CONCEPTUAL CHANGE VIEWS AND THE REALITY OF CLASSROOM PRACTICE

Ari Widodo and Reinders Duit, IPN – Leibniz Institute for Science Education at the University of Kiel, Germany
Email: widodo@ipn.uni-kiel.de duit@ipn.uni-kiel.de

Abstract

This study investigates whether a sample of 13 German physics teachers is familiar with constructivist conceptual change views of teaching and learning and whether their instruction meets key characteristics of such approaches. Analyses of the literature has resulted in an instrument that allows to analyse key characteristics of "constructivist oriented science classrooms". This instrument is used to investigate teachers' views as documented in teacher interviews and to analyse the actual teaching documented by videotapes. Results show that there is a substantial gap between views of teaching and learning in the constructivist literature and the views of our teachers. Further, in most cases actual classroom practice meets characteristics of "constructivist oriented classrooms" only to a limited extent. It appears that most of the teachers in our sample have limited "subjective theories" about what they do as teachers. Their thinking about instruction is very much "topic oriented". They have a substantial repertoire of what to do when a certain topic has to be taught. They lack however a more overarching theory of teaching and learning science.

Aims

Constructivism and conceptual change views have played significant roles in science education research and attempts to improve science teaching and learning since the 1980s (Duit & Treagust, 1998; Schnotz, Vosniadou, & Carretero, 1999; Duit, 1999). Numerous research studies have shown that conceptual change approaches may in fact improve students' understanding of science (Guzetti, Snyder, Glass, & Gamas, 1993). At the heart of recent large scale projects to improve the quality of science instruction are constructivist conceptual change ideas of teaching and learning (Prenzel & Duit, 2000).

Hence, conceptual change strategies should be taken into consideration in science instruction. However, studies in the domain of teacher development (see the studies listed in the bibliography by Pfundt and Duit, 2001) indicate that many science teachers hold ideas of teaching and learning that are not constructivist but transmissive. Such limited views are seen as the key barrier towards improving science teaching and learning in such a way that a scientific literacy may be achieved that is suited to deal with the challenges of the future (Anderson & Helms, 2001).

The study presented aims at investigating physics teachers' subjective theories of teaching and learning on the one hand and their teaching behaviour on the other. It is embedded within a larger project on investigating physics instruction in German schools. The team of that larger project comprises: Manfred Prenzel, Reinders Duit, Manfred Euler, Helmut Geiser, Lore Hoffmann, Manfred Lehrke, Christoph Müller, Rolf Rimmele, Tina Seidel and Ari Widodo[1] (http://www.ipn.uni-kiel.de/projekte/video/main.htm). The project is part of the priority program "*BIQUA* - The Quality of School: Studying Students' Learning in Math and Science and Their Cross-Curricular Competencies Depending on In-School and Out-of-School Contexts" (http://www.ipn.uni-Kiel.de/projekte/biqua/biqua_eng.htm) sponsored by the German Science Foundation that includes 23 projects In total 78 lessons (grade 7 and 8) of 13 teachers were video-documented. Additional data sources are teachers'

[1] Ari Widodo is a lecturer at the University of Education, Indonesia, working in the group under the sponsorship of the German Academic Exchange Service (DAAD)

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interviews (including stimulated recall parts) and students' questionnaires (addressing affective and cognitive variables).

An instrument has been developed called COSC (Constructivist Oriented Science Classrooms) in order to allow to categorize teachers' subjective theories as expressed in the interviews and to code their actual teaching behaviour. The COSC includes key characteristics of constructivist oriented learning environments as presented in the literature.

Constructivist views of teaching and learning

Constructivist principles of teaching and learning (e.g. Driver, 1989; Duit & Treagust, 1998; Matthews, 1998; Phillips, 2000; Tobin, 1993; Watts, 1994) provide the theoretical framework for the development of the above instrument COSC. Constructivism suggests at least three principles about what knowledge is. First, knowledge is human construction. From the constructivist point of view, knowledge is not an objective representation of the world, rather it is human construct (Phillips, 2000). Natural objects or phenomena are themselves "objective" and "real" but the observations and interpretations of them are surely affected by the subjective interpretation schemes of the observer. Second, knowledge is socially constructed (e.g. Driver, 1989). Knowledge is constructed within certain social and material contexts and consequently it is affected by sociological forces, including ideologies, religion, politics, economics, human interests, and by the particular material features of the learning environment. Third, knowledge is tentative. Our knowledge about the world is not a mere copy of reality outside but it is our tentative construction about it. Scientific truth is not absolute but it is relative and may change over time (e.g. Taylor, Fraser & Fisher, 1997).

The constructivist literature suggests at least six principles related to these issues:

1. ***Learners have developed pre-conceptions prior to formal schooling.***
   Learners are not empty vessels ready to be filled with knowledge by the teacher, instead they own pre-instructional conceptions. Even first year elementary school pupils have developed some conceptions about the world since they certainly have interacted with their environments and have collected experiences.
2. ***Learners are active constructors of knowledge and learning is an active process of constructing new knowledge based on the existing knowledge.***
   Learners are not passive recipients of knowledge but they are active constructors of knowledge. They do not simply receive packets of knowledge from the teachers or other resources but they actively construct and re-construct their own conceptions based on their existing conceptions.
3. ***Learners are purposive and ultimately responsible for their own learning.***
   Learners come to schools with certain expectations and purposes. They have to take a certain control of and a certain responsibility for their own learning.
4. ***Learning is a change in the learners' conceptions.***
   Learning has to be viewed as "conceptual change". Learning pathways from students' pre-instructional conceptions towards the science concepts have to be carefully designed. As the pre-instructional conceptions are often (at least in science) in stark contrast to the science concepts these pre-instructional conceptions usually are both necessary starting point and hindrance of learning.
5. ***The process of knowledge construction is embedded within a particular social and material context.***
   Within the constructivist view knowledge construction is seen as a process that takes place in the individual mental system. However, it has also to be taken into consideration that the social and material learning environment substantial shape the individual

constructions. Therefore, not only students' pre-instructional conceptions but also the social and material context provided by the learning environment have to be seen as co-constructors of knowledge.

6. ***Learning experience should generate perturbation to the learners.***
   Individuals make sense of the reality by first assimilating the new information to their already existing cognitive structures. If this process is not successful the cognitive structures have to be further developed. Piaget called this process accommodation. An experience will only be perceived as new and novel when it generates perturbation relative to the expectation.

Since constructivism includes views of what knowledge is and how knowledge is acquired, principles emerge from both perspectives that need to be taken into account in developing criteria for "constructivist learning environments". Science learning should provide students with opportunities to experience science as a body of knowledge and as a knowledge generation process (Duschl & Gitomer, 1991). Students should learn facts, laws, and theories *and* how science works and knowledge is developed. It suggests that principles of the nature of science (McComas, 1998; OECD, 1999) should also be considered in teaching science.

Characteristics of constructivist oriented science classrooms

The key ideas of the constructivist view as outlined above provide the base for what may be called "constructivist oriented" learning environments. The term "constructivist oriented" denotes learning environments that deliberately support students' construction processes. Key characteristics of such learning environments have been provided in a number of research projects. In developing our COSC instrument we draw especially on the two versions of CLES (Constructivist Learning Environment Scale; Aldridge, Fraser, Taylor & Chen, 2000; Fraser, 1998; Taylor, Fraser & Fisher, 1997; Taylor & Fraser, 1991) and STAM (Secondary Teacher Analysis Matrix – Science Version; Gallagher & Parker, 1995) and criteria for constructivist learning environments developed by Labudde (2000) and Tenenbaum, Naidu, Jegede and Austin (2001).

The COSC consists of five categories and each was developed further into four to six subcategories (Table 1).

1. The first category, ***"Facilitating Knowledge Constructions",*** represents that knowledge is seen as human construction, that learners own pre-instructional conceptions, that learning is an active process of knowledge construction, and that learning is a change in learners' conceptions. It identifies the extent to which students' prior knowledge and conceptual change strategies are explored and employed to facilitate students' knowledge constructions.
2. The second category, ***"The Relevance and the Meaningfulness of the Learning Experience",*** represents the view that knowledge construction is embedded within a particular social and material context that may support or hamper conceptual change, i.e., students' construction processes. This category identifies the extent to which students' learning needs are addressed and how resources are utilised to provide relevant and meaningful learning experiences to the students.
3. The third category, ***"Social Interactions",*** focuses on the issue that knowledge is socially constructed. It identifies the extent to which students are given opportunities to socially interact with each other and the teacher, in different forms of social organisation. Different social organisation forms provide different learning experience to the students.

4. The fourth category, ***"Fostering Students to be Independent Learners",*** represents constructivist views that learners are purposive and ultimately responsible for their own learning. It identifies the extent to which students are given some sort of responsibility for their own learning and are fostered to be independent learners.
5. The fifth category, ***"Science, Scientific Knowledge, and Scientists",*** represents the constructivist views that science knowledge is human construction and that science knowledge is tentative. It identifies the extent to which science lessons provide the students with opportunities to experience how scientific knowledge is constantly being developed and revised.

Table 1. Overview of the categories for "Constructivist Oriented Science Classrooms" (COSC)

A. Facilitating knowledge constructions	**B. The relevance and the meaningfulness of the learning experience**	**C. Social interactions**	**D. Fostering students to be independent learners**	**E. Science, scientific knowledge, and scientists**
1. Making the students aware of the status of their learning within the whole subject. 2. Exploring students' prior knowledge or ideas. 3. Exploring students' ways of thinking. 4. Providing thinking-provoking problems. 5. Addressing students' conceptions in evolutionary ways. 6. Addressing students' conceptions in revolutionary ways.	1. Exploring students' interests, attitudes, and feelings. 2. Addressing students' learning needs. 3. Addressing real-life events, phenomena, or examples. 4. Using resources from everyday life. 5. Discussing applications of the concepts learned.	1. Student - student interactions. a. Simple interactions among the students. b. Students exchange ideas with other students. 2. Student - teacher interactions a. Simple interactions between students and the teacher. b. Students exchange ideas with the teacher. 3. Social organisation of the class. a. Individual setting b. Group setting c. Classroom setting.	1. Encouraging the students to re-think their own ideas. 2. Encouraging the students to take some responsibility for their own learning. 3. Encouraging the students to be self-regulative and reflective. 4. Taking into account students' critical voices.	1. Acknowledging the tentativeness of science. 2. Acknowledging differences in theories or views. 3. The roles of observation and evidence, hypotheses, theories, and laws in science. 4. Acknowledging differences in the ways to do science. 5. Acknowledging the limitations of science explanations. 6. Cultivating scientific values, attitudes, and skills.

These categories are interrelated, however, for coding purposes they are treated as completely separate categories. In this way, a certain behaviour may be coded into one or

more categories. The COSC is a set of time based categories, which means that the result does not show how many times a particular behaviour occurs during a lesson but in how many of the time slots of the analysis (e.g. 10 seconds slots in case of the coding system we use) a certain behaviour can be observed. Coding results are, therefore, percentages of the duration of the particular behaviour as compared to the duration of the lessons.

The COSC is not only used to analyse characteristics of actual teaching as documented in video-recordings of physics lessons. It is also used to analyse teachers' views of teaching and learning as expressed in the teacher interviews.

Methods

Data in this research study are gathered from 13 teachers from two regions of Germany (Bavaria and Schleswig-Holstein). Nine of them teach at the highest level and the other four in the middle level of the German three-level school system. All teachers are also engaged in a quality development program in Germany. Hence, we have a special sample of teachers participating in a program that provides access to other information for improving science teaching and learning. The number of students in the classes varies from just nine to about 30. Three lessons from each topic ("Introduction into the Electric Circuit" and "Introduction into the Force Concept") were video-documented. The second topic was taught about 6 months later. Students in our study are in their first year of physics instruction. In Bavaria physics instruction begins in grade 8, in Schleswig-Holstein in grade 7.

The set of methods employed includes student and teacher questionnaires, a teacher interview, and videos of every lesson. Videotaping the lessons is the central data source. Lessons are video-documented using two digital video cameras. One camera is directed to the teacher and the other camera is directed to the class as a whole. This strategy enables us to pick up interactions between the teacher and the students without losing the view towards the whole class.

At the beginning and at the end of the school year students were given a questionnaire on affective variables like interest and self-concept, on their meta-cognitive views and their physics knowledge in the two topics. At the end of each lesson, they are requested to fill in short questionnaires on their mental activities and learning motivation during the lesson. At the beginning of the study, the teachers are given a short questionnaire, mostly on technical issues and on their meta-cognitive views. After documenting the second topic teachers are interviewed on various facets of their views of teaching and learning physics, such as their views of taking into account students' perspectives and students' prior knowledge. These interviews included stimulated recall of parts of their teaching.

A combination of quantitative and qualitative method is employed to analyse our data. The COSC will be used as an instrument to code the videos and as a framework to analyse teachers' interviews. A video analyses software, CatMovie (Wild, 1999) and a qualitative data analysis software, NUD.IST (Qualitative Solution and Research, 1995) are used to analyse the data. Such analysis strategy is chosen to enable us to make use of the rich data available and to enrich the general findings and provide deeper insight into science teaching and learning.

Results

Data analysis is still in progress. Preliminary results reveal that physics instruction documented on our 78 video-taped lessons shows characteristics of constructivist learning environments as underlying our COSC instrument only to a rather limited degree. Lessons usually are not sufficiently organised to facilitate students' knowledge constructions, there is

little consideration on the relevance and the meaningfulness for the students, social interactions are mostly teacher dominated, teachers seldom encourage the students to be independent learners, and the nature of science and scientific knowledge is not addressed at all. In the following we provide some more details following the five categories of our instrument (see Table. 1).

(A) Facilitating knowledge constructions:

The data strongly suggest that the lessons are not aiming at facilitating students' knowledge constructions. Limited efforts are done to make the students aware of the status of their learning. The teachers do not provide students with clear orientations of what is expected to be learned. The teachers sometimes briefly mention the purpose of the lesson and what the students are expected to do but they do not explicitly explain the aims of the whole lessons. Furthermore, there is little evidence for learning as a cumulative activity. That concepts are related to each other is never addressed. The classes also seldom discuss how the current topic relates to other topics or other school subjects. Some teachers spend a lot of time discussing homework from the previous lessons but do only rarely explain in which way the homework tasks relate to what follows.

Students' prior knowledge is not sufficiently explored. Some teachers try to find out features of students' prior knowledge, for instance, by asking the students to explain their understanding about the topic in question. However, no further attempts to develop students' prior knowledge are made. The teacher interviews reveal that a number of our teachers admit that it is necessary to take students' ideas and conceptions into consideration. But asked which students' conceptions they expect in the two topics investigated (electric circuit and force concept) most of them are unable to provide examples of conceptions which are at length discussed in the literature on students' alternative conceptions. They also lack ideas on how to make use of students ideas and conceptions in the lessons.

It seems that many teachers do not have clear ideas of conceptual change and ways to facilitate it. Activities involving conceptual issues are often short and do not address students' entrenched conceptions. Our data also suggest that evolutionary conceptual change strategies (i.e., strategies employing continuous pathways from students' conceptions towards science concepts) are used slightly more often than the revolutionary strategies (i.e., strategies using discontinuous pathways, i.e., employing cognitive conflicts). Attempts to guide students from their conceptions to the science concepts are usually embedded in a somewhat limited and rigid questioning-answering-approach. The teachers usually begin with students' responses but ignore the aspects that appear to be irrelevant from their view. They pick up the answers that are appropriate from their view and develop them step-by-step towards the target conception planned. The common use of a revolutionary (cognitive conflict) strategy is direct confrontation. The teachers usually express their disagreement with students' responses and then explain their views or ask the student to compare his or her ideas with those of others.

(B) The relevance and the meaningfulness of the learning experience

The data show that there is rather little consideration in the lessons on the relevance and the meaningfulness of the activities for the students. Students' interests, attitudes and needs related to the topic are not sufficiently explored and addressed. In most lessons, however, resources from everyday life are used and real life events are discussed, which may promote students' interests, but no teacher deliberately asks for students' comments about the lessons. It appears that orientation of instruction towards issues of real-life is given substantial attention by most of our teachers.

(C) Social interactions

Student-student interactions rarely happen in whole class instruction. Dominating are simple interactions in which the teacher asks questions and the students answer them. Interactions among students are quite frequently observed, of course, when the students work in groups. When the teacher circulated among the students, sometimes, intensive discussions between the teacher and the students happen.

Where the social organization of the class is concerned two types of classes may be differentiated. The first type is characterized by the dominance of whole class activities. Group work and individual work is missing or seldom occurs. Experiments are nearly exclusively demonstrations – sometimes carried out solely by the teacher. The second type may be indicated by a "fair" balance between whole class activities and student work (in groups or individual). Student experiments are often carried out. It may be interesting to note that our findings show that the learning outcomes (regarding cognitive achievement and affective variables like interest) do not substantially differ in the classes of the two types (Prenzel et al., 2002). Regarding achievement there is only a small advantage in favour of the more student oriented type. It appears that the "internal" structure of the two types, especially the extent of providing students with opportunities to think and to be mentally active plays a key role in more "effective" classes.

(D) Fostering students to be independent learners

In many cases teachers make some efforts to give the students responsibility to organise their own learning, such as to decide how a certain activity should be done. Another aspect of encouragement observed is teachers' encouragement for students to consider the appropriateness of their ideas. An important aspect to be independent learners is certainly that students should be able to learn how to learn, how to control and to monitor their own learning. Unfortunately, these issues are not addressed.

(E) Science, scientific knowledge, and scientists

Teachers in our study very seldom address issues that fall in this category. Some teachers occasionally mention issues of the particular view of physics. In most of these rare cases they explain the particular way the physicist speaks about phenomena. However, it should be taken into consideration that our students are in the first years of their introduction into physics (grades 7 and 8). It is somewhat difficult to address already issues of the nature of science in a substantial manner in that early state.

Discussion

The data available so far show that there is a large gap between views of teaching and learning in cognitive science and science education research on conceptual change and constructivist learning environments on the one hand on classroom practice on the other. Most of the 13 teacher we investigate do not hold views of learning that meet constructivist ideas. It is even striking that a number of them are not able to explain their views of how learning of their students happens and which role they take in the teaching-learning-process. Their subjective theories here are at best implicit (tacit). As stated already in the abstract their thinking about instruction is very much "topic" oriented. They have a substantial repertoire of what to do, when a certain topic (like the two topics we investigated, the electric circuit and force) has to be taught. They lack however a more overarching theory of teaching and learning science. Where teachers' classroom activities are concerned there are only a few characteristics to be seen for most teachers that meet characteristics of constructivist learning environments. We also observe what is known from other studies that teachers views and

their actual teaching behaviour are not necessarily in accordance. To refer just to some anecdotal evidence from our data we have a teacher who is very familiar with the constructivist literature but there his way of teaching is not constructivist at all. In the class of this teacher there is no gain regarding cognitive achievement over one school year. We also have a teacher (the teacher with the largest gain regarding achievement) who is not at all familiar with the constructivist and science education literature but there are some ideas of constructivism in his view of teaching and learning and there are also some characteristics of constructivist learning environments in his instruction.

The study reveals disappointing results regarding the kind of instruction given by our 13 teachers. But it is also fair to point out that there are many positive aspects in every lesson we observed. Some of our teachers present exiting new ideas how to teach the two topics in question. These ideas will be very valuable in improving physics instruction. The whole study (i.e., the results from the many other research instruments we employed) provides insights which particular features of instruction have proven effective, i.e. lead to more effective cognitive gains. These analyses, therefore will provide research based information on how to improve instruction (Prenzel et al., 2002).

It is only possible at this state to present preliminary data. The COSC instrument is in the final state of development. At the conference in Turku we will be able to present interpretations that rest on the whole set of data. The results presented here are predominantly on the descriptive level. Work is in progress on investigating relations between certain profiles of our teachers concerning the categories of the COSC instrument and students' achievement and the development of affective variables like interest, self-concept and expected competence gain over the school year we observed these classes.

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