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Learning environments in primary school science

Scaffolding students' and teachers' processes of conceptual development[1]

1 Introduction

In recent years, a resurgence of interest in the processes of early science learning has been observed, combining the approaches of educational and psychological research (e.g. Clement, 2000; Lehrer, Schauble, Strom, & Pligge, 2001). However, there is still considerable need for clarification with regard to the specific characteristics of early learning environments intended to promote students' scientific understanding, as well as to the role which teachers play in these learning environments. This discussion is particularly concerned with the way in which learning opportunities should be scaffolded or structured and guided by the teacher in order to facilitate students' meaningful learning (Kirschner, Sweller, & Clark, 2006; Mayer, 2004). Accordingly, establishing an appropriate balance of support for independent student activity, on the one hand, and guidance through elements of instructional support provided by teachers, on the other hand, can be seen as a major instructional challenge for science teachers (e.g. Brown & Campione, 1994; Edwards & Mercer, 1987). Thus, the appropriate structuring of learning opportunities with the goal of enabling constructive student activity is fundamentally tied to teachers' attitudes in the ongoing lesson. A teacher's ability to appropriately scaffold and structure a lesson may then be regarded as a facet of teacher expertise, specifically targeting the construct of pedagogical content knowledge (cf. Baumert & Kunter, 2006; Shulman, 1987). With regard to research on early science learning, three questions are of particular interest: How can conceptual development in science be supported by instruction? Which aspects of teacher knowledge are particularly important for successful early science teaching? How can this knowledge be conveyed effectively in in-service teacher education programmes? The research project presented below was designed to shed light on these three aspects of early science education.

2 Scaffolding in constructivist learning environments

2.1 Conceptual change in science learning

Science learning has frequently been described as conceptual change resulting from processes of active cognitive restructuring (Duschl & Hamilton, 1998; Tytler, 1998;

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Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). Learning is thus seen as being dependent on the concepts and explanations initially invoked, in a given situation, by the students themselves. At the same time, learning also requires learners to achieve a successive integration and differentiation of these often inadequate and incomplete concepts (e.g. Linn, 2006). Research on conceptual change has shown that this integration, far from being a sudden shift from naive explanations to scientifically adequate views, is a gradual process of restructuring interrelated concepts, with misconceptions frequently re-occurring (e.g. Vosniadou et al., 2001; Wandersee, Mintzes, & Novak, 1994). Teaching and learning environments which rely on a constructivist view of learning therefore aim to alert students to the inadequacy of their prior conceptions and to provide opportunities for them to construct more adequate scientific explanations. Accordingly, constructivist environments have been characterised by such elements as support of active cognitive engagement, authenticity and complexity of investigated topics, opportunities for multiple perspectives, self-direction of learning, and collaborative learning (cf. Gerstenmaier & Mandl, 1995; Jonassen, 1991; Wilson & Cole, 1991). Despite these basic principles of constructivist learning environments, it may make sense to constrain the degree of student self-direction within complex learning environments as long as the goal of ensuring goal-oriented cognitive activity for all learners (including those with less cognitive resources) is pursued. In contrast to radical constructivism, *moderate constructivism* (Gerstenmaier & Mandl, 1995; Renkl, Gruber, & Mandl, 1999) assumes that there is a reciprocal relationship between learners' independent construction of meaning and the use of elements of instructional support during learning processes. Accordingly, successful learning environments will be based on a well-balanced combination of these two factors. Elements of instructional support, or scaffolding, will be used to constrain and focus learners' cognitive activities on the essential features of a scientific phenomenon and to provide models for how to make sense of and relate these features within a larger scientific context (see Pea, 2004; Reiser, 2004).

2.2 The teacher's role in constructivist learning environments

Scaffolding is regarded as support provided by the teacher, in terms of an appropriate structuring of learning environments and of processes of individual knowledge construction (e.g. Bruner, 1961; Wood, Bruner, & Ross, 1976). Bruner refers to it as teachers providing cognitively supportive processes that enable students to find their own solutions for those parts of a task that are within their cognitive reach. At the same time, interaction with the student should also enable teachers to identify those elements of a task with which students will need help. Scaffolding, thus, aims at reducing task complexity while simultaneously creating a cognitively engaging environment that allows for the active construction of new insights. Recent work on scaffolding has been particularly concerned with the effects of different functions and types of teacher prompts. In science education, these prompts may serve as a mere summary or recapitulation of students' contributions, they may encourage students to think ahead and to voice supporting arguments, they may be a means of highlighting differences between students' contributions, they may be used to stimulate transfer, or they may combine several of these objectives (e.g. Davis, 2003; Davis & Miyake, 2004; Duschl & Gitomer, 1997; Hogan & Pressley, 1997; O'Connor & Michaels, 1993). In their survey of the theoretical and empirical conceptualisations of scaffolding, Puntambekar

and Hübscher (2005) note that the original construct has been extended to cover applications in complex learning environments, especially by conceptualising resources such as visualisations as elements of scaffolding. The adequate use of these elements of scaffolding will require professional teacher knowledge both on the content level and on the level of didactics and methodology.

2.3 Constructivist learning environments fostering conceptual understanding by means of instructional support – The experimental classroom study

In an experimental classroom study with a total of six experimental classrooms and two baseline classrooms, we investigated the effects of instructional support, within constructivist learning environments, on third grade students' long-term conceptual understanding of the topic of "floating and sinking". In addition, differential effects for students with differing cognitive ability were investigated with regard to cognitive and self-related variables.

2.3.1 The topic of "floating and sinking"

Research findings from interviews show that children's naive explanations for why objects float and sink tend to focus on a single dimension instead of considering relationships between quantities (e.g. Möller, 1999; Smith, Carey, & Wiser, 1985). For example, these explanations may focus exclusively on the aspect of mass ("everything that is light floats"), on the aspect of volume ("big objects will sink"), or on the aspect of shape ("everything with holes in it will sink"). In contrast, an advanced stage of explanation for floating and sinking requires learners to consider the relationship between the object and the fluid in which it is immersed. At an intermediate level of explanation – the so-called explanations of everyday life – the two measures of mass and volume are being qualitatively related, resulting in descriptions of objects such as "heavy for their size". At this level, students also take into account the role of the water ("water keeps things floating") and may classify objects that float or sink by material kind ("everything made of wood floats"). Finally, on a scientific level, students explicitly compare the density of an object to the water displaced by it (explanation based on comparison of densities) or compare its buoyancy and weight (explanation based on buoyancy).

2.3.2 Description of experimental variation

We developed two instructional units on the topic of "Why does a large ship made of iron float?" for primary school, each of them consisting of eight 90-minute lessons. The two units differed in their degree of instructional support with regard to the sequencing of content and the use of cognitively structuring teacher prompts. In the group of High Instructional Support (HIS), the initial question was segmented into subordinate questions that were supposed to help students to proceed to an ordered construction of adequate concepts. Structured tasks and experiments as well as a wide range of material were provided for each conceptual aspect involved (e.g. concept of material kind, water displacement, density). Students in the group of Low Instructional

Support (LIS) were asked to perform the same tasks and experiments as students in the HIS group; however, as no sequencing of content was provided, LIS group students were allowed to use the experimental material at any time throughout the curriculum, thus increasing their number of choices on the content level.

Apart from the sequencing of content, the experimental groups also varied in the type of teacher engagement during whole-class discussions. In the HIS group, the teacher used cognitively structuring prompts more frequently than in the LIS group. She pointed out contradictions more often, repeatedly asked for supporting arguments and summaries, and helped focus attention by means of presentations, blackboard sketches or written texts. In the LIS group, it was up to the students themselves to determine the aspects to be discussed. Here, teacher action consisted in helping to manage discussions, with limited use of cognitively structuring prompts. She asked for comparisons, supporting arguments, presentations, and analyses less frequently and summarised the current state of students' insights less often. The children did, however, receive individual feedback from the teacher in their student portfolios. To rule out teacher-related instructional effects, both experimental groups were taught by the same teacher. Students in both groups were comparable in their socio-economic status and previous knowledge.

Two screening methods were employed in order to check the implementation of the planned differences between the two curricula. Based on a list of characteristics for the instructional units of LIS and HIS, twelve independent observers correctly assigned in-class video recordings to the two experimental conditions in 45 of 48 cases. In order to check the variation with regard to the use of cognitively structuring prompts during whole-class discussions, a coding system was developed and used to analyse, in 10-second intervals, 30% of classroom discussions. This random selection made sure that all the instructional topics and all the classrooms were included in the sample. An evaluation of teacher comments showed a significantly higher amount of cognitively structuring prompts in the HIS group than in the LIS group. For a description of the exact research design and detailed results of the screening methods, see Hardy, Jonen, Möller, and Stern (2006).

The experimental groups consisted of six third-grade classrooms from three different schools, i.e. a total of 149 children (65 girls, 84 boys), with a comparable socio-economic status. Two third-grade classrooms from two further schools with a total of 41 children (27 girls, 14 boys) served as the baseline group, receiving no instruction at all on the topic of "floating and sinking" and taking only the pre- and post-tests. Instruction in the experimental groups was carried out in three segments, over a period of four weeks each. During each segment, instruction based on the curricula of HIS and LIS respectively, was carried out for two consecutive weeks in one school each, with the instructional groups randomly assigned.

2.3.3 Assessment of conceptual understanding

Test on floating and sinking

The "Test on Floating and Sinking" was implemented as a pre-test, post-test and follow-up-test one year after instruction. It consists of 36 items, with 33 multiple-choice items (17 true/false items and 16 multiple-choice items) and three open-response items. Questions as well as answering choices were based on typical misconceptions of third-grade students (for example, misconceptions about the role of weight, size, shape, or air), on conceptions of everyday life such as the concept of material kind, and on scientific explanations (displacement, comparison of densities, buoyancy). Key words such as "lighter/heavier than" and "(to) push" that frequently came up during the lessons were offered once in a correct and once in an incorrect wording within one item. For a detailed description of the test, see Hardy et al. (2006).

As an index of students' conceptual understanding, we used a sum score for integrated understanding, taking into account the correct rejection of misconceptions and the correct acceptance of scientific explanations (Cronbach's α [pre-test, post-test, follow-up] = .48, .82, .81). Due to the stringent scoring procedure, the variance in the pre-test, where students are often confronted with explicit explanations of floating and sinking for the first time, is more restricted than in the post-test and follow-up-test. Furthermore, we computed single sum scores for three individual conceptual levels (misconceptions, explanations of everyday life, scientific explanations). In these sum scores, answers pertaining to one of the three levels of conceptual understanding were added up separately across all items (multiple-choice and open-response questions were separated as well), yielding satisfactory internal consistencies (misconceptions: .59, .62, .75; explanations of everyday life: .57, .62, .63; scientific explanations: .70, 78, .81; inter-rater reliabilities for open-response items > .95).

Transfer test on floating and sinking

The eight multiple-choice items of this test require students to apply the concepts of density and buoyancy force to contexts not treated in class. For instance, one item asks students to determine the weight a cube of a certain material would need to sink in oil but to float in water (given the masses of a cube of oil and a cube of water of the same size). Another item asks for explanations of why fish rise to the surface when they enlarge their gas bladder. For statistical analyses, the sum scores for scientific explanations (Cronbach's α = .53) and misconceptions (Cronbach's α = .54) were used.

2.3.4 Results

Results of this study have already been published with different foci of analysis (Blumberg, Möller, & Hardy, 2004; Hardy et al., 2006; Möller, Jonen, Hardy, & Stern, 2002); in the following, an overview of the main results will be given.

Achievement gains in conceptual understanding

With regard to the score of integrated conceptual understanding, the two instructed groups differed significantly from the baseline group, but not from each other at the time of the post-test. In the follow-up-test, however, the HIS group showed a significantly higher mean for the score of integrated conceptual understanding than the LIS group, while both groups scored significantly higher than the baseline group. While the HIS group did not reveal a change in its mean values between post-test and follow-up-test, the LIS group showed a significant decrease (Hardy et al., 2006).

A subgroup analysis of students of differing cognitive ability (according to teachers' ratings) showed that particularly the students with low cognitive ability were able to profit from the HIS curriculum. For this analysis, a sum score was used that gave credit, beyond the score of integrated conceptual understanding, to students' answers on the level of explanations of everyday life across all multiple-choice items. Results

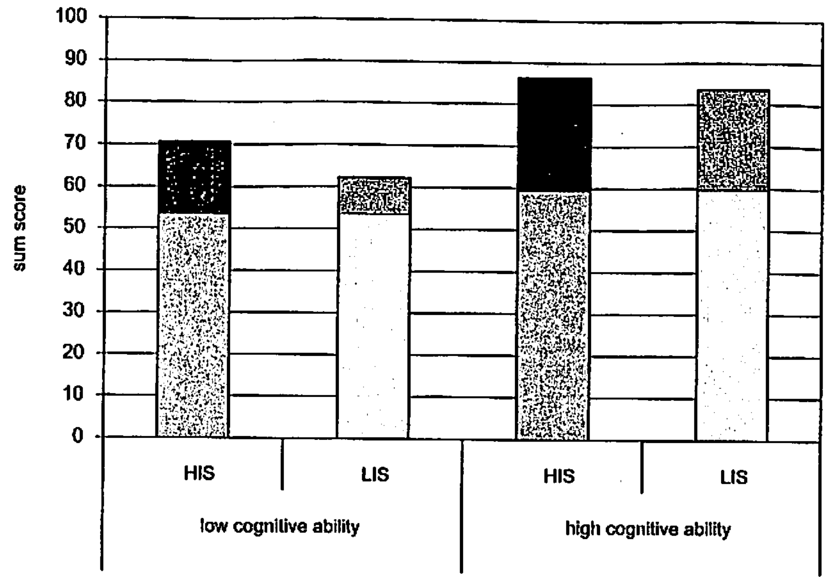

Figure 1: Means of pre-test (light colours) and post-test (dark colours) of the sum score for students with high and low cognitive ability in the HIS and LIS experimental groups

showed that, although the achievement gain of the subgroup with low cognitive ability clearly remained below that of the subgroup with high cognitive ability, only those students with low cognitive ability who were included in the HIS curriculum showed a significant increase in their level of conceptual understanding of "floating and sinking". In contrast, the achievement gains of students in the subgroup of high cognitive ability did not significantly differ between the two curricula (Figure 1; Möller et al., 2002).

Analyses of open-response items showed that the HIS group significantly outperformed the LIS group in the use of scientific concepts while, at the same time, naming misconceptions less frequently. Thus, in the LIS group, misconceptions that had been reduced at the time of the post-test resurfaced after one year, while the HIS group was able to achieve a long-term reduction of misconceptions. Due to this increase in misconceptions, the score of the LIS group no longer differed significantly from that of the baseline group one year after the instruction. The HIS group outperformed the LIS group in the transfer test as well, as shown by their significantly more frequent use of scientific explanations (Hardy et al., 2006).

Results for motivational and self-related variables

With regard to motivational and self-related variables which were additionally assessed in the experimental groups before and after the instructional units, there was no difference in students' perceived satisfaction with their individual learning progress, which was generally high in both experimental groups. Specifically, students' judgement of self-direction and participation within the curriculum was similar in both groups. Similarly, there was no difference between the HIS group and the LIS group with regard to their interest as assessed after the unit. However, the HIS group showed

significantly higher means for self-determined motivation, perceived competence and perceived involvement during instruction, and perceived confidence with regard to students' future involvement with scientific topics. Apparently, the cognitive support in the HIS group was related to students' perceiving themselves as more involved, more competent, and more intrinsically motivated (Blumberg et al., 2003). Further analyses showed that this effect was mainly due to the subgroup of students with low cognitive ability who showed higher means on these variables in the HIS group than in the LIS group. For the subgroup of children with high cognitive ability, no such differences were found between instructional groups.

2.4 The use of visualisations as a means of instructional support – The visualisation study

In the experimental classroom study outlined above, we varied the degree of instructional support within constructivist learning environments by relying on content sequencing and the use of cognitively structuring statements during whole-class discussions. In the following study, we used visualisations as a means of instructional support. Visualisations such as graphs or diagrams are an appropriate means of structuring complex scientific constructs, as learners can actively gain new insights and learn to see relations between variables when engaging with them (e.g. Clement, 2000; Cox, 1999). Visualisations also support knowledge construction on a discourse level since they provide students with a common frame of reference for their discussions (Roth & McGinn, 1998). Furthermore, the use of visualisations can contribute to the development of "visual literacy," one of the goals of science learning and interdisciplinary learning. In constructivist learning environments, visualisations serve to model demanding content, allowing for students' active and focussed cognitive engagement with a task, rather than serving as mere illustrative devices (e.g. Lehrer & Schauble, 2000).

2.4.1 Differentiating between provided and self-constructed visualisations

Especially in primary education, it is crucial to employ forms of visualisation that allow students to establish meaningful connections between their intuitive scientific understanding of a situation and specific representational elements. Here, one may differentiate between the use of provided, or conventional, forms of visualisation such as the Cartesian graph on the one hand, and visualisations developed by the students themselves on the other hand (Lehrer & Schauble, 2000; van Dijk, van Oers, & Terwel, 2003). Since it may be assumed that students' conceptual understanding of a topic as complex as "floating and sinking" will be incomplete at the beginning of an instructional unit, a spontaneously constructed visualisation is likely to rely on students' misconceptions, e.g. a one-dimensional focus. Thus, teacher guidance will be needed to help students to develop visualisations that are more in line with mathematically and scientifically correct representations of the respective relationships (e.g. Gravemeijer, 1999). In contrast, if provided forms such as the graph or the balance beam described below are employed in instruction, quantities and their relationships will usually be depicted in a scientifically correct way due to the inherent structural characteristics of these devices. In this case, however, the challenge is to (meaningfully) familiarise the children with the conventional interpretations of the respective forms during instruction.

In our study, we varied whether third-graders developed their own visualisations of the densities of objects in the context of "floating and sinking" or whether they used a provided form of visualisation, the balance beam. We were interested in the effects of these forms of visualisation on students' conceptual understanding of "floating and sinking," on their proportional understanding, and on their ability to interpret graphs. Because of its quantitative and two-dimensional nature, we expected the balance beam to be particularly suitable for fostering students' proportional understanding and visual literacy, i.e. their interpretations of graphs. The functioning of the balance beam (see Figure 3) is assumed to be easily understood by children since it is based on an equilibrium and allows the students to directly, and by active manipulation, experience relations of cause and effect (see diSessa, 1993). When the balance beam is used to represent density, blocks that are put on one side of the beam represent the volume of an object and blocks on the other side of the beam represent its mass. By doubling the number of blocks on each side, a larger object of the same material can be represented, with the beam maintaining its balance. In contrast to the balance beam that was provided for students of one experimental group during the instructional unit, the students of the other experimental group were provided with different types of material which they could use to represent the volume and mass of different cubes (see Figure 2). Students' self-constructed visualisations were presented and discussed in whole-class sessions. The instructional units were based on selected lessons of the HIS-curriculum (Hardy et al., 2006; Möller et al., 2002) with embedded sequences on the respective forms of visualisation, resulting in a sequence of eleven 45-minute lessons (see Hardy, Jonen, Möller, & Stern, 2004, for a description of the lessons with visualisations).

Figure 2: Self-constructed visualisation: mass is represented by wooden chips, volume is represented by the size of the base

Figure 3: Use of the balance beam: Lego blocks for mass (left) and Duplo blocks for volume (right). The students mark the location on the beam where the blocks for mass have to be placed in order for the beam to maintain its balance for different types of material

2.4.2 Description of the experimental variation

The study was conducted in four third-grade classrooms that were comparable in their size, social composition, and prior experience of the scientific topics treated. The classes were randomly assigned to the two experimental groups of "self-constructed" and "balance beam" visualisations. In addition to the "Test on Floating and Sinking", students' understanding of proportionality was assessed by a pre-test and a post-test, each consisting of six items in the domains of velocity, mixtures, and density which required the construction of proportions (for a detailed description of these items, see Hardy et al., 2004). In order to assess students' ability to interpret graphs, 56 randomly selected students were interviewed five months after the instructional unit. The interview began with an introduction to the coordinate system, followed by ten questions on the interpretation of density and six questions on the interpretation of velocities represented in Cartesian coordinate systems (for a detailed description of the interview, see Hardy, Schneider, Jonen, Möller, & Stern, 2005).

2.4.3 Results

For both groups, a sum score of integrated understanding revealed a significant improvement in the "Test on Floating and Sinking" between the pre-test and the post-test. Similarly, both groups showed a significant improvement in the tests on proportional understanding, albeit in different domains (for further analysis, see Hardy et al., 2004). Thus, contrary to our hypotheses, the group of self-constructed visualisations also improved with regard to their proportional understanding. In the long run, however, the children in the balance beam group, as expected, showed superior results in the graph interview with regard to the interpretation of graphs in the context of velocity (for further analysis, see Hardy et al., 2005). Overall, we thus showed that working with visualisations fostered not only students' conceptual understanding of the represented content but also their understanding of the underlying mathematical structures. Furthermore, we found that instruction with a provided form of representation supported students in making sense of a new form of visualisation, the Cartesian graph.

3 In-service teacher courses designed to foster the implementation of constructivist learning environments in science

In a study on in-service teacher courses we investigated the extent to which primary school teachers may be trained to teach demanding science lessons based on a constructivist approach. We were especially interested in the effects of these in-service teacher courses on facets of professional teacher knowledge – especially teachers' conceptions about teaching and learning – as well as on motivational and self-related variables. Furthermore, we examined the relationship between teachers' knowledge and students' scientific understanding. Below, effects of a variation in in-service teacher courses on outcomes on the levels of teacher variables and student variables are presented.

3.1 Design of in-service teacher courses promoting change in teachers' conceptions of teaching and learning

The present study is centred on promoting change in teachers' pedagogical content knowledge which is considered to combine aspects of content knowledge, pedagogical knowledge and psychological knowledge (Shulman, 1987), with a particular focus on domain-specific conceptions of teaching and learning (Magnusson, Krajcik, & Borko, 1999). Conceptions, as defined here, also include beliefs, i.e. evaluative aspects (Furinghetti & Pehkonen, 2002). Numerous studies show that teachers' conceptions of teaching and learning conflict with conceptions that emphasise cognitively engaging science instruction oriented towards conceptual change. For example, there is evidence that so-called "transmissive" or "hands-on/minds-off" conceptions are widespread among primary school teachers. In contrast, conceptions of teaching and learning that consider it necessary to change students' preconceptions are very uncommon (Smith & Neale, 1991; Porlán & Martin del Pozo, 2004; Keys, 2005). We therefore assumed that, in order for teachers to implement cognitively engaging primary science education, some sort of conceptual change first needs to take place on the part of primary school teachers themselves. This change is difficult to achieve since teachers' existing conceptions of teaching and learning are often deeply rooted in their prior teaching and learning experiences and, thus, tend to be robust. Therefore, short-term interventions are clearly insufficient for promoting long-lasting change in teachers, while in-service teacher courses that strongly rely on an orientation towards conceptual change seem more promising (Northfield, Gunstone, & Erickson, 1996). Because of primary school teachers' lack of experience in advanced science instruction and knowledge of science, in-service teacher courses that offer tutorial support, or scaffolding, seem to be especially important (Richardson & Placier, 2001). Some authors even propose completely individualised coaching in order to effect change (Staub, 2004). Based on these considerations, it may be further assumed that self-directed learning, for example on the basis of written material, is insufficient for changing teachers' conceptions of teaching and learning.

While teachers' conceptions of teaching and learning have been shown to shape teachers' instructional practices (Kagan, 1992; Calderhead, 1996), there are hardly any studies that have investigated their impact on students' achievement. There is some evidence from mathematics instruction showing that students' achievement gains tend to be higher (especially in the domain of complex word problems) when they are taught by teachers whose conceptions are based on a cognitive-constructivist framework rather than on a direct-transmission view of teaching, as is indicated by associationist theories of learning (Staub & Stern 2002). However, the question of the effects of changes in teachers' conceptions of teaching and learning through in-service teacher courses on student outcomes remains largely unexplored.

In this study, our research questions were: Can teachers' conceptions of teaching and learning be changed by extensive in-service teacher courses? What is the role of tutorial support within these courses? Does the participation of teachers in in-service teacher courses also affect students' understanding of scientific concepts? What is the effect of teachers' conceptions of teaching and learning – as modified through in-service courses – on students' achievement?

3.2 The design of in-service teacher courses

In order to address these questions, three in-service teacher courses were designed for primary school teachers: Two experimental groups (EG) received a total of 16 all-day in-service courses on science topics appropriate for primary school such as air and air pressure, magnetism, electrical circuit, or floating and sinking. Guided by a tutor, participants were supported in developing pedagogical content knowledge in the domain of science. The design of these in-service courses was based on conceptual change approaches, i.e. teachers' professional and science-related preconceptions were specifically addressed and challenged by the tutor. In the courses, teachers were encouraged to discuss their conceptions of the science phenomena at hand and to develop ways of verifying their conceptions by empirical evidence. The tutorial scaffolding of this process was similar to that used in the HIS group in the curriculum on "floating and sinking" described in the Experimental Classroom Study, i.e. the tutor repeatedly challenged conceptions, asked for explanations and transfer, and provided counter-examples. Furthermore, she encouraged participants to reflect on their own scientific learning process and to discuss the significance of making preconceptions explicit, as well as the conditions needed to induce change in terms of scientifically appropriate conceptions. Both experimental groups were instructed by the same tutor.

A third group served as the control group (CG). This group received written information on eleven science-related topics which addressed issues relevant to the development of pedagogical content knowledge in science. In the general introduction, they received a description of constructivist approaches to teaching and learning science. Each of the respective topics was addressed in a separate section, in which teachers were given information on typical student preconceptions, on lesson designs, and on relevant science concepts. All three groups worked on the same eleven science topics and were provided with the same written material. The three courses took place over a period of five months. Within this period, the teachers were asked to realise three of the course topics in their own classes.

3.3 Description of the research design and sample

Figure 4 outlines the research design. A baseline group which only received the instruments was added to the three groups described above. The teachers conducted lessons on two prescribed science topics before and after the in-service courses. Both lessons were recorded on video. In the lesson videotaped after the in-service courses, the topic of "floating and sinking" was to be taught in order to allow for an assessment of student outcomes in the "Test on Floating and Sinking." For these lessons, each teacher received a box with the relevant instructional material in order to ensure that the equipment available to the teachers for these lessons was kept constant. Before and after the lessons, students' conceptual understanding of "floating and sinking" was assessed with a slightly modified version of the "Test on Floating and Sinking". Pre- and post-test data for 932 students are available.

The teachers completed a questionnaire before the intervention, directly after the intervention, and as a follow-up measure one year after the intervention. This questionnaire assesses teachers' conceptions of teaching and learning as well as motivational and self-related variables. Results of the follow-up measurement are not yet available.

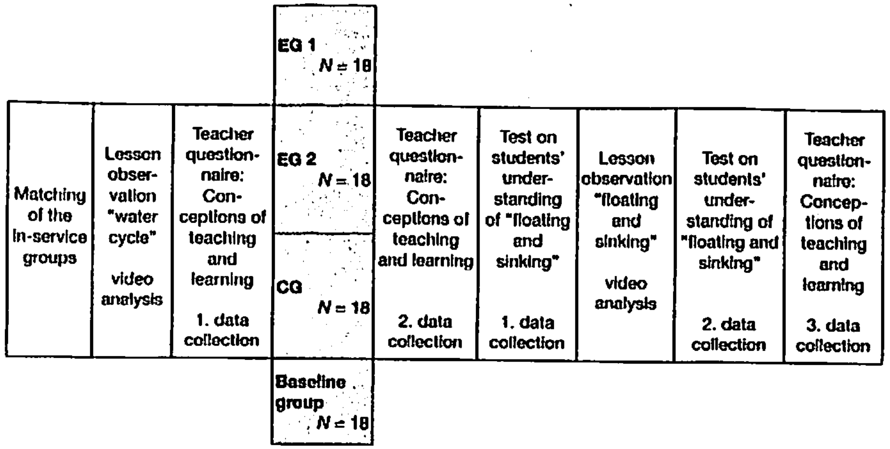

Figure 4: Design of the study

Based on the results of the pre-questionnaire, participants of the in-service courses were selected from a group of 96 teachers who had applied for the courses. In a matching process, three groups of teachers were assembled with regard to their conceptions of teaching and learning, motivational orientation, and educational background. The baseline group was made up of those teachers who had been interested in participating but could not be considered for one of the three in-service courses. Generally, it should be taken into consideration that the participants of this study tended to be interested and motivated to participate in in-service courses. However, further checks of teachers' conceptions showed that these teachers also tended to regard themselves as novices in the field of science.

3.4 Assessing teachers' conceptions of teaching and learning

We developed a questionnaire with 48 Likert-type items assessing teachers' conceptions of teaching and learning with regard to the domain of science. The reliabilities for the scales are reported in Table 1 (for the development of the scales, see Kleickmann, Möller, & Jonen, 2005). All items are related to the domain of science and science education.

Table 1: Scales for the assessment of teachers' conceptions of teaching and learning

Scales on "constructivist conceptions of teaching and learning"	*N* (items)	α (pre/post)
Motivation as a necessary precondition for learning	4	.70/.74
Students should develop their own ideas and be allowed to follow individual learning paths	9	.83/.74
Teaching and learning as conceptual change	6	.71/.86
Children show preconceptions that may lead to difficulties in learning	3	.69/.82
Students' conceptions should be discussed in class	4	.71/.65
Learning opportunities should be embedded in everyday contexts	5	.68/.75
Scales on other conceptions of teaching and learning		
"Transmissive" conception of teaching and learning	7	.65/.70
"Very open" conception of teaching and learning, according to which students should engage in self-directed learning, and scaffolding by the teacher is not necessary	5	.73/.76
"Hands-on/minds-off" conception: teaching and learning based on mere hands-on experience	5	.72/.75

Regarding the scales on constructivist conceptions of teaching and learning, we expected a greater increase in the three in-service teacher groups than in the baseline group, and due to the tutorial guidance in the experimental groups, we expected a higher increase in the two EGs than in the CG. For the scales on the other conceptions of teaching and learning, we expected a larger reduction of these conceptions in the in-service groups than in the baseline group.

3.5 Results

3.5.1 Effects of in-service courses on teacher variables

Contrary to our expectations, we did not find a significant increase in the scales of "motivation as a necessary precondition for learning," "developing own ideas," "discussing ideas," and "everyday contexts" in the two experimental groups as compared to the control group. In these scales, mean values had already been rather high in the pre-questionnaire. Similarly, there was no significant decrease in the scales of "transmissive teacher conceptions" and "very open teacher conceptions". In these scales, initial mean values had been rather low before the intervention (see Kleickmann, Möller, & Jonen, 2006).

However, the experimental groups did show a significant increase in the scales of teachers' conceptions of "conceptual change" and "preconceptions" as compared to the control group. Thus, teachers of the experimental groups were more likely than teachers of the control group to develop conceptions holding that processes of conceptual change will occur during science instruction, as well as conceptions holding that children will assert naïve conceptions on the science phenomena under investigation (see Figure 5). Additionally, the teachers of the two experimental groups reduced their conceptions of "hands-on/minds-off" to a higher degree than the participants of the control group.

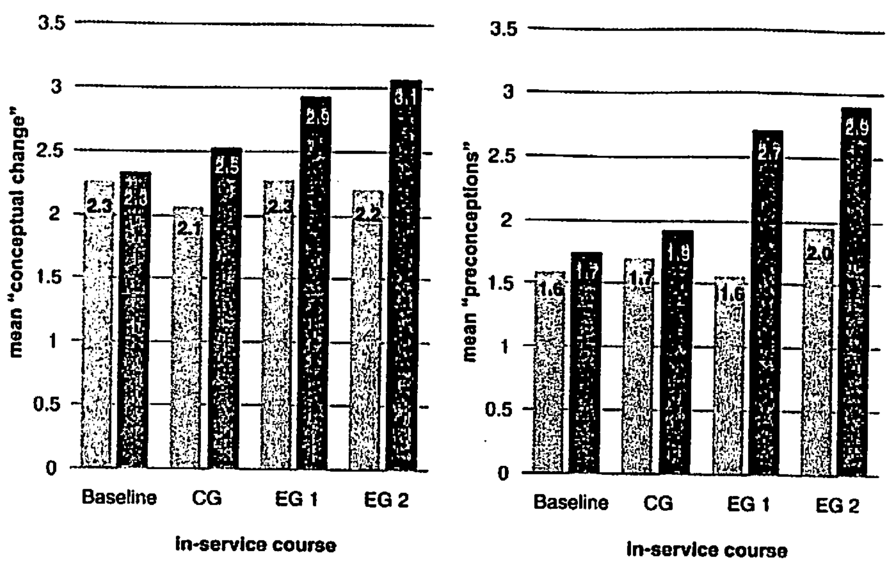

Figure 5: In-service course effects on teachers' conceptions of "teaching and learning as conceptual change" and "students with preconceptions"; first (light columns) and second (dark columns) data collection

3.5.2 Effects of in-service courses on students' gains in conceptual understanding

Apart from the question of whether in-service courses can bring about changes in teachers' conceptions of science teaching and learning, we also investigated whether these in-service courses, mediated by the conceptions of teachers who had participated in them, have a differential effect on students' conceptual understanding. To this end, we analysed gains in students' understanding of "floating and sinking" which was taught by 46 teachers from all three groups after the in-service courses. In a first step, the mean achievement gains of students in the 46 classes were determined. Classes that had been taught by members of the experimental groups were compared to classes whose teachers were participants of the control group (see Figure 6).

A multilevel analysis that took the hierarchical structure of the data into account (students are nested within a class and assigned to one teacher) shows that the mean achievement gains of students in classes with EG teachers differ significantly from those of students in classes with CG teachers. This difference remains significant even when lesson duration and teachers' prior work experience are controlled for. Further multilevel analyses showed that achievement gains are accounted for by teachers' conceptions of "teaching and learning as conceptual change" and "significance of preconceptions" in particular. For these analyses, lesson duration, teachers' prior work experience, physics-related self-concept, and interest were controlled for.

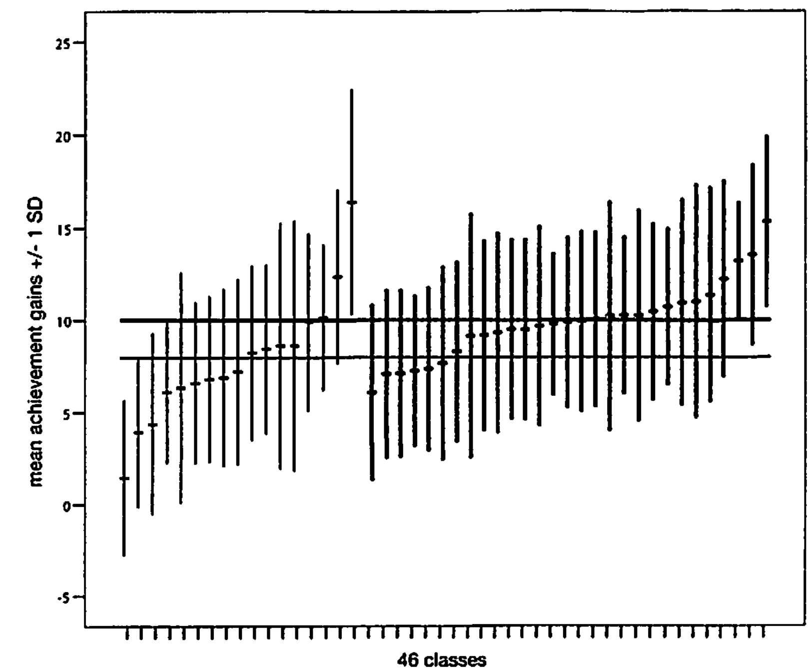

Figure 6: Mean achievement gains (+/- 1 standard deviation); thin lines stand for classes taught by CG teachers; bold lines stand for the EG teachers' classes. The upper (bold) horizontal line shows the mean achievement gains of all EG classes, the lower (thin) line shows the mean value of the CG teachers' classes

3.6 Summary of key results of the in-service course study

On the level of variation between teachers, results show that extensive in-service courses which are based on conceptual change approaches and include tutor support lead to changes in teachers' domain-specific conceptions of teaching and learning as part of their pedagogical content knowledge. This change was especially evident for conceptions viewing science teaching and learning in terms of change in students' existing concepts (i.e. for the scales of "conceptual change" and "preconceptions"), as well as for the reduction of conceptions of science teaching and learning as "mere hands-on experience". In contrast, knowledge acquisition by mainly written information as provided for teachers in the control group does not seem to be sufficient for effecting change. It should be noted that conceptions of teaching and learning shown by the participating primary school teachers were highly "student-oriented" (see Levitt, 2002) even prior to this study, so that effects on some of the scales could not be shown due to ceiling effects.

Apart from the reported changes in the teachers' professional knowledge, teachers' interest in physics-related topics and teachers' self-efficacy with regard to teaching these topics could be fostered and improved significantly in all three in-service courses.

On the level of student variables, students taught by teachers from the experimental groups showed higher achievement gains than students taught by teachers from the control group. This in-service course effect on student outcomes could be detected although all participating teachers were provided with material for experiments on the topic of "floating and sinking" as well as with teacher guidelines that included subject-related and methodological information. As work in progress, we hope for insights from an analysis of the questionnaire's open-response questions and of the interviews conducted with the teachers. The analysis of videotaped lessons and of further student data is still in progress. This analysis will yield further insights into the relevance of the assessed teacher conceptions of teaching and learning both for instructional behaviour and for students' successful learning.

4 Discussion

Results of the experimental classroom study and the visualisation study show that, as early as in primary school, children can develop scientific understanding on a level far beyond the acquisition of mere factual knowledge. Within the topic of "floating and sinking," cognitively activating lessons with instructional support encouraging the students to check and revise their naive conceptions were shown to be particularly successful in fostering students' acquisition of advanced conceptual knowledge. For scientifically demanding topics, especially students with low cognitive ability need to be able to participate in class discussions where teachers repeatedly provide cognitively structuring prompts and help students to manage a complex learning environment by segmenting a topic into subordinate conceptual units. It is important to note that this type of scaffolding does not mean that students are provided with partial solutions or explanations, or that the lesson script needs to be worked out in closed discourse patterns. In this respect, our instructional unit of High Instructional Support (HIS) was shown to be superior to the unit of Low Instructional Support (LIS), not only in terms of students' long-term scientific understanding but also in terms of their motivation, their perceived competence during instruction, and their confidence with regard to future involvement with science topics. Furthermore, the visualisation study showed that visualisations that reflect the argumentative or structural relations of basic science concepts can function as meaningful "thinking tools" for students. These tools can broaden students' scientific understanding and foster the acquisition of cross-curricular abilities, such as proportional thinking.

In a study varying in-service courses with and without tutorial support we were able to show that in-service primary school teachers without scientific background could be motivated to teach scientifically demanding topics. This was achieved by means of long-term in-service courses based on conceptual change approaches to learning and providing teachers with intensive tutor support in order to facilitate their acquisition of content knowledge and pedagogical content knowledge. Such in-service courses can help teachers to give up their naive conceptions of science teaching and learning for more appropriate conceptions in line with conceptual change theories. Apparently, merely providing teachers with written material on the respective content along with material for lesson preparation does not suffice to bring about conceptual change. The higher effectiveness of tutor-guided in-service courses was demonstrated even at the level of student achievement gains. Given the correlations between teachers' conceptions of teaching and learning and students' achievement, it seems to be of

particular importance to support teachers in developing an understanding of science teaching and learning conceived of as a process of conceptual change. This process of conceptual change can be particularly fostered – in primary school teachers and primary school children alike – by implementing elements of instructional support into complex learning environments.

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