A Circular Model of Thinking Processes as a Basis of Technical Understanding

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Abstract

Children often experience the influence of technology around them, but there is little emphasis placed on technology within a scientific education in Grundschule (primary schools) in Germany. One of the reasons for this could be a lack of research projects that ascertain young learners' conceptions of technical issues. So there is no basis for creating learning environments that enable and motivate children to actively and purposefully work on questions of technical procedures. An investigation into the previous knowledge held by nine to ten year old children of simple machines has demonstrated children's reasoning. It shows that experiences handling materials can lead to children's understanding of technological processes. Starting from the *intuitive level* of understanding, the children can attain the *factual level* and finally the level of *technical awareness* in a circular model. This model of thinking processes provides a basis for creating teaching modules that extend current technological education in German schools.

Key words

simple machines, technological thinking processes, technological education, teaching and learning

Introduction

Children's everyday life and their questions about it are at the core of technology education in primary schools. Children are surrounded by an immense complexity, both in technical contexts and procedures. The question is how to plan and structure teaching units that help pupils to improve their knowledge and understanding of complex phenomena in everyday life. To answer this question it is necessary to investigate the way pupils deal with complex issues. Unfortunately, however, in the published teaching resources available in Germany, one can only find concepts that ignore the pupils' previous knowledge; use abstract methods of explaining complex issues; and have little connection with real-life situations.

The following article presents the results of a research project with third and fourth graders on the complex topic 'Transporting a heavy weight using simple machines'. It focuses on the pupils' attempts to analyse the functionality of a rolling board, a fixed pulley and a pole. It identifies whether, and how, children are able to formulate and identify important elements of a meaningful explanation. The findings are presented in a model that suggests a circular development of thinking processes which is used to develop teaching resources that correlate with the children's thinking, communication capability and previous knowledge.

Research Context

In the last thirty years knowledge of children's concepts of scientific topics has increased (Duit, 2009), but there has been far less research concerning technological issues, particularly in Germany. Therefore it was necessary to choose a topic and develop a research design that could generate findings about the children's capacity to deal with technical procedures as well as about the structure of appropriate knowledge and thinking processes. Simple machines surround children in many transportation processes in their everyday life, so we can assume that they are familiar with this issue. Furthermore this topic is sufficiently open-ended that the findings might be transferable to other contexts in technology education. The investigation does not focus on particular scientific terms or laws, rather on the ways children use simple machines to transport a heavy weight and develop their ideas about the lightening of the load that they could feel during the transportation. Thus the research project is based on four central questions:

1. How do primary school children create possible solutions for the transportation of a heavy weight and which simple machines do they use for this purpose?
2. What knowledge do children have concerning the mechanical functionalities?
3. What is their knowledge based upon? Are they able to find analogies to similar constructions or parts of it?
4. What terms do children use when they try to explain the facility of motion?

Since the research project deals with modes of understanding, qualitative methods were applied.

The model of educational reconstruction (Kattmann et al, 1997, Duit et al, 2005) forms the framework of the research project, which is based on a moderate constructivist epistemological view. It closely links three components (Figure 1): analysis of science content structure, in this case based on didactics (1); analysis of children's previous knowledge about the content, here simple machines (2); and the development of (pilot) instruction combining all findings (3).

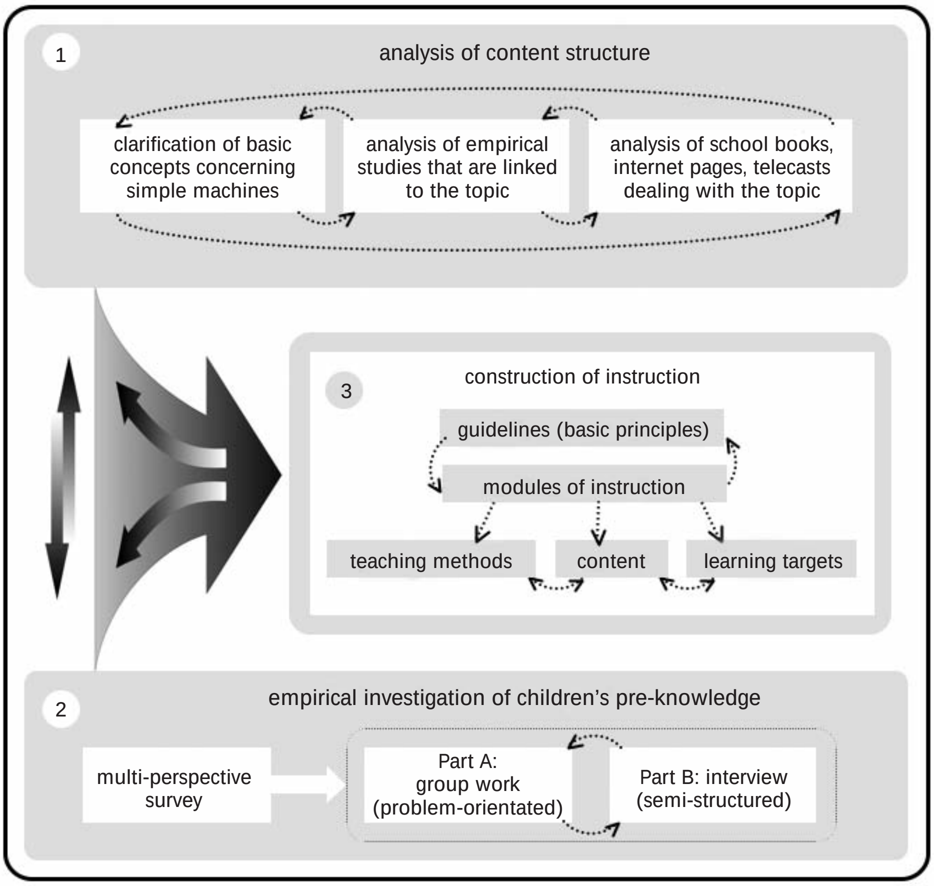

Figure 1. The model of educational reconstruction applied to simple machines

1. Analysis of content structure

To construct teaching units that support children in understanding technical issues the content structure has to be analysed from the current scientific point of view. The topic 'Simple machines' includes various components of engineering mechanics. In this research project the analysis of the content structure aims to determine children's current understanding of scientific concepts, laws and technical terms that form the basis of each simple machine. The physical background is only one important factor in understanding the cause of lightening the load while transporting a weight via simple machines. By using machines the human body is relieved of some of the burden of the load, so the second domain in the scientific clarification is the physiology of the body. The analysis of selected scientific publications provided information about the bodily processes during the transportation. The educational analysis included, on the one hand, studies concerning related contents (e.g. general findings concerning technology education in Grundschule (primary school) and, on the other, specific findings concerning learning processes involving simple machines in Hochschule (secondary school). Additionally, curricula, school books, teaching materials and web pages were analysed to gain a meta-perspective of the scientific clarification.

2. Empirical investigation of children's previous knowledge

For the investigation of the students' perspective it was necessary to choose an open and multi-perspective research design because of the complexity of the topic and the children's age. The investigation was composed of two phases where problem-solving situations (part A) were combined with cognitive thinking elements (part B).

Part A: Construction of simple machines (problem-oriented group work)
After a short introduction the students were set a technical problem. The task was to put a heavy bucket onto a box. Several materials could be used to solve the problem (a broomstick, a wooden board, several rollers, a rolling board, adhesive tape, measuring tools, ropes, wedges, a log). The children could freely use the materials as helpful tools, as simple machines were not provided. Using the materials should make transportation of the bucket easier in comparison to transportation without any assistance. Throughout the problem-solving process, the pupils engaged in discussion in order to test and improve several suggestions. The work with materials (unlike a solely cognitive oriented research design) is of particular importance here because the children observed immediately if a suggestion did not work, which provided self-evaluative feedback. The children could conduct practical experiments with simple machines, decide on the best combination of the materials provided and determine possible constructions, all at the same time. Thus this phase provided the opportunity to activate the children's previous knowledge and the researcher was able to observe the children's work. This provided insight into the terms the children used while discussing their ideas and the way they made use of the materials. After the group arrived at a solution, each child made a sketch plus a written description. In this way, the children organised and structured their knowledge and the children's technical terms could be documented.

Part B: Semi-structured interview of the group
The observation process could be perceived as a general probe, but to get to know something about the children's thinking processes and structures, a semi-structured interview was necessary. Selective questions and stimuli (concerning the material choice, the mechanical processes, analogies and relations to real life situations, terms and so on) would encourage the pupils to explain their concepts as to how the tools helped to make the transportation of the bucket easier when the mass was the same as before. Thus the pupils were forced to reflect on the functionality of the simple machines they had used. They compared their solutions; found parallels and differences; and related these to their everyday-life.

3. Construction of instruction
Results of the analysis of the content structure (linking clarification of the core concepts and analysis of the educational significance) as well as preliminary ideas for the content of teaching units played an important role in planning this empirical study on teaching and learning. The interactive comparison of the children's previous knowledge with the scientific content produced guidance in terms of basic principles for teaching units that involve simple machines. Based on these guidelines, an on-going longitudinal comparison enabled the development of teaching units that included teaching methods, content and learning targets. Thus the analysis of the survey data and its interactive comparison with the content structure led to the design of teaching units that, hopefully, could be expected to enhance technological education.

Pupils' explanations of the functionality of selected simple machines
A content analysis of the data shows recurrent themes in different interviews, as shown in Figures 2-4.

Why does the load feel easier to move when its mass stays the same?
It becomes apparent that all explanations are subjective, objective or logical. *Subjective explanations* always refer to an experience that pupils have already had, either shortly before or in the more distant past. Two experiences are shown in all interviews: teamwork is better than carrying a weight alone; relieving/helping the arms (whether using

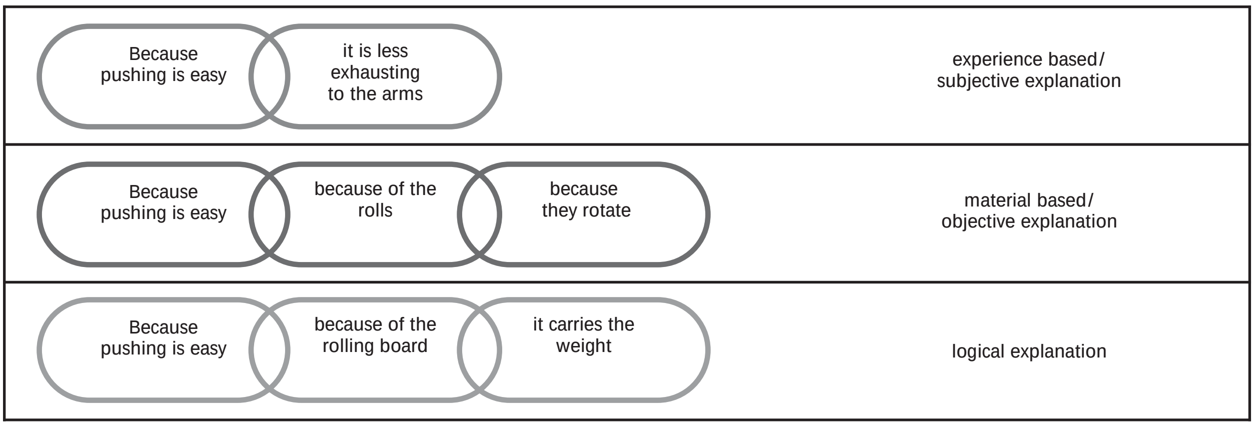

Figure 2. Conceptions of the functionality of a rolling board

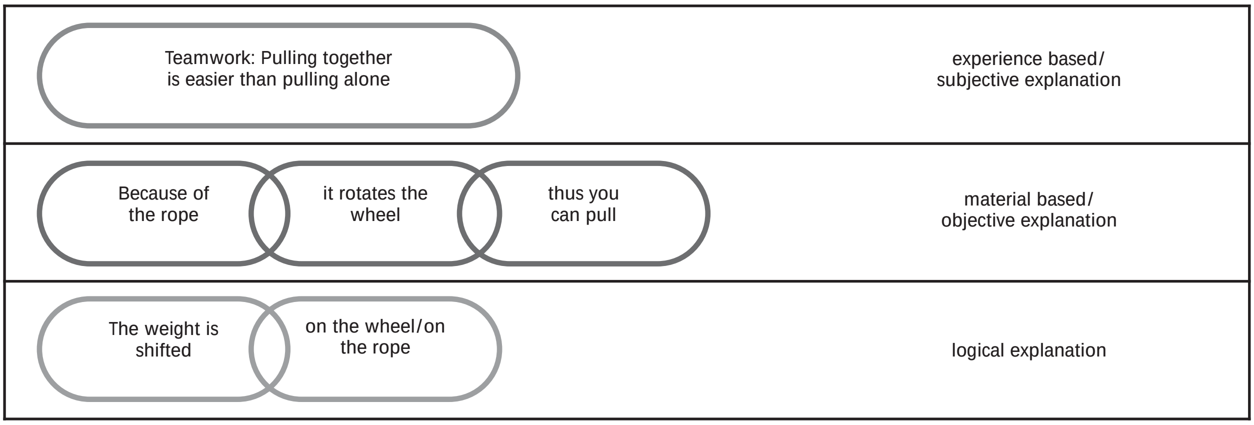

Figure 3. Conceptions of the functionality of a fixed pulley

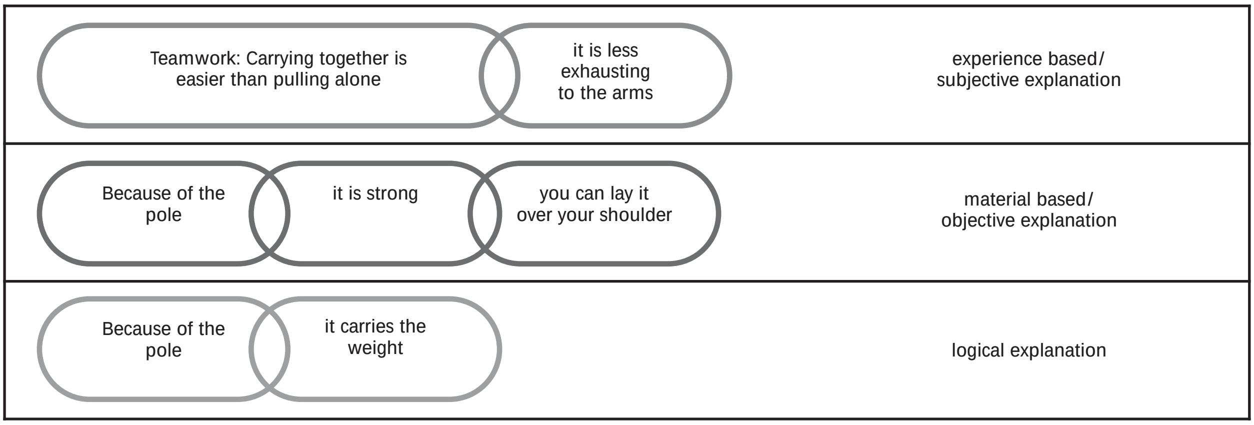

Figure 4. Conceptions of the functionality of a pole

materials to aid pushing or pulling or by using the broomstick over the shoulder).

Objective explanations include elements which are related to the material itself. It is either an observation (e.g. the pupil realised that the balls under the rolling board rotate) or a property (e.g. the pole is strong and thus you can place it on your shoulder).

A characteristic element of *logical explanations* is the concept that the material (the pole, wheel or the rolling board) carries a part of the weight. These explanations are called logical because their core is a logical reasoning which is connected to the teamwork concept: the pupils have experienced an easing of the effort but they also knew that the weight was still the same. So the pupils transferred their teamwork experience, where the weight was divided into two or more parts, to this situation. The logical conclusion in this case was that the material substitutes the partner and carries a part of the weight.
It was apparent that the children often used the same arguments when trying to explain the functionality of a machine. To fully understand the functionality of the devices, subjective and objective aspects have to be combined (see figure 4). Pupils need to identify material-based and experience-based components and relate them to the problem. Some explanations already contained such connections or fragments of them. So the pupils' explanations and concepts form a good basis on which learning can be built. It has to be worked out during the lessons in school that the connection of objective and subjective components is the key to understanding the reason why the task becomes easier.

Circular model of thinking processes as an outcome of the findings

The evaluation of the data reveals that the children's experience becomes paramount. Without experiencing the lessening of the effort required to transport the weight, the children would be dependent on an abstract cognitive understanding of the scientific content. While dealing with concrete material they can gain an awareness of the physiological relations which prompts them to look closer, to observe and to reason. The children profited especially

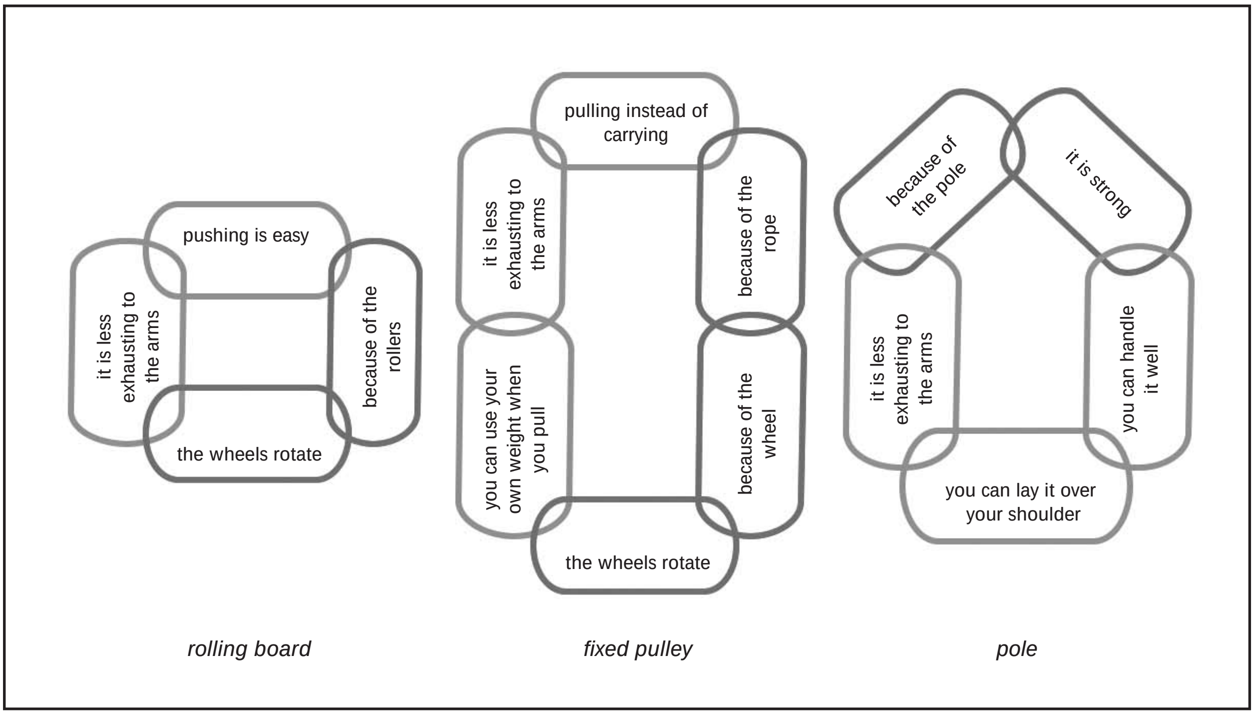

Figure 5. Connection of subjective and objective components

by working together with their classmates in small groups because communication processes were generated naturally. They needed to be aware of their observations before they could discuss, reflect and evaluate them. Through these multiple acts of communication and explanation, subjective and objective components became internalised and the children could discover new analogies in their everyday life. They understood the core of all these various situations, namely the basic principles of the functionality, and developed an appreciation of the general principles and scientific laws. Thus the concrete particular case was united with an overall context. Within this circular model (Figure 6), technological thinking processes can be initiated and extended, starting from the *intuitive level reaching the factual level,* ending in the *level of technological awareness.*

Learning by doing, reflecting and communicating within the example of a teaching unit on simple machines

The research results clearly indicate that it is possible and meaningful to teach such a complex issue like simple machines. Regarding the pupils' explanations and their behaviour during the interviews we can deduce basic principles and modules of a potential teaching unit (Figure 7).

Three basic principles

1. Adequate time for pupils' activities

Learning by doing is fundamental to children's learning processes. Accordingly, lessons should give pupils time and opportunities to discover and assimilate (Soostmeyer, 2002). Therefore, when it comes to planning a teaching unit on complex ideas such as those underlying simple machines this principle is of particular importance. This is based on the fact that simple machines are mechanical aids and mechanics always involves the combination of technical procedures and human perception. Many mechanical processes are not noticeable by just observing or thinking about them, but have to be perceived, like the lightening of the load caused by simple machines during the transport of a heavy weight, or the effect of different material properties. Thus it is very important to give pupils the opportunity to act and experiment with different materials, devices and weights.

2. Communicative processes

Children never learn silently. In communication, subject knowledge can be structured and connected with different insights (Kaiser, 2006). When experimenting with the simple machines, the children's conversations were very important. The evaluation of the data revealed that most of the children had experiences and previous knowledge about simple machines. The learning target of a teaching unit should first be the structuring and development of

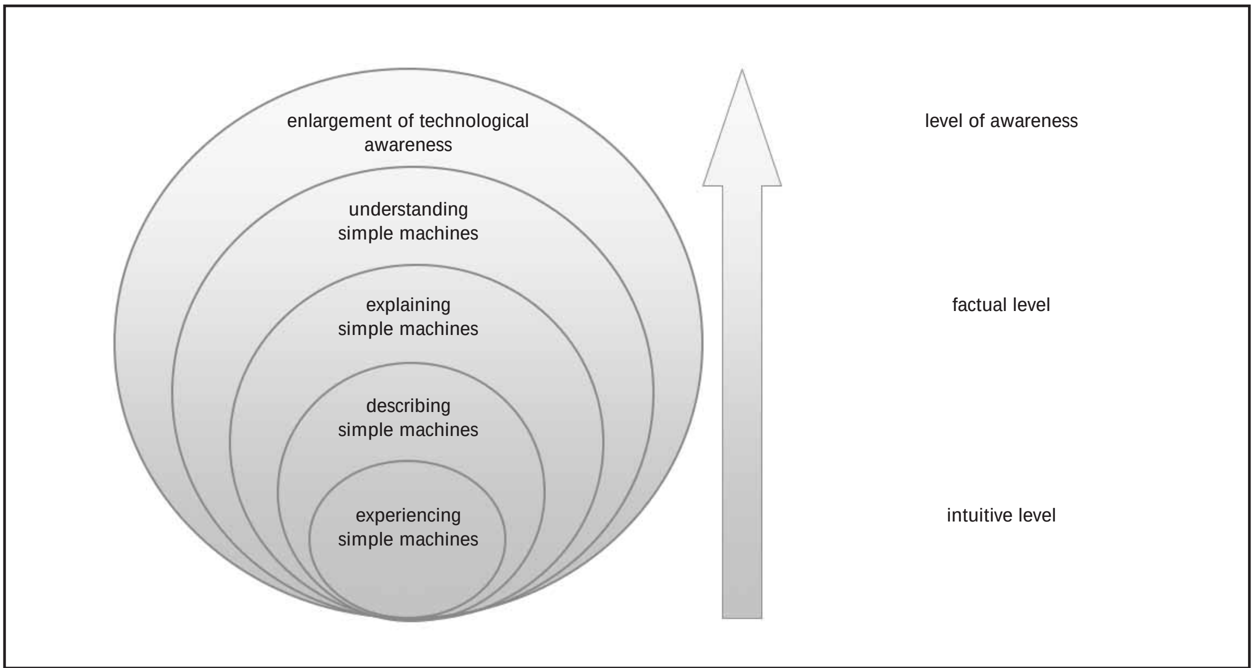

Figure 6. Circular model of thinking processes

this knowledge, but in the long run also to develop the understanding of the mechanical procedures. Looking at the structure of the children's concepts it appears that children need aid with the correct connection of the single elements. Then children can understand the functionality of several simple machines and they have a firm basis for developing their understanding. To this purpose, conversations in which teachers and pupils provide inputs, and reflect upon and discuss each thought are meaningful. Effective classroom discussion only works with good teacher guidance, otherwise inadequate conceptions could be reinforced (Kahlert, 2002).

3. Everyday language instead of technical language
During small group or whole class discussion, it is essential to use the children's everyday language. The pupils should be encouraged to describe precisely and coherently. The focus must be on the issue, and not on the technical language. The teacher talks and behaves in these situations as someone who thinks alongside the

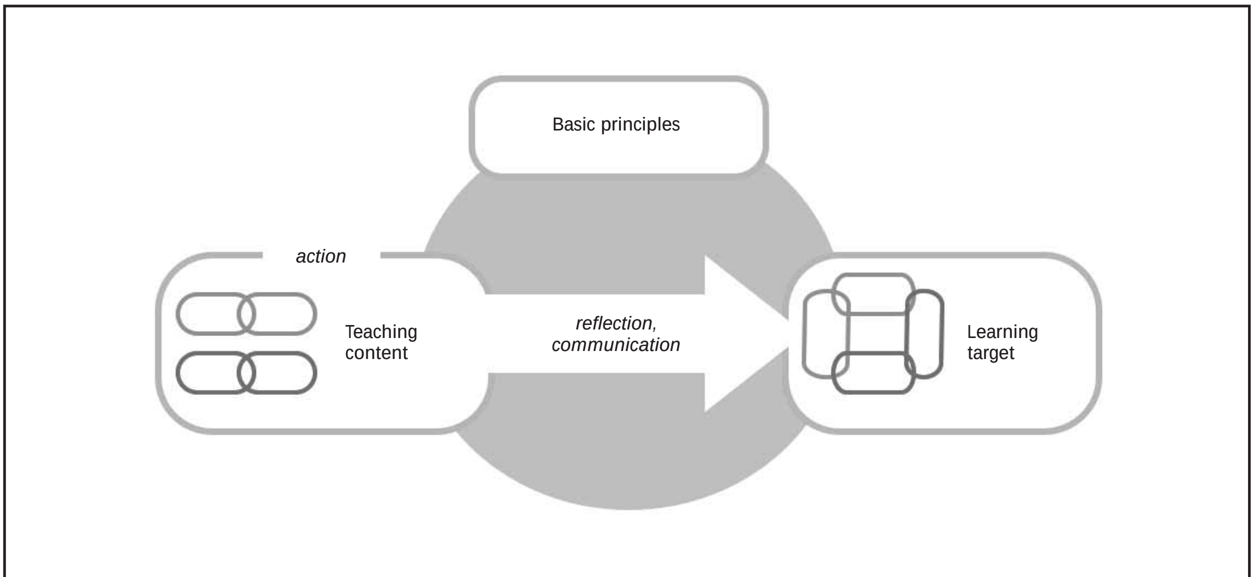

Figure 7. Teaching principles and modules

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children (Wagenschein, 1962, p. 132). The data reveal that the children's arguments and explanations on simple machines were not opposed to technical language. The notions used formed a base for further learning therefore it is neither necessary nor expedient to use technical language in primary school lessons.

Teaching content
As shown by the data, the connection of subjective and objective elements is important to understand the functionality of the devices. Following this result, lessons should contain parts in which the pupils concentrate both on the material and on themselves, their experiences and their bodily awareness. Pupils can do this in a free way (for instance, in problem-solving situations) or in a directed way (in structured learning environments). Both options should be embraced in the lessons because both pursue different aims. In a problem situation pupils can gain shared experiences with the transportation of a heavy weight. They can test different methods of using several materials and discuss their different solutions. It is important to allow pupils a free exploration of the problem because the research has shown that some pupils had no experience of transporting a heavy weight prior to the investigation. Those who already had experience could remember and structure their previous knowledge while discussing with peers. After this open-ended testing period the pupils had a good basis to reflect on the functionality of the machines. This could happen in a structured learning environment. The pupils should concentrate either on the material or on their body. With special tasks focusing on observing the materials, testing them and analysing their properties, the pupils can understand the essential aspects of the material-based components. These are supplemented with experience-based components concerning the body and the body awareness as they could compare different ways of transportation focusing on their bearing or their effort.

To understand the coherence between different material-based and experience-based components, both self-directed thinking and interactive thinking processes should be encouraged in communicative exchanges (Köhnlein, 2001). Self-directed thinking could be initiated by the pupils themselves (s/he observes something while experimenting, is astonished and tries to fit the new aspects into their available knowledge), or by the teacher (s/he gives prompts to look closely or to question something). Pupils make up their minds and comprehend contexts intuitively. While communicating they prove, judge, structure and reflect their thoughts and thus they move forward their individual understanding processes. When every pupil can convey everything s/he thinks about, the thoughts are communicated and pupils exchange their ideas (Wagenschein, 1962). So it should be the aim that every pupil takes part in classroom conversations. It is the collective work of teacher and pupils to reach this aim (Wagenschein, 1989); teacher and pupils have to perform like a communicative team to succeed.

Summary
This investigation shows that it is possible and reasonable to analyse complex issues like simple machines in primary school. The complexity of the issue should motivate teachers to consider the topics and connections that are important for the pupils in their class. When a teaching unit does not possess a specific focus it runs the risk that pupils only learn the terminology, without wholly understanding the context of the issue. Pupils need a lot of time to observe, think and talk; then and only then can they learn to understand.

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