RESEARCH AND THE QUALITY OF SCIENCE EDUCATION

Research and the Quality of Science Education

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PREFACE

In August 2003 over 360 researchers met in The Netherlands to exchange experiences and discuss results in the field of science education research. The Conference was organized by the European Science Education Research Association (ESERA), the fourth since the foundation of the Association in 1995. The participants came from 39 countries, mainly from Europe, but also from other continents. Almost all European scholars with a long record of eminent work were present, but also many young researchers who were in the stage of preparing their PhD theses. The abstracts of the more than 300 papers were published in the Book of Abstracts; synopses were published on a CD-ROM.

The general theme of the Conference was Research and the Quality of Science Education. This theme was chosen with the importance of science education at all levels of schooling in mind, formal and informal, from primary to higher education. The significance of science education is not only felt by teachers and school administrators, but also by many others: researchers, industrialists, politicians, and parents. Over the last decade science education has been a topic of public debate, related to the results of international comparisons (such as the TIMMS and the PISA studies), the fall of interest in science studies in higher education, and the shortage of teachers. At the same time educational research showed that learning results were often not as good as expected and that the motivation of pupils for science education was less than adequate. Also opinions on effective learning changed from a classical teaching methodology and content to approaches which put more emphasis on concept development, collaborative work, connections with the world outside the classroom (such as modern developments in science and technology), argumentation, modelling, the nature of science, and the use of computer technology. Many innovations have been initiated and practised by science educators, teacher trainers, national curriculum institutes, and professional scientific bodies.

In such a dynamic educational setting, research plays an important role: it provides theoretical guidelines, it brings together knowledge and experiences from many countries, and it poses critical questions before, during, and after innovations. In this way it could (and in our opinion should) play a major role in monitoring and promoting the quality of science education.

This book is not intended to be proceedings of the conference. The CD-ROM with three-page synopses fulfils this role. Our aim for this book is to publish just a selection of those papers which in our opinion are outstanding, representative of the progress in a variety of fields, and worthwhile enough to be made accessible to a larger audience. We selected around 40 of the 309 presented papers and invited the authors to rewrite their papers according to our format. Each of these rewritten papers was independently reviewed by two experts, and based on their comments, the editorial board returned all submitted papers with guidelines for improvement. Finally, 38 of the papers were approved for publication.

In order to facilitate reading, the papers were ordered according to the research fields they represent:

- The quality of science education
- Science curriculum innovation
- Science teacher education
- Teaching-learning sequences
- The nature of science
- Models and analogies
- Discourse and argumentation
- Teaching and learning of concepts.

In most cases the position of each paper was clear, in some cases, if various themes were covered, we had to make a choice. For instance, many of the modelling papers dealt with teachers' professional development.

Finally, we would like to thank all those who contributed to the publication of this book: our colleague-organizers of the Conference, the authors, the reviewers, the secretaries of the Centre for Science and Mathematics Education, and the language editor.

The editors:

Kerst Boersma
Martin Goedhart
Onno de Jong
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PART 1

The Quality of science education

FROM NORMAL TO REVOLUTIONARY SCIENCE EDUCATION

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ABSTRACT

This paper has the explicit aim to raise questions about ourselves, in fact, to question the very ways in which we science educators do business and understand ourselves. Would it come as a surprise if some readers were upset with me for raising such questions?[1] Negative responses to the issues I articulate in this paper are at the very heart of what my chapter is about. How does a community of practice renew itself when at the very moment that those of its members who propose change are often silenced by journal and book reviewers who see their power, which they have gained in the existing community, threatened by new or different ideas? And how can we begin talking about such issues without upsetting those who have different stakes and views? But then, we also need to ask, how can the science education community renew itself if there are gatekeepers who uphold the old order? That is, how can the science education community (of practice) change itself from doing normal science to doing revolutionary science?

1. INTRODUCTION

Over the past decade since leaving fulltime classroom teaching, I developed interests and conducted research that took me beyond my root discipline, science education including social studies of science, anthropology of the workplace, and linguistics (pragmatics). Working and publishing in these fields, I encountered theoretical frameworks, ways of relating to the research participants, and forms of scholarship that differ from our discipline. Upon coming back from time to time to my root discipline, I come to see it differently, see it struggling with issues that elsewhere have been settled. With more than a little concern, I frequently see my own discipline plodding along instead of engaging in efforts that change the world. In this chapter I hold up a mirror, thereby allowing the science education community (including myself) to look at itself.

The need for change in science education practices has emerged for me particularly while researching controversy and environmentalism in one community (e.g., Roth & Lee, 2002), on the one hand, and while researching in urban schools where approximately 90% of the students are from home conditions of relative poverty (e.g., Roth et al., 2004), on the other. In the first instance, I came to realize that it is not necessary for every citizen to know how to balance a chemical equation,

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recite the Krebs cycle, or use Newton's third law to explain some phenomenon; rather, what we need are structures that allow citizens to solve problems and controversy in a collective manner. More important than everyone knowing scientific facts and concepts is that everyone, whatever his or her predilections, penchants, and beliefs, can participate in collective decision-making. In the second instance, I realized that science education contributes to reproducing an unjust, iniquitous, and inequitable society (Hein, 2004). More science education is continuously producing scientists who build weapons of mass destruction and work for ruthless multi-national companies that exploit a planet, which, as a proverb among the First Nations people on the Canadian Northwest Coast goes, we did not inherit from our ancestors but are borrowing from our children. What we therefore need is a discipline that goes beyond interpreting science teachers and students in various ways; the point of the existence of science education has to be the production of a better world.

When existing paradigms cease to function adequately—for example, in the exploration of an aspect of nature—substantial change (revolutions) is in order (Kuhn, 1970). Because of the nature of science education as an applied discipline, substantial change may occur at three levels. First, I think that there is a need to revisit the theoretical frameworks we use to understand the world. Second, there is a need to revisit the way in and for which we prepare future science teachers. Third, there is a need to theorize the second issue in ways that lead to change so that it contributes to the production of a more reflexive and equitable society.

In the remainder of this chapter, I present a framework that allows us not only to understand teaching and learning, but also to reflect upon our own actions and how these co-produce some of the phenomena we report in our journals. This framework has allowed us (my colleagues, students, and me) to bring about changes in the way we teach science teachers, the way science teachers teach in one school, and in the way students participate and take charge of their own learning. Most importantly, as I articulate below, this approach has led us to an active participation of university supervisors, teachers in training, science methods instructors, school administrators, and researchers in the teaching of students. This, readers will readily recognize, constitutes a substantial (revolutionary) departure from current practices in our discipline. I begin by briefly articulating the framework that allows us to theorize not only the phenomena of interest, but, much as quantum theory has done for physicists, also allows us to theorize how any observer participant mediates the production of data. I then use this framework to look at a range of activities in science education practice and research to show how they constitute a radical departure from what science educators have done in the past.

2. AGENCY AND STRUCTURE

In many disciplines, researchers recognize the productive nature of human agency: not only do humans react to sociomaterial (including their own bodily) conditions, but they also produce and reproduce these conditions. Thus, neither the environment nor bio/psychological factors *determine* human actions. Such an approach necessitates a theoretical frame in which human subjects and their environment are related dialectically; that is, they mutually constitute one another rather than being dualistically opposed, as is currently the case in other psychological, sociological, and even discursive approaches.[2] Though differently articulated and named, the dialectic of agency and structure is fundamental to approaches in many disciplines, including cultural sociology (e.g., Sewell, 1992) and cultural-historical activity theory (Leont'ev, 1978). Agency requires structure—without the human body, articulated as it is with all of its components, we cannot think of someone who acts; structure requires agency—any cognition requires the active engagement of an organism in a structured world (e.g., von Uexküll, 1973/1928).

Structures come in two kinds: within the agent, there are schemas; in the environment, there are sociomaterial resources. (The predicated sociomaterial is used to approach social and material phenomena symmetrically.) The two are again dialectically related, for the schemas allow us to recognize environmental structures for what they are; but the structures in the environment have led to the formation of the schemas in the first place. This may sound like a chicken-and-egg situation, which would be difficult to explain in traditional logic. But such systems are as easy to explain in dialectical logic, or even in chaos- and catastrophe-theoretic approaches, where new, multi-state variants emerge as complex systems move through bifurcation points (e.g., Roth & Duit, 2003).

Cultural-historical activity theorists provided a useful heuristic for identifying structure in an activity system (Engeström, 1987). This heuristic includes material structures in the form of tools and objects, on the one hand, and social structures in the form of communities with their rules and divisions of labor, on the other hand (Figure 1). Thus, scientists who take the genes of corn plants as their object of inquiry may produce not only genetically modified corn but also research articles. In this productive activity, they draw on a variety of means which, in fact, mediate the engagement with the object. The outcomes of the activity are intended for a particular community that consumes the product, and they therefore mediate the productive process. Interactions with the community and interactions with the object are mediated by rules, such as codes of ethics or appropriate scientific procedure. Within the research group, a division of labor mediates the different forms of engagement with the research object (e.g., as head of lab, lab technician, postdoctoral fellow); within the community, division of labor mediates, for example, the production of tools or the role of the individual subject in the community (i.e., someone who does genetic engineering of corn [DISTRIBUTION in Figure 1]). It is important to note that the subjects not only produce outcomes that are consumed within the community, but also they produce and reproduce themselves as members of the community.

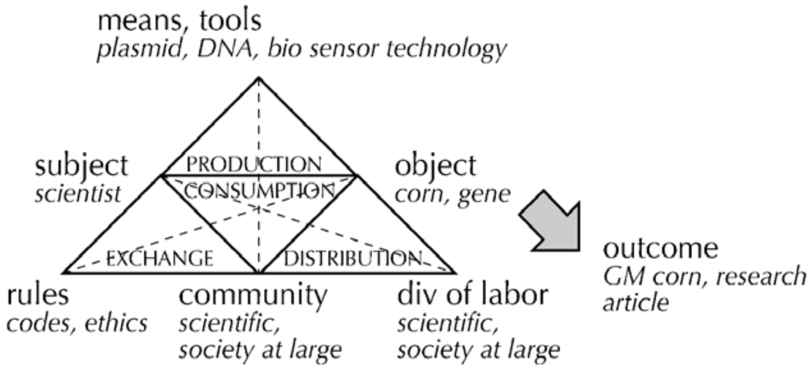

Figure 1. The heuristic for articulating the indivisible unit of an activity system: no part can be understood independently of the others and the relations that they mediate. For example, subjects do not directly relate to the object, but the subject-object relation is mediated by, for example, the tools or the division of labor.

Sociocultural and cultural-historical systems are far from equilibrium (e.g., Prigogine & Stengers, 1979). In dialectical approaches to social theories, disequilibrium is theorized in terms of contradictions which constitute the drivers of change and development (Il'enkov, 1977). Like physical systems that operate in a state of disequilibrium, human activity systems are unpredictable because of bifurcations along their historical trajectories. Because any change ripples through and affects the entire system, understanding what happens within an activity system at any point in time requires a study of its dynamics and history. Further, it does not suffice to study static structures (e.g., material or schemata) to understand actions of a system; understanding requires the study of the actions as a function of the entire system. The interesting aspect about dialectical approaches is that they recognize contradictions in their own theorizing as necessary drivers for theoretical development. They are not master theories or grand narratives, as one reviewer suggested, but tools for raising doubt, thus enabling one to become self-reflexive and self-aware without falling into the trap of solipsism.

The dynamics in activity systems are described at three levels. Activities, such as researching or schooling, are characterized by collective motives; goals motivate the individual actions that concretely realize the activity when properly sequenced. Activities and actions are dialectically related, because actions constitute an activity, but activities guide the nature and sequence of actions; the relation between activity (motive) and action (goal) is called *sense*. Although directed towards conscious goals, actions are realized in practice by unconscious operations. The relation between action and operations is again dialectical, because actions (goals) provide a referent for the nature and sequencing of operations, but the operations constitute actions; the relation is called *reference*. The two relations, sense and reference, also stand in a dialectical relation called *meaning*. That is, one can speak of meaning only when there are ongoing processes; meaning is neither an attribute of texts and images, nor is it behind or underneath them. The dialectical nature of the activity-action and action-operation relations has substantive consequences. Any action will be associated with a different sense if it is employed in a different activity system; any operation will be associated with a different referent if the goal has changed.

3. CREATING UNDERSTANDING IN SCIENCE EDUCATION

The framework outlined so far has considerable consequences for the way we see and go about research in science education. I articulate and discuss two examples: interviewing as a way of getting at beliefs and conceptions, and researching classrooms.

A science education researcher sits together with a science teacher for the purpose of conducting an interview about teaching and teacher beliefs. The outcome of such an interview is usually a text, often produced from a mechanical recording (video, audio) and more seldom from handwritten notes made during the interview. The interview text is normally taken as a data source for getting at teachers' beliefs or ideas about teaching, which are taken to have a direct bearing on what a teacher does in the classroom.

A framing within a dialectical approach shows us that the interview text is inherently the product of a system and therefore *cannot* be attributed to the interviewed teacher alone. Here, the activity is "interviewing for research purposes"; the motive is understanding or theorizing teaching. Any action, such as an uttered sentence (a speech act [Hanks, 1996]), is related to the motive of the activity; the sense associated with the action depends on the activity-action relation. Thus, anything a teacher says is uttered in relation to the motive, interviewing about beliefs and teaching, not with respect to the praxis of teaching. Whatever the outcome, it is not for teaching and its community, but for science educators and their community (Figure 2). The means drawn on in the production of the interview (e.g., belief discourse, talk about science pedagogy) are very different than the tools drawn on in teaching (e.g., enacted science pedagogy, physics discourse [about atoms]). Because actions enter a referential relation to operations, the latter will likely be different too, including, for example, the gestures and body positions, the stance, the signs of confidence produced.[3] That is, the interview text cannot be ascribed to the interviewee; it bears all the marks of the entire system which it therefore reflects.

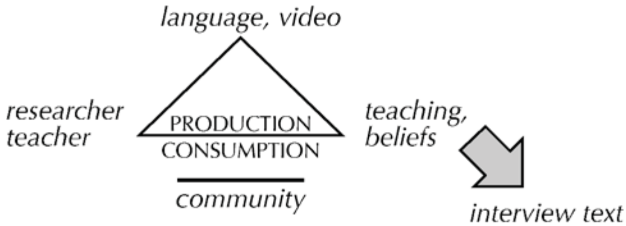

Figure 2. In an interview about teaching and teaching beliefs, the researcher and teacher co-produce the interview text, which therefore cannot be understood as something that signifies the teacher alone. The text reflects the system as a whole, including teacher, researcher, community, tools, and the object (of inquiry).

Sociologists know very well that interviews are co-produced even when they are conducted under the most rigorous conditions in the production of preformatted questionnaire answers (e.g., Suchman & Jordan, 1990), and the relationship of anything said in an interview to what the practice is about has to be established empirically and cannot be taken for granted. Even practitioners have no better insight into their practice than theorists (e.g., Bourdieu, 1990). It is not surprising then that interviewees (e.g., scientists, engineers, teachers) often contradict themselves within minutes during the same interview when they describe or explain something from their practice. It would be much more challenging and much more scientific if science educators were explaining strong coherence (consistency of actions across contexts) than mocking themselves, as they have in the past, about any observed weak coherence (between beliefs and actions). Strong (thick) coherence is the exception; thin coherence, the rule (Sewell, 1999).

In much of science education research, the independence of observer and the observed phenomenon is taken for granted. Researchers think of themselves as being able to act like flies on the wall or that they can be objective recording instruments. Thus, they observe classrooms or simply take recordings others have made (e.g., in the many analyses of TIMMS videos) and write research reports, destined for the community of science educators. They are then astonished that whatever they do and think has little or no bearing on science classrooms—during ESERA 2003, I overheard several different conversations to this effect. Having been a teacher for many years and having continued to teach with them over the past decade, I am not surprised by teachers' distrust of researchers. Many teachers do not like to have researchers in their classrooms; some feel threatened, while others hate the disruptions that this might cause. If science educators truly want to contribute to classroom teaching, they have to change substantially (radically) the way they do business.

Taking the theoretical lens that I propose here, the situation between teachers and researchers should not be astonishing. Science education researchers who study teaching and learning take science classrooms as their objects of inquiry (Figure 3); they record the events or take field notes, and subsequently, after having searched

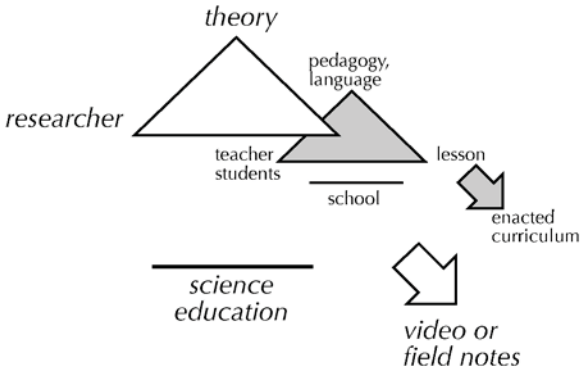

Figure 3. The researcher makes a classroom his/her object of inquiry, thereby objectifying the classroom, its events, participants, and objects. The products of research are consumed in a community with which the stakeholders in the school (teachers, students, parents, administrators) do not identify.

for patterns and themes, write articles about them that are shared with and read in the science education community. The literary genres used are those accepted by and consumed in the research community. In taking classrooms as their objects of inquiry, researchers objectify the classroom, the people that inhabit and populate it, and the events that occur in it. Teachers are not true participants; they are therefore not part of the subject in the research triangle (Figure 3). Rather, teachers find themselves in a subject-object relationship; typically, they might indicate that they do not want to be "lab rats," research objects in another field. The outcomes of the research activity systems are intended for other science educators. It therefore comes as no surprise that teachers and students think that these researcher-oriented texts have little to say to them and that they are not useful tools for teaching and learning. Again, I would expect this because cultures are characterized by thin rather than thick coherence.

4. THE POINT IS TO CHANGE SCIENCE EDUCATION

In this chapter, there is insufficient room to account for the trajectory that has led my colleagues and me to a radically different research and teaching practice—such accounts have been provided elsewhere (e.g., Roth, 2000; Roth & Tobin, 2002). It was an arduous and sometimes painful journey, contradictions moving us continuously ahead as we pitted our existing theories against our practice of teaching in some of the most difficult, urban schools of the United States. Here I simply sketch how research and teaching are intertwined in one U.S. urban high school that serves more than 2000 students, predominantly from (extreme) poverty. Our work is based on two practices that stand in a dialectic relationship: co-teaching | co-generative dialoguing (Roth, 2002).

Understanding activity, as evident from the exposition above, requires participation in the productive process—the kind of and reasons for choices made in some fields are only apparent to the practitioner oriented to the object (Bourdieu, 1990). Thus, co-teaching involves all non-student adults present in the science classroom and sometimes even some students (Figure 4, shaded system). University-based researchers and methods professors, and school-based supervisors and administrators are no longer allowed simply to watch, as if they were flies on the wall, and then sit in judgment over (write reports about) classroom processes, teachers, and students. This, most readers will recognize, is a radical (revolutionary) departure from current practice where university-based researchers and teacher educators pronounce judgments from on high. In our situation, however, everyone present contributes as a co-teacher to the teaching and attempts to address any problematic issue as it arises; therefore, the teacher collective does its best to support student learning. Teaching is a collective responsibility.

Directly after class or after school—the frequency depending on the particular situation and the sociomaterial constraints—all participating teachers and students (or student representatives) meet to analyze what has happened. The motive of this form of activity is to generate theory and plans of actions to improve classroom events. As its name indicates, co-generative dialoguing is designed to have all participating stakeholders contribute to the generation of theory and action plans. For such plans to be useful, all stakeholders need to have the sense that they are in control of the object, the production means, and therefore the outcomes. As Figure 4 shows, the participants in co-generative dialoguing are the same as those in co-teaching; however, the division of labor has changed. While in co-teaching there is a division between students and teachers, co-generative dialoguing provides all participants with equal opportunities and power for generating understanding, and plans of actions—in this way, some students in fact become teachers and some teachers (including university professors) become learners (e.g., Roth, Tobin, Zimmermann, Bryant & Davis, 2002). The outcomes of these co-generative dialogues, understanding and action plans are intended for classroom use by the same participants, and therefore have a much higher likelihood to lead to (lasting) change than in traditional science education. Rather than telling administrators, teachers, and students how to improve their practices, we engaged with them in trying to understand the events and contributing our little bit to help improve the situation.

Interestingly enough, this model has been shown to be an extremely effective environment for learning to teach. Not only do new teachers (in training) learn to teach as they co-teach with more experienced others, but veteran teachers also improve their practices while co-teaching with less experienced teachers and even novices. It is immediately evident that in this generative model, science teachers in training and university-based supervisors and science methods teachers become resources for science teaching and learning in elementary and high schools. In the process they not only reproduce themselves, they also become better science teachers.

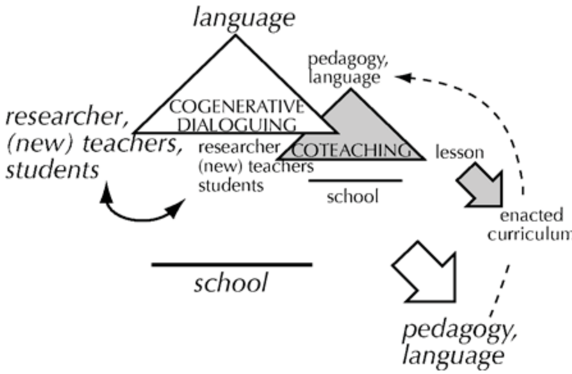

Figure 4. The primary purposes of co-teaching | co-generative dialoguing are learning and teaching and the improvement of the learning environment. The outcomes of the collective, sense-making processes are fed back into the classroom.

It is evident that this practice constitutes a substantial, even radical or revolutionary departure from the predominant practice in science education in which professors and instructors generally do not contribute to science teaching in schools and often are far removed from what is workable in science classrooms. The talk on both sides of the school-university divide concerning ivory towers and real classrooms, or the theory-practice gap, provides ample evidence of a chasm. In our research approach, we see all university-based individuals and school administrators as important resources for the events in classrooms, resources that are currently under-utilized; and we see this form of practice as an important way not only to describe and understand but also to bring about real and lasting change in science education. Just imagine all professors, instructors, and science teacher aspirants contributing to teaching and learning in schools rather than talking about it in university lecture halls! This does not preclude our continued contribution to a literature for other university-based science educators, with its own genres; but the data have been co-produced while contributing to the activity that we all claim our own actions to be about: teaching and learning science in the classroom.

5. CODA

In this chapter, I described a theoretical approach that is very different from those currently used in science education; in effect it questions the products of much of existing research, which does not account for the fact of its own contribution to the research outcomes. I also described a very different conception of science teaching and learning which requires researchers, science teacher educators, and science teachers in training to contribute actively to science teaching. Instituting such activity more broadly would constitute nothing less than a revolution.

The theoretical framework allows us to understand in new ways many problems science educators face. For example, the "cook book" labs high school students conduct do not work because students follow steps, that is, implement operations without knowing or understanding the goals of the actions thus constituted. Furthermore, without an understanding of how these actions relate to the motive of activity (schooling), and therefore without the experience of sense, there is little chance that these laboratory tasks lead to anything that resembles science learning on a broader scale. Here, the analysis begins with the identification of a contradiction that, once recognized, can be used to drive change and development.

The theoretical and practical approaches offered here not only are consistent but also lead to substantial change. Shifting from current ways of doing and thinking about science education research and practice to those proposed here requires nothing short of a radical change, a revolution. However, prerequisite to any revolution is a sense of malfunction and crisis, a sense "that existing institutions have ceased adequately to meet the problems posed by an environment that they have in part created" (Kuhn, 1970, p. 92). This growing sense is often restricted to a segment of the community. I intend this chapter as a mirror for other science educators and myself and point out some contradictions in our discipline. Consistent with my framework, I do not despair because I see contradictions and inconsistencies as opportunities for change, development, and growth. Change does not come easily, for "like the choice between competing political institutions, that between competing paradigms proves to be a choice between incompatible modes of community life" (p. 94). In the spirit of the power of collective action, I suggest that we engage together to bring about what now may look like revolutionary changes in the way in which we go about our daily business as science educators. The most important issue is this: the point of science education is change to make this a better, more just and equitable world.

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I am grateful to Kenneth Tobin, the members of the working group on cultural-historical activity theory at the University of Victoria (Diego Ardenghi, Leanna Boyer, Damien Givry, Marines Goulart, JaeYoung Han, Michael Hoffmann, SungWon Hwang, Yew Jin Lee, and Lilian Pozzer-Ardenghi), and two reviewers for their helpful comments in revising an earlier version of this paper, in particular, in assisting me to find the right tone.

ENDNOTES

1. Because the reviewers of this chapter made comments such as "Rather high-flown about revolutionary changes which would be necessary. Some relativisation and

modesty would be better, but this is a question of personal taste", or "The theoretical frame does not offer anything new and is not necessary for what is propagated", I expect other readers to react in a similar way.

2. One reviewer suggested that there is nothing new to such a perspective. But in fact, a dialectical perspective on social-psychological phenomena is radically different from all other approaches (Engeström, 1987) that dichotomize individual and society or culture, intra- and inter-psychological phenomena, the subject and its object of action, and so forth.

3. Again, one reviewer criticized me on this point, suggesting that science educators have been aware of this. He (or she) wrote, "depending on the kinds of information sought, an interview may yield valid data—and triangulation with other data sources can increase validity further". I am writing not about lack of validity but about the collective nature of interview texts, reflecting both interviewer and interviewee. Furthermore, triangulation does not make sense if particulars of the (changing) situations change the outcome, that is, the interview text.

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REFLECTIONS ON A PROBLEM POSING APPROACH

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ABSTRACT

This paper describes some general aspects of the problem posing approach, as developed at the CSMEU. It describes why this approach has been developed; what didactical problem it tries to focus on; from what perspective this is done; to what didactical structures such an approach may lead, and what its application may involve for a teacher. The arguments are endorsed by examples taken from recent PhD work, but placed within a wider perspective.

1. INTRODUCTION

In the recent past, much work has been done on the cognitive aspects of science learning, e.g., by developing and studying exemplary teaching sequences (Méheut & Psillos, 2004). However, Leach and Scott (2002) argue that in the latter work not enough attention has been given to the role of the teacher. Others focus on the role of motivation for science learning, while Osborne (this volume) emphasizes the importance of adequate scientific argumentation. This paper deals with a line of work at the CSMEU in which all these aspects more or less come together, i.e., the development of what we call a problem posing approach to science education. It addresses some small steps forward in our didactical insight, as this is the most that can be expected from science education research.

The origin of this approach lies in our work on curriculum development, i.e. the former PLON-project (Lijnse *et al*., 1990). This project had a major influence on contextualising Dutch physics education, though its cognitive learning effects were not as positive as expected. In retrospect, we may say that we overestimated the positive influence of contexts on conceptual learning, particularly as far as the experienced functionality of the concepts to be learned is concerned. A main problem was that, though we did our utmost to make the contexts used relevant for our students, due to our mostly *top down* didactics, from their point of view students often got the idea that they had now to describe more or less familiar life-world contexts in a – for them – strange way of physics. Since then, we have been looking for ways to improve the quality of our didactical approach. We have done this by means of developmental research (Lijnse, 1995, 2003) which nowadays has probably become better known as design research (Cobb *et al*., 2003), i.e.,

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developing, testing, and reflecting on actual teaching/learning processes in order to come to new didactical insights and theory. In fact, this connects in some way to much other research that has been done on developing research-inspired improved ways of teaching

2. WHAT IS THE PROBLEM?

In the final decades of the last century, extensive reports were published on all kinds of conceptual problems that students appeared to have with the learning of science. In relation to these conceptual difficulties, other problems were also reported that have more to do with the way students perceive the detailed teaching/learning process. It appeared that during the process of teaching and learning, very often students do not see *the point* of what they are actually doing. This was not only the case in our context-related teaching, but it also applies, e.g., to the relation between theory and experiment as reported by Joling *et al*. (1988) who concluded, in an evaluation report about an innovative teaching method in a chemistry classroom, that students "*carry out assignments without knowing what function they have. The relation between observations and conclusions becomes blurred due to a lack of purposiveness in the experiment"*. However, the problem is much more general. To give another example, Gunstone (1992) reported as follows:

> *"In the following typical example, the student (P) has been asked by the interviewer (O) about the purpose of the activity they have just completed.*
>
> *P: He talked about it……..That's about all…..*
>
> *O: What have you decided it [the activity] is all about?*
>
> *P: I dunno, I never really thought about it …. just doing it – doing what it says its 8.5 …. just got to do different numbers and the next one we have to do is this [points in text to 8.6]."*

In addition, Gunstone (1992) writes: *"This problem of students not knowing the purpose(s) of what they are doing, even when they have been told, is perfectly familiar to any of us who have spent time teaching. The real issue is why the problem is so common and why it is very hard to avoid."*

Now, in our approach we do not focus on explaining this problem, but on trying to find ways to avoid it. The commonality that Gunstone mentions, reflects an often occurring mismatch between the ways teachers and students perceive the teaching/learning process. In the teaching situation referred to by Gunstone, the teacher probably had a coherent conceptual pathway in mind, and thus also perceived his/her teaching activities as coherently aiming at a certain purpose, but from the point of view of the students this coherence broke down to separate learning activities that had to be worked through according to their number. Some of them may have been understandable, but others too difficult, thus blocking an experience of coherence and purpose. In our experience, this is not really amazing as, in spite of their perception, teachers often teach separate activities according to their number, i.e., they teach subsequent activities without relating them to one another. In such cases it is clear that students may wonder what they are supposed to do, as they do not (and cannot) experience and perceive the activities in the intended way. One could symbolise this as follows (Figure 1).

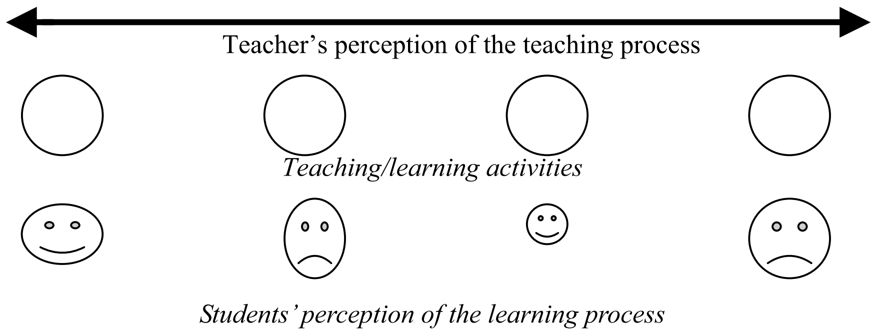

Figure 1. The teaching process consists of subsequent activities that are not explicitly related to one another. Nevertheless, the teacher perceives his/her teaching as coherent and aiming at a certain purpose, while the students perceive the activities as largely non-related, more or less in a non-intended way, and with an unclear purpose.

3. OTHERS' SOLUTIONS

In the literature, we have seen many efforts to remedy conceptual shortcomings, most of them from a more or less constructivist perspective (Scott *et al*., 1992). A first step that constructivists often advocate involves that we should start conceptually from where students are and stimulate students' 'deeper' thinking during the respective teaching/learning activities, e.g., by asking 'deeper' qualitative, conceptual questions. As a consequence, it may become clearer to students, what they are supposed to learn from a particular activity with the result that there is less conceptual confusion.

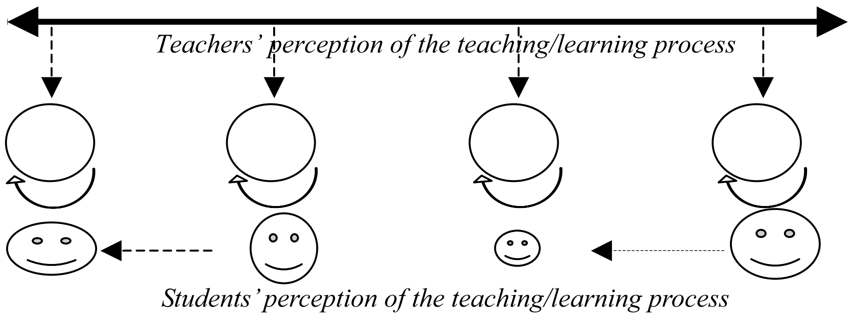

Figure 2. The curved arrows indicate activity-related deeper-thinking questions, which are to be used and monitored by the teacher (indicated by the vertical arrows), resulting in improved conceptual understanding and sometimes in some implicitly perceived backward coherence (as indicated by the two horizontal arrows).

However, such measures do not necessarily result in a sense of purpose, even though, implicitly, they may foster the perceived coherence between activities. The teacher must, of course, make sure that these deeper questions lead to the required understanding of the respective tasks. However, in examples from the literature that I have come across, it still seems that a teacher is not supposed to pay much *explicit* attention to activities' mutual coherence or to a sense of purpose (Figure 2).

Others have, in addition, advocated the importance of paying explicit attention to more general aspects of meta-cognition. Students should learn to learn actively and cooperatively and to show good 'learning behaviours', i.e. to take responsibility for their own learning processes. An example of this is in the Australian PEEL project in which students were taught to ask reflective 'self-questions' like: *How does today's lesson connect with yesterday's lesson?, Are there any new ideas today?, Am I clear about what I have to do?* At the same time, teachers developed teaching strategies to foster such 'quality learning' (Figure 3). However, such procedures and strategies that aim at making students more aware of the quality of their learning, appeared not at all easy for teachers.

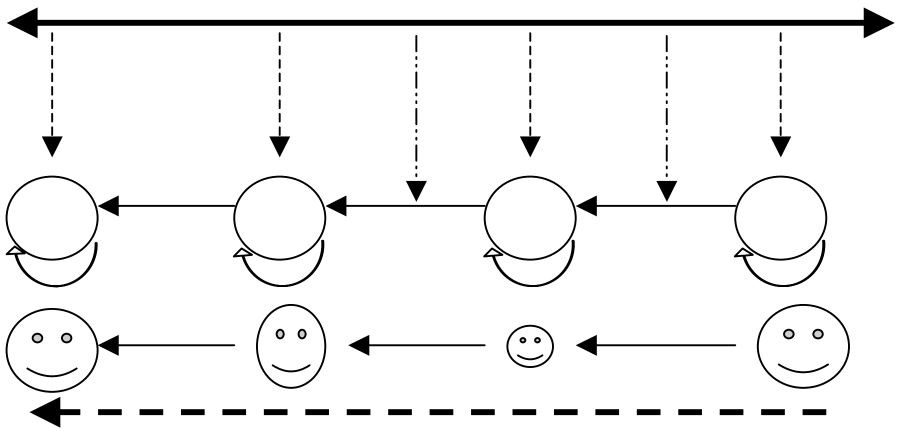

Figure 3. Now also explicit teaching activities (longer vertical arrows) are being used to stimulate the experience of a backward coherence between activities for students (horizontal arrows).

4. OUR APPROACH

In light of our indicated problem, we think the approaches just described to be insufficient since they may lead to a backwardly experienced coherence but not to a forward-looking sense of purpose. Therefore, we have adopted the *additional* view that *on content related grounds* during students' learning process, it should, as much as possible, be clear to them why they are doing something and where it should be leading them. More precisely, students should at any time during their learning process be able to recognize *the content-related point* of what they are doing. We think that if this is the case, the process of teaching and learning will probably be *more meaningful* to them, and it then becomes more probable that they will construct or accommodate the required new knowledge on grounds that they themselves understand.

An approach to science education that explicitly aims at this is called *problem posing* by us. In our problem posing approach, guided by the teacher, we want the students as much as possible to frame themselves or at least value, the problems that they will work on, in contrast to just *solving* a problem as put to them by the teacher (Taconis *et al.*, 2001). The emphasis of a problem posing approach is thus on bringing students to such a position that they themselves come to experience a content-related *sense of purpose* and come to see the *point* of *extending* their existing conceptual knowledge and experiences in a certain direction, i.e. in the direction of the concepts to be taught. Thus formulated, this starting point seems rather trivial and hardly new at all, and indeed it is. Since in itself such a starting point doesn't give any further detailed, didactical guidance, the real *non-trivial* didactical challenge lies in the quality with which it can be put into practice. Further, the challenge to such an approach is that it does not only ask for a considerable change in didactical contract, as compared to that which teachers and students are mostly accustomed; it also requires teaching activities which are as much as possible structured and formulated *bottom-up*, i.e., from the point of view of *understanding, coherence,* and *purpose* for *students*. In fact, one could say that in our approach we want students, guided by the teacher, to walk as much as possible on, what is for them, an explicit, rational, and meaningful pathway of questions and answers that eventually leads them to the concepts to be taught. Put in this way, it will be clear that our approach involves in principle nothing new, even though it appears to be rather difficult to put into practice. In fact, one could say that this approach includes naturally, a content-related 'good argumentation' viewpoint (Osborne, this volume).

For fostering meaning-generated learning, we should make a distinction between *seeing the point* of something and *liking that point*; or, in other words, between *having a motive* for doing something and *being motivated* to do it. Much work has been done on the role of motivation in education, for example, Boekaerts (2002) writes: "*By organizing learning situations in such a way that students are always encouraged to begin the learning process by generating learning goals from their own goal hierarchy, teachers allow their students to experience situational meaningfulness*", because "*students who engage in meaning-generated learning, experience positive effect*". Therefore, Boekaerts pleads for more attention to socio-emotional goals, as: "*personal goals give meaning and organization, or in other words purpose, to a student's adaptation processes in the classroom*". Examples of such personal goals, as given by Boekaerts, are: "be successful", "be respected", "make many friends", and so on. Without arguing about the value of this position, we may expect that the learning of scientific content matter will not easily be perceived by students as personal goals of such a kind. Therefore, we do not try to relate to such general goals, but rather we focus on finding a way to engage students in meaning-generated learning by making them *have content related motives for* learning some topic and its concepts, which should enable them to experience the teaching process as coherent, useful, and possibly also more interesting.

Apart from a very careful design and outline of the detailed teaching activities from a student's perspective, we have tried to achieve this ideal in the following way. First, we develop with students a means that allows them to look forward and that at the same time may serve as a means to monitor 'how far we already have come'. This is done by starting with a global orientation in which a *global motive* is developed for the topic under concern that should enable students to have the required 'sense of purpose'. From this global motive, a storyline is developed, e.g., by splitting the global motive up into several *local* motives that are developed bottom-up at appropriate places during teaching, e.g., by encouraging students to ask, value, or reflect on questions that have been worked on in previous activities, or which will be worked on in future activities. In fact, we have now developed several teaching/learning sequences from this perspective, which has led to the emergence of a certain pattern that, in our experience, also has prescriptive value as a heuristic for the design of new teaching sequences, including appropriate teacher preparation (Lijnse, 2000; Lijnse and Klaassen, 2004).

To make myself more clear, let me show you an example of such a storyline as developed by Kortland (2001). He tackled the didactical problem of how to teach the 'general skill' of decision making, being formulated as being able to present an argued point of view, in relation to teaching about the environmental waste issue. Kortland developed a problem posing teaching sequence for 14 year old lower ability students which can be summarised in a didactical structure (Figure 4). This 10 lesson sequence focussed on the question of how to deal best with household package waste, from an environmental point of view.

After an orientation on personal decision making about household waste, at the level of using both life-world knowledge and intuitive decision making, students come to the recognition that they first need to know more about household package waste. In this phase, students' pre-knowledge is activated, structured, and productively used for formulating a *knowledge need*. Then, after having acquired and applied this knowledge in situations that ask for decision making and about which they have to present their point of view, they come to realise that it is not obvious at all what it means to present a 'well argued' opinion. As a consequence, in this phase a need emerges for some 'norms'. Thus, in reflection, a (still contextualised) number of heuristic rules are made explicit and used, that help students to structure and check their reasoning.

The resulting pattern (mentioned above) is illustrated in the general structure of Figure 4. In designing a teaching sequence, one should clearly establish and distinguish its main independent objectives on which one wants to work. Then for those main objectives, teaching/learning pathways are designed that start from where students are and lead in a bottom-up way to the intended end points. In the design, a central problem posing feature is the idea to intertwine these pathways in a 'natural way' for students via motives that are to be developed during the teaching process.

Another aspect of this general pattern is that in the didactical structure the following phases can be distinguished, which relate to particular didactical functions that have to be fulfilled in such a way that they assure the necessary coherence and purpose in the activities of students.

- Phase 1: Orienting and evoking a global interest in and motive for a study of the topic at hand.
- Phase 2: Narrowing down this global motive to a content-specific knowledge-need.
- Phase 3: Extending students' existing knowledge in view of the global motive and the more specifically formulated knowledge-need.
- Phase 4: Applying this knowledge in situations for which the knowledge was meant.
- Phase 5: Creating, in view of the global motive, a need for a reflection on the skill involved.
- Phase 6: Developing a (possibly still contextualised) meta-cognitive tool for an improved performance of this skill.

We remark that phases 2 and 5, consisting of *creating* relevant needs, represent one of the main points of a problem posing approach. Such phases are not present in teaching cycles as published in the literature (Abraham, 1998). Those cycles almost exclusively deal with cognitive learning, even though it is also often written that one should not forget about the importance of motives. In our approach, however, in some sense both cognitive learning *and* motives are taken together and integrated from the start.

5. OUR EXPERIENCES

The teacher's role

Let me now focus on the didactical role of the teacher in this approach, as it has turned out that this role is not at all easy to fulfil. In fact, the teacher has two main content-related roles. In the first place, the didactical task at the conceptual level involves a change with respect to 'traditional teaching'. The teaching has to be bottom-up, i.e., students have to have more opportunities either to be guided to ask their own questions or to value those brought forward by the teacher, and to follow their questions up by investigating and discussing their ideas, though within the intended sense of direction and purpose. A main didactical problem is, thus, how to set students initially on the right track.

As regards this bottom-up character, a trial school teacher noted: *"...I more often try to get into the skin of the pupils……. It has already yielded fruit (still to be seen whether it is ripe) in my daily teaching practice. Holding back, listening to pupils, adjusting a little later. A changed attitude with regard to pupils' making notes of observations. Less direct explaining."* But also: "*In fairness I have to tell that teaching in this way, with 'holding back' and 'listening', does require quite an effort. After these lessons I generally was more tired than after lessons taught in my old way. The question then presents itself whether that additional effort balances the achieved result. I do give this question a cautious 'yes' though.*

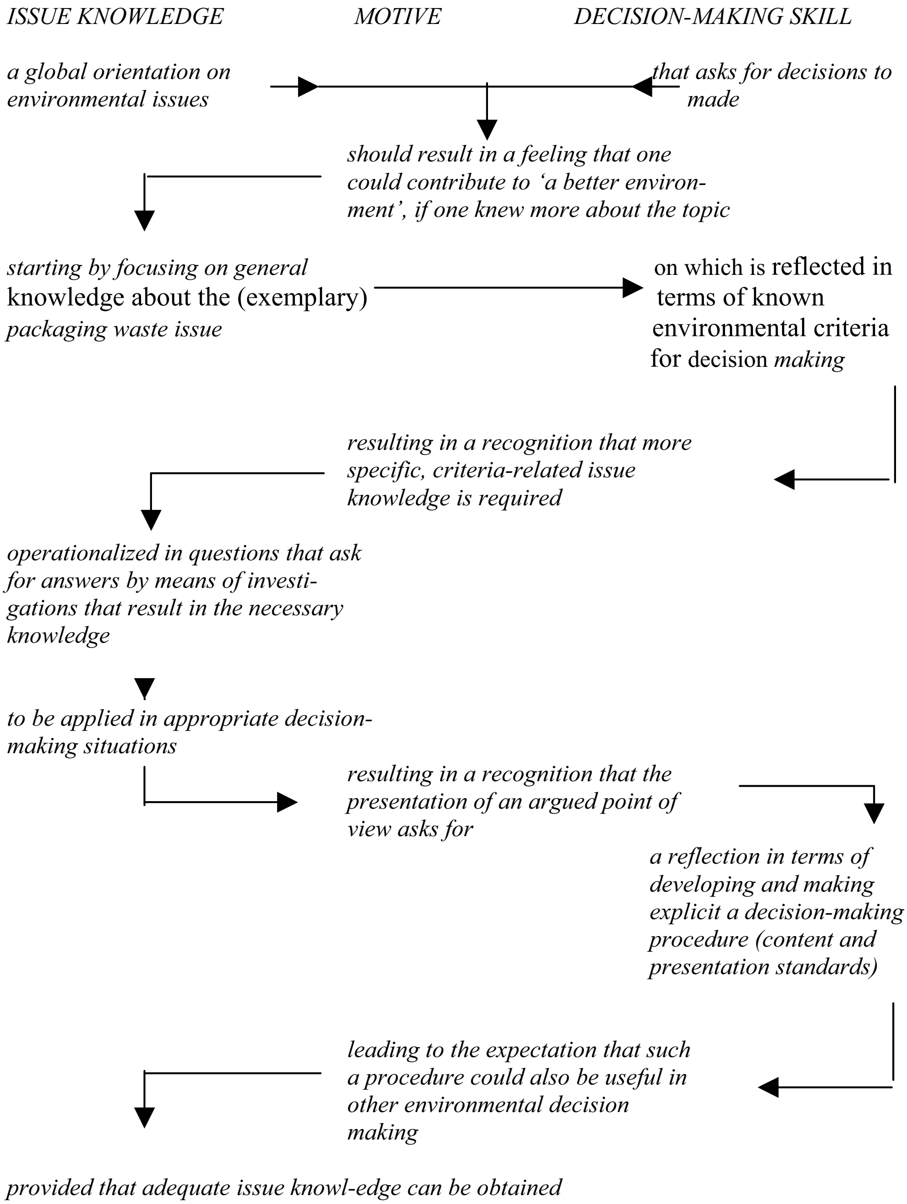

Figure 4. A didactical structure for a problem posing approach about decision making on the waste issue.

One could say that this comment largely resembles what is known about teachers' experiences with 'constructivist teaching approaches'. It has to do with giving students more construction space and thus more responsibility for their conceptual learning, which shifts the role of the teacher towards more guidance and procedural control.

However, in our work this procedural control gets an extra dimension, as the teacher also has to make sure that students connect their learning experiences with the to-be-developed local and global motives; or, in other words, making sure that students experience the teaching/learning process as coherent and maintaining their sense of purpose and direction. The teacher, therefore, also has to monitor and guide the teaching/learning process at what could be called a *meta-didactical* level (Figure 5).

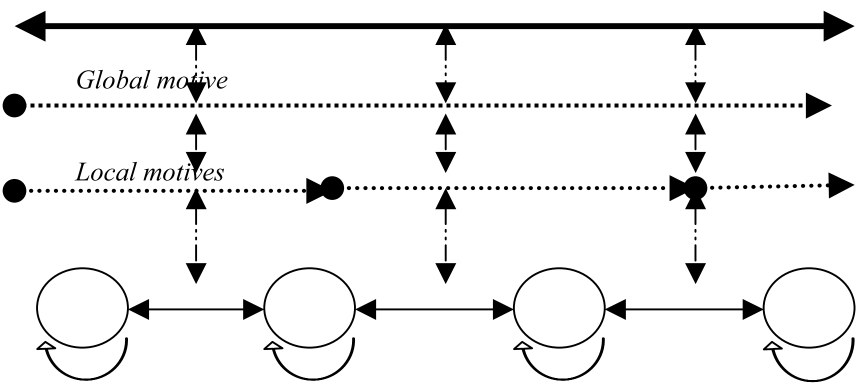

Figure 5. This figure shows that during the teaching process, the teacher has to develop global and local motives and has to monitor the teaching/learning process regularly in view of these motives in order to establish for students the intended coherence and sense of purpose.

In practice, it appeared that this can best be done while rounding off previous and starting a new series of activities. So, the teacher must regularly focus on questions like: 'how far have we come in answering our main questions', 'what problems did we already solve and which ones remain that we still have to work on', 'what new questions result from the foregoing', etc. It is our experience that precisely this meta-didactical activity appears to be rather unusual and difficult for teachers. We call it a meta-level activity as it involves a reflection on the outcomes of the didactical process so far, resulting, if necessary, in restoring the results of poor previous didactical activities. Though such a reflection at the conceptual level is not uncommon for teachers, it is the relationship to motives that is rather new and difficult for them. In our experiments, the fact that trial school teachers were not always sufficiently able to deal with this meta-level appeared to have direct negative consequences for the experienced coherence and problem posing character of the teaching/learning process involved.