science engineered to solve one problem may generate new and worse problems, and that science can not answer all types of questions; some for instance are questions of ethics. If scientists are to become productive partakers in social reflectivity, science students can not leave university with the attitude that "ordinary people" are simply too stupid or frightened to understand anything or that science "knows" all the answers. Instead, they must appreciate the fact that everything is more or less uncertain and that attention must also be given to these uncertainties and to potential "blind spots" in our knowledge. A crucial aspect of scientific reflectivity is the realization of the extremely difficult position in which science and society are caught; while we do not know everything, we have to make decisions. And development of professional humility may be one way of attempting to minimize the risks we inflict on ourselves.

For example, in the case of DDT the discourse in the community debating and influencing the use of DDT and other pesticides remained dominated for a long time by a focus on the actual, immediately recognizable damage; this was despite the fact that in debates on pesticide use an emerging focus on potential damages as opposed to immediate ones date back to the late 1920s (Böschen, 2002). A more pronounced professional humility, that is more explicit awareness of the limitations of our knowledge and of the blindness that goes hand in hand with any focused attention, might have given the potential damages connected to the widespread use of DDT more weight at an earlier stage in the discussion and decision-making process.

2.6 Anchored Ethical Dialogues

Having now, through the concepts of contextual awareness, gap sensitive interaction, and professional humility interpreted and developed aspects of scientific reflectivity, let us turn instead to the process: how exactly are we supposed to develop students' contextual awareness and so forth? I have suggested that the answer may be case based exemplary work and ethical dialogue. Below I will take a closer look of a teaching and learning "method" that aspires to combine the two things.

2.6.1 A Note on Anchorage

I suggest the introduction of "anchorage points" on a regular basis (e.g., twice or thrice a year) into the planned study programmes. That is, opportunities for the students to reflectively relate to the bigger picture. Further, I suggest that these anchorage points may take the form of *anchored ethical dialogues*. By this notion I mean ethical dialogues anchored to a concrete case (with a basis in students' course work) that students work with for some time. It has been suggested here that engaging in dialogue and being challenged by different viewpoints on the situation in question is crucial for a reflective educational practice. And here the anchored ethical dialogues enter the stage. The students' in-depth work with a concrete case provides an excellent opportunity for discussing ethical questions connected to the case. In this way the ethical dialogue becomes anchored to concrete circumstances and to the other aspects of the case on which the students have worked extensively.

2.6.2 A Note on Ethics

In a science teaching context ethics is often interpreted as good scientific conduct. It is my claim that this interpretation of ethics in the university chemistry teaching setting is inadequate. The difference between my idea of the ethical sphere introduced previously and good scientific conduct boils down to the following "learning how to do science the right way" versus a critical approach "what is the right thing to do and why?" Contained in this latter is a broadening of the students' world perspective and the ability to see the relatedness of various spheres, whereas a limited, internal perception of ethics leaves out reflections on science as a social actor. At its extreme, the limited, internal perception of ethics teaching could convey to the students the idea that when everything is being performed according to the internal ethical guidelines, it constitutes "good science," the responsibility of the scientist is fulfilled. This leaves out the social dimension and as Ziman (2002, p. 43) points out:

> [T]he scientist who takes a job doing research on Napalm on the grounds that it is 'good chemistry' is almost as much a pervert as the medical researcher who experiments on patients without their informed consent. Doing 'good science' is not synonymous with being a good person.

So, we can add that this view on science is definitely not the answer to the call for increased reflectivity. In continuation of this, I suggest perceiving ethics in relation to chemical education as *contextualized ethics* and to include under this heading reflections via for example historical, philosophical, and sociological analysis on the chemical enterprise and the values governing this endeavour, including the discussion of the adequacy of these values. Ultimately, the ethical sphere thus refers to the question of how we want to live and it encompasses reflections on scientific development and its consequences for humankind.

In order to make this idea of ethics operative in teaching, some additional reflections are needed. The kind of ethics we are talking about is obviously a sort of practical or applied ethics (Thomassen, 1997, p. 38). Bent Flyvbjerg's (1993, pp. 20–22) interpretation of a phonetic idea of an applied ethics focuses, for the choice of a line of action, on studies and analysis of the concrete case within its context, not on the application of a general ethical theory on specific cases. This understanding of applied ethics does not exclude the use of ethical theory in decision-making, it merely emphasizes that the basis is always the specific case, not the application of a specific ethical theory. Thereby, the phronetic idea of an applied ethics is in accordance with the methodological idea of *contextualism* as introduced by Earl Winkler (1993, p. 344):

> [Contextualism] is the idea, roughly, that moral problems must be resolved within concrete circumstances, in all their interpretive complexity, by appeal to relevant historical and cultural traditions, with reference to critical institutional and professional norms and virtues, and by utilizing the primary method of comparative case analysis.

2.6.3 A Note on Dialogue

As the notion "anchored ethical dialogue" indicates an important aspect of the teaching method I advocate here is dialogue. It was argued above that engaging in dialogue and being challenged by different viewpoints on the situation in question is crucial for a reflective educational practice. As discussed, it is important that this dialogue is anchored in a concrete case. Further, it is crucial that a genuine dialogue is taking place, and that the case work thus represents an opportunity for breaking the sender-recipient relationship between teachers and students. One may easily imagine that students who "come back" from the mental journey into an exemplary case, present their results, and in class discuss with the other groups ethical questions related to the case, will experience a very different meeting with their teacher.

Suddenly students will have "been to places" that the teacher has not necessarily "seen." I believe such experiences could be important for students' ability to develop an own attitude to the scientific game they are becoming partakers in.

Other, more practice tied, considerations must be made: These include "dialogue catalysts" and "dialogue shapers." In order to create a catchy dialogue in a group of students, a large number of who are likely to share professional viewpoints, the discussion material or the discussion format must somehow act as a catalyst. And in order to create a constructive dialogue that will actually enrich and refine students' viewpoints and dialogical approaches, the students must be introduced to various tools for shaping the dialogue. Relating to the catalysts, several suggestions may be proposed: the case that provides the basis for the ethical dialogue could include materials that provoke firmly cemented attitudes. Or, as part of the project students may be asked to produce arguments for opposing viewpoints (not necessarily their own ones). More interesting – when also considering the development of professional humility and gap sensitive interaction – is the idea that the anchored ethical dialogues should include people from "outside," for example students from other faculties than that of science. For example, biology, medicine and psychology students discussing the brain and the experience of self, or biochemistry and theology students discussing the concept of life would, given the proper guidance, probably develop students' comprehension of both their own discipline and of differences and similarities between this and other disciplines, their basic assumptions, and approaches to the material world. In this way students could become sensitized to other ways of comprehending the world.

About the discussion shapers, we may propose that students need to be introduced formally to ways of building an argument; to an overview of different ethical theories; and to epistemological reflections on science if the ethical dialogues are to become sufficiently concrete to the students.

To put it briefly, we may say that in anchored ethical dialogues one may at the same time stimulate several aspects connected to the development of students' reflectivity. Thus, the combination of casework and anchored ethical dialogues seem to tie together the development of contextualized awareness, professional humility, as well as gap sensitive interactive skills (see Fig. 2.1).

2.7 Conclusion

In conclusion, the present study suggests that one challenge science education is currently facing is to prepare students for the changed societal role of science, and that this implies that future scientists must be prepared to see science as an integral part of societal development and for partaking in social reflectivity. Further, that this necessitates a reflective educational practice which aspires to develop (at least) students' *contextual awareness, professional humility*, and their ability to *interact in a gap sensitive way*. Finally, the idea has been developed that one road towards this goal could be to include in the curriculum, project work and *anchored ethical* *dialogues* that “force” students to contemplate the contextualized nature of science, to engage in discussions of ethical questions, and to become challenged by different viewpoints on the case, science, and the world in general.

While the introduced notion of social reflectivity relates to general socio-political considerations, the presented operationalization of reflectivity, and the development of the idea of anchored ethical dialogue, transfers the discussion to the micro-level and thus focus directly on changes to the processes of teaching and learning.

A further refinement of our understanding of development of students’ scientific reflectivity and more concrete suggestions for teaching “approaches” await more empirically based data. Currently Danish higher educational institutions are working to implement mandatory philosophy of science courses into their study programmes. Gathering experiences from the science departments could be an interesting place to start.

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