SCIENTIFIC LEARNING IN PRIMARY SCHOOL EDUCATION: A MODEL STUDY ON CHILDREN'S CONCEPTS OF PHYSICAL MATERIAL[1]

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Our study examined five first grade classes to determine the scientific learning processes children require to develop concepts of physical material. It applied the Rostock Model, in which the example of water serves a model lesson topic. A qualitative evaluation of the results was achieved by conducting a comparative analysis based on the Grounded Theory. We determined that in the context of classroom instruction, the children's knowledge concerning the location of water and their cognitive concepts concerning the particle structure of this substance developed in a lasting and sustainable manner regardless of their nationality or school.

Keywords: Concept Shift, Comparative Analysis, Rostock Model

Introduction

Our research can be seen as a contribution to the frequently contentious discussion concerning how best to improve science education (*Sachunterricht*). In particular, there have been calls for he urgent need for research aimed at finding new didactic approaches to natural science education (Einsiedler 2002, p. 35). In this context, attention must be placed on various research topics:

1. The development of cognitive thinking during childhood
2. The development of natural scientific thinking
3. Didactic approaches to planning and organizing scientifically oriented instruction

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As for the first area of research, there is a general consensus that Jean *Piaget's* (2003) theory of cognitive development during childhood has gained wide acceptance, and that it dominates current theoretical conceptions of learning. The considerable influence of Piaget's theory is certainly astonishing, insofar as Lew *Vygotskij* (2002) published - parallel to Piaget - a theory of the development of cognitive development, the central positions of which contradict the paradigms set forth in Piaget's work. Only recently have researchers seriously challenged the notion that cognitive development during childhood takes place in distinct phases, during which concrete thought processes lead to more abstract ones. We should thus ask: Are the thought processes of six to ten year olds truly trapped in concrete-intellectual operations? Does this phase constitute a period of development that must necessarily precede the development of formal-cognitive thought? Despite its solid empirical foundation, *Vygotskij's* theory, in our opinion, has so far been given only marginal and fragmentary attention in the didactics of science education. For instance, *Howard Gardner* proposes that cognitive processes develop in a much more differentiated manner than Piaget claims. For Gardner, intelligence is composed of relatively distinct and independent types of intelligence, which manifest themselves in the child's tendency to prefer and optimize certain forms of activity. Each of these types of intelligence constructs its own symbolic system, which, in turn, represents a specific assesses point for the acquisition of scientific knowledge. According to *Gardner,* school children already possess a fully developed intelligence profile, composed out of the various types of intelligence, which allows each child to approach and appropriate knowledge in their own particular manner. In this case, intelligence is not a monolithic block, but rather a set of relatively independent "intelligences" which are suited to their particular field of activity and which develop in their own particular way. The distinct phrases considered by Piaget are hence only one of many conceivable sequences of development.

The extensive investigations conducted by Ulrich *Stunk* (1998) on elementary school children's perceptions and explanations of inanimate natural phenomena supports our reservations about accepting the idea of a general cognitive development. *Stunk* has come to the conclusion that the process of thought development is primarily based the accumulation of new physical experiences and of knowledge of the physical world.

Last but not least, pediatric research has shown that a child's concrete, physical experiences have a decisive influence on when the child reaches a particular stage of development and how long they remain at that stage. It is now indisputable that eight year olds, depending on their previous experience and current knowledge, are quite capable of abstract thinking, even if they formulate their results in their own language (Tomasello 1999, Stern 2003, Pageorgiou, Johnson 2005). Further studies have proven that primary school children are thoroughly capable of theoretically guided thinking if the chosen topics are compatible with their interests and their previous experiences (Mahler 1999; Schremp & Sodian 1999).

As for the second focus of research, all individuals possess extensive conceptual knowledge based on their everyday interaction with the world around them. This is especially true of so-called everyday concepts that, in most cases, successfully orient our thoughts and actions in concrete situations. Within our everyday world, the sciences form relatively stable culturally and historically situated sphere, characterized by specific actions, language, concepts, generalization, ideals, and symbols (Singer 1991). There is a strong reciprocal influence between everyday and scientific concepts, despite their fundamental differences. Everyday concepts form the basis on which scientific ideas progressively develop. In turn, scientific concepts gradually seep into everyday concepts, causing them to change (Vygotskij 1987, 2002).

The "conceptual change" model, conceived in the early 1980s to explain the development of scientific ideas (Posner, Strike, Hewson, Gertzog 1982), was applied by Susan *Carey* (1985) to primary school education. This model describes natural scientific learning as a shift from everyday ideas to scientific concepts, a change in which motivational and emotional factors play a substantial role (West & Pine 1983; Pintrich, Marx, Boyle 1993). According to this line of research, structures of knowledge develop more or less continuously within delineated areas and can be restructured when specific spheres of knowledge interact or when higher patterns of abstraction are achieved. Formal-logical thinking is therefore not the consequence of a progression of development determined by age but rather a result of the presence and density of knowledge structures. Studying the learning processes involved in science education, Derek *Hodson* (1997) expanded the "conceptual change" model into a comprehensive theory of enculturation. He refers to *Vygotskij* (1987) when he characterizes scientific learning as enculturation by means of guided participation *and* structured practice. Conceptual shifts are linked to instruction and to activities in which the pupils can investigate and test phenomena on their own. Children must be introduced to the cultural field of the natural sciences by a competent individual, that is to say, by an "enculturated" teacher. Given the right conditions of learning, even younger children can be instructed using "precursor models", models that are compatible with natural scientific models because they already contain elements taken from natural scientific models. The teacher guides the children's learning processes, structuring their social interaction and proposing tasks in the zone of subsequent development.

It is crucial that international teams conduct research on children's ideas about everyday natural phenomena, ideas that form the content of their everyday concepts. By the time they reach school age, children already have acquired ideas about animate and non-animate nature on the basis of their own experiences ("intuitive knowledge") or through the media ("lay knowledge") (Claxton 1993). There are various studies on pupil's ideas about natural phenomena, especially those that focus on children in the fifth to the tenth grade. For the most part, studies concerning primary school pupils concentrate on children in the third and forth grades (e.g. Faust-Siehl 1993 {light and shadows}, *Kircher & Rohrer* 1993 {Magnetism}, *Kircher & Engel* 1994 {Sound}, Moller 2002 {floating and sinking}, *Stern* et als 20002 {graphic-visual presentations}. In contrast, there are fewer studies focusing on children in the first and second grades.

Of particular importance for our study are the ideas young children hold about "material". As stated above, there are few studies dealing with this age group on this topic. In order to identify and structure the relevant concepts, we have thus drawn from studies on older children, in which pupils were asked about their ideas about material and/or particles. In his study, *Rennstroem* (1998, 1990) classified six developmental stages in children concerning their concept of "material" (A: material is interpreted as a homogenous substance; B: Material consists of particles, varieties of material differ, and exist in more than one form; C: Material consist of small particles, which can be different than the material they are embedded in. D: Any material is determined by the condition of the particles, which can be divided as many times as one likes, and need not consist of the particular material being examined; E: Material consists of particles that cannot be divided and that have particular characteristics (form and structure), which explain the macro-characteristics of the material; F: Material consists of systems of particles and the particular characteristics of a material are determined by the features of the particle system and the particles themselves.)

Studying the ideas held by pupils in the fifth to tenth grades about the concept of material, *Johnson* (1998a, b) distinguishes between four model stages in the development of concepts (Model X: unitary material substance - particles do not play a role; Model A: undifferentiated particles are distributed in a unitary material; Model B: small particles form the material; Model C: particles make up material, and the particular characteristics of the material's state arise due to the interaction among the particles.) In the context of his investigations on children's ideas about bubble formation in boiling water, he was able to show that eleven to fourteen year olds use the communicated ideas about particles in order to grasp and accept scientific concepts. The difficulties pupils had understanding the idea of particles in relation to the concept of material should not, I believe, be solely ascribed to the pupils' insufficient cognitive abilities. One could just as well ascribe these difficulties to insufficient instruction. Pupils need initial aids, in particular visual ones, to grasp scientifically oriented concepts and to think along scientific lines. One such aid could be the particle model itself, provided it is taught so that it increasingly replaces the already present "macroscopic supports".

In his study on children's conception of inanimate natural phenomena, *Struck* reaches the conclusion that, for example, 25 percent of six year olds have not formed a conception of how water is physically constituted. He established a similar tendency concerning the development of an understanding of particles. According to him, children possess a macroscopic granular hypothesis. Accordingly, he opposes introducing the particle model too soon.

Challenging this view, comparative studies (e.g., Papageorgiou, Johnson 2005) show that primary pupils can indeed apply the particle model in a meaningful manner, thus making far better progress than control groups. If the right concepts are present, the tools will be available, with which micro and macro interpretations of phenomena can be carried out.

On the basis of his studies on how three to thirteen year olds conceive of physical material, *Knrel* (2005) concludes that there is a connection between speech development and the creation of ideas. This interpretation tends to support *Vygotskij's* view that words prepare children for future actions rather than Piaget's belief that words follow actions.

As for the third focus of research: In our article "Naturwissenschaftliches Lernen in Primarbereich - The Rostock Modell (Science Education in Primary School - The Rostock Model)" we provide an overview of the didactic basis for planning and structuring science lessons and set out our own didactic concept.

Research Goals

We have concentrated on the following goals:

- Developing tools that can be used to investigate an increase in knowledge and the development of concepts in scientific learning
- Testing the Rostock Model for its effectiveness in conveying content-based scientific knowledge.

- Generating a relevant theory of scientific learning in primary schools.

Research Methodology

We have carried out a long-term qualitative study in Germany and Hungary from 2006 to 2008 and in Lithuania from 2006 to 2009, which began by studying first grade classes and continued to investigate them over the course of three years, a strategy that has provided a (relatively) stable sample of test persons (in total, 94 pupils from five classes).

To develop a relevant theory of scientific learning, we evaluated our data in terms of the *grounded theory* (Glaser, Strauss 2005). We employed c*omparative analysi*s as our primary method, comparing a number of groups belonging to the same field.

To create a theory of scientific learning, we relied on two categories central to scientific learning: Knowledge acquisition and cognitive concepts. Knowledge acquisition refers primarily to the process of acquiring facts, terms, and notions. Cognitive concepts include assumptions, explanations, and grounded claims about phenomena and processes. By their very nature, they can appear as everyday or science-based concepts. Everyday concepts are characterized by the fact that they rely on pseudo-notions and potential notions (Vygoskij 2002). In such cases, subjects arrive at explanations by listing examples and features or by describing functions. We considered views and ideas as scientific concepts that employed, in some form, the particle model.

A central feature of knowledge acquisition is the fact that the acquired knowledge is lasting and sustainable. The essential characteristic of cognitive concepts is the development of everyday concepts that have begun to be oriented by scientific concepts.

We examined changes in knowledge and its sustainability by carrying out a comparative analysis. The starting point for the analysis was provided by a teaching unit on water for first grade pupils outlined in the *Rostock Model* (Schneider et al. 2006). In individual interviews that took place before the unit and immediately afterward, pupils were asked about their views on the various locations where water can be found and about their ideas concerning the material composition of water. These interviews were repeated once again at an interval of approximately six to eight weeks. The pupils' answers were recorded descriptively.

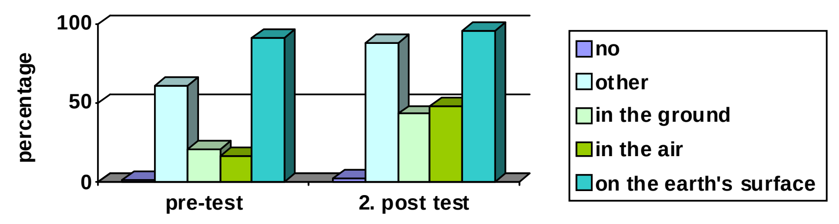
The progress of learning was investigated by means of an intrapersonal comparison of the pupils' answers (A, B, C)[3]. To determine the pupils' acquisition of knowledge, we focused on questions concerning the various locations were water can be found. To judge the development of cognitive concepts, we concentrated on the issue of whether children in early grades were able to respond to questions by drawing on explanations based on their knowledge of the material structure of water.

[3] Legend: A = knowledge in pretest, B = knowledge in 1st post test, C = knowledge in 2nd post test

Investigative Results of Grade One Pupils

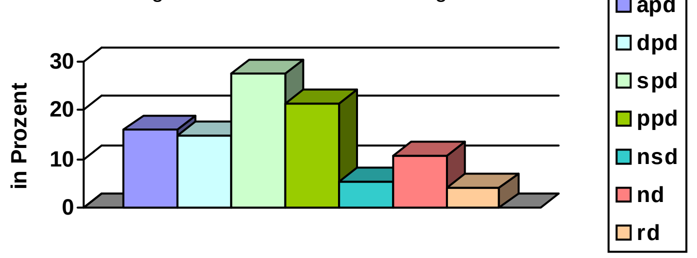
On the basis of the interviews, we arrived at categories to describe the pupils' knowledge structures and the characteristics of their everyday concepts about the material composition of water. In regard to the acquisition of knowledge about the location of water, we identified the following content-based structures: "in the ground", "on the surface of the earth", "in the air", and "other locations" (figure 1). To investigate *the sustainability of acquired knowledge* about the location of water, we determined seven different learning effects by comparing the test answers. Some children were able to increase the extent of their knowledge concerning the location of water from test to test. They accumulated their knowledge (**a**ccumulated **p**ositive **d**evelopment: APD). Other children did not show any improvement in their knowledge (or even showed a decrease in knowledge) from the pre-test to the first post-test, but in the second post-test showed an improvement in knowledge in relation to their initial position in the pre-test. Their development can be described as **d**isplaced **p**ositive **d**evelopment: DPD. Another group of children showed an initial increase in knowledge that did not alter in the second post-test. The increase in their knowledge had stabilized (**s**tabilized **p**ositive **d**evelopment: SPD). A partially positive development was observed among those children whose knowledge increased from the pre-test to the first post-test but whose second post-test results fell below those of the first post-test, nevertheless remaining above the results of the pre-test (**p**artial **p**ositive **d**evelopment). These four development trends all show, albeit to different degrees, a sustained acquisition of knowledge.

Figure 1: Knowledge Development "The Locations of Water""



We can define non-sustained learning effects as results indicating that pupils increased their knowledge from the first to the second test but subsequently failed to sustain their knowledge in the third test, falling below the level of the first test (**n**on-**s**ustained **d**evelopment). It also occurred that there were no changes in the pupils' knowledge, the child remaining at the same level throughout all three tests (**n**o **d**evelopment). And, to our astonishment, we observed a phenomenon that we describe as reverse development: In the second test, the pupil's level of knowledge is either greater or equivalent to that displayed in first test, but in the third test drops

Figure 2: Distribution of Learning Effects



below the level of the initial pre-test (**r**everse **d**evelopment). As a whole, the tests offer the following results (figure 2).

The second main issue under analysis concerns the children's *development of cognitive concepts* in the classroom. Our questions (What is water? What do you know about water) provoked various answers, such as liquid, transparent, blue, snow, lakes, water pipes, drinking, washing, bathing, necessary to life, people die without water, etc. Using these answers, we structured the children's everyday concepts (A) about water into characteristic concepts (A1), appearance concepts (A2) application concepts (A3), and meaning concepts (A4). The lesson was meant to prepare the ground for science-based thinking. In the instruction period, the children were taught that water is composed of particles and that the changes in the aggregate states of water can be explained using this model. In structuring the children's science-based concepts (S), we took the children answers into consideration but also oriented ourselves on the basis of preexisting structures: particles in material (W1), particles form material/small particles of material (W2) and the system of relations between particles determine the state and other characteristics of the material (W3). For each child, the cognitive concepts conveyed in the respective tests were determined according to this structure (Figure 3).

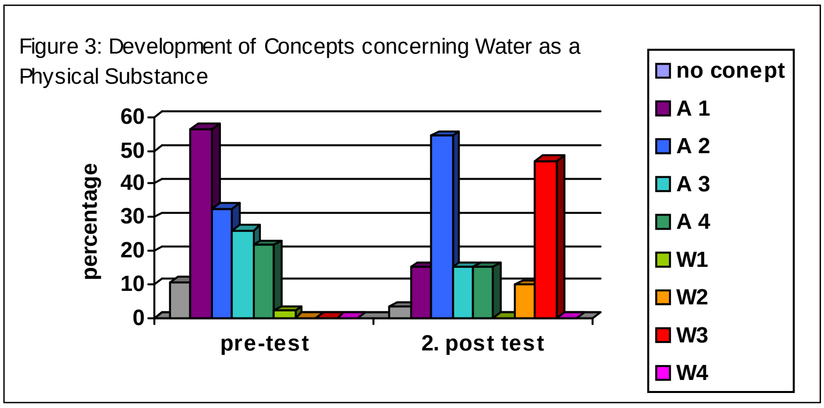
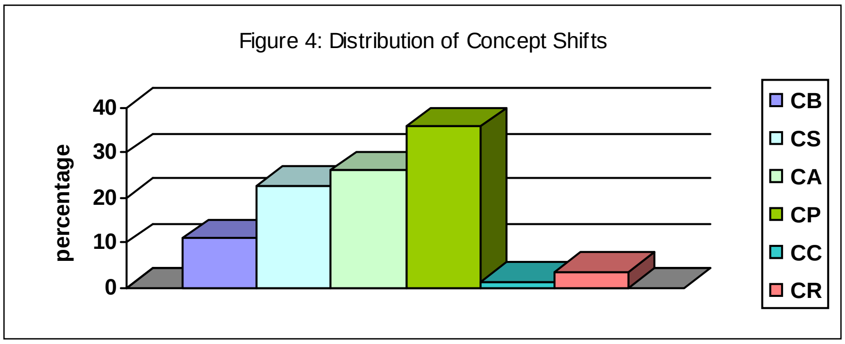


Figure 3: Development of Concepts concerning Water as a Physical Substance

Subsequently, we recorded the changes in the children's concepts by comparing their initial concepts with the concepts displayed in the second post-test. In the course of our investigations, five different types of concept change were observed. Before the lesson, some children could not express a single view on water as a material substance (0). In the lesson, they developed either an everyday concept (Ax with x = 1-4) or a science-based concept (Wy with y = 1-3). This kind of concept change can be described as *concept building (CB)*. Cases in which everyday concepts were replaced by science-based concepts can be referred to as *concept shift (CS)*. A further type of concept change is *concept addition (CA)*, which appear in various forms. So it would be possible that everyday concepts (Ax_m) with another structure were added to everyday concepts (Ax_n) or scientific concepts were added (Wy). Otherwise scientific concepts (Wy_m) could be added to other scientific concepts (Wy_n), which are different in structure from the initial concept; also scientific concepts (Wy) can be extended by everyday concepts (Ax). If existing concepts are not changed, independently if these are scientific or everyday concepts, we name this *concept persistence (CP)*. Also we observe a development from parallel existence of concepts to one concept. These we call *concepts concentration (CC)*. We were surprised of the fact, that obviously there exists also a *concept reduction (CR)* without any substitute. In a sum up of the investigation we find out the presented pattern of distribution of concept changes (Figure 4).



Summary

The *Rostock Model* is a didactic concept that can be successful employed to teach science units in early primary school education. *Comparative Analysis* provides a tool with which one can determine knowledge growth during the development of scientific learning.

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