RETHINKING PRIOR KNOWLEDGE: Facets instead of Misconceptions

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Although it was mainly progress in physics, chemistry and engineering that has contributed to prosperity in western industrialized countries, these subjects are particularly difficult to learn and hard to teach in school. It is especially true for physics that quite a lot of instructional effort does not bear fruit. The majority of students probably leave their lessons with only negligibly more fundamental understanding of the physical world than they had when they had entered it. In each classroom only a handful of students, predominantly males, gets a deeper conceptual insight and thereby acquires transferable knowledge. Often these successful children had already acquired knowledge in the subject matter outside of school and only needed to put the finishing touches on their knowledge.

The full extent of failing in science education is often hidden by the way the minimum achievement demands are defined. For passing exams with mediocre or lower grades the use of survival strategies may be sufficient. In case of physics this means knowing several formulas by heart and having some skills in manipulating them. Research in mathematical word problem solving has proved that survival strategies are used by children as early as in elementary school (Stern, 1993). At all age levels, the majority of students knows how to fulfil minimum achievement criteria despite lacking deeper conceptual insight, and only those students who do not even know how to use survival strategies are revealed as failures.

WHAT ONE CAN LEARN DEPENDS ON WHAT ONE ALREADY KNOWS

According to Hunt and Minstrell (1997) children's difficulties with science occur because students' prior knowledge is not taken into account and therefore communication barriers between teachers and learners cannot be overcome. Most of the teachers, however, hardly share this view and this may go back to what they learned about psychology during their own training. In Germany, and probably

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not only there, teacher training in psychology is often confined to the Piagetian theory of cognitive development and psychometric intelligence theories. Therefore, teachers take for granted that children entered the world as a tabula rasa and that general cognitive constraints prevent them from understanding abstract concepts and relationships in the first twelve years of their lives. Achievement differences are explained as differences in general intelligence, which is often understood to be the ability to think in abstract ways. Such views, of course, do not reflect the state of the art in psychology. Research on cognitive development and on expertise has emphasized the impact of domain specific knowledge on performance in many subject matter domains, among them physics.

Cognitive development has shown that at all age levels human beings possess knowledge about how the physical world works. Infancy research has shown that newborn children are endowed with implicit knowledge about features of the external world (Karmiloff-Smith, 1993; Spelke, 1990; Wynn, 1992) which allow them to understand physical and mathematical principles prior to personal experience. Preschool children can talk about object features like size or weight, although their ideas sometimes contradict those of adults (Carey, 1991). Elementary school children, like many adults, have developed belief systems about falling objects that show some similarity to the medieval impetus theory (McCloskey, 1993).

Research on differences between experts and novices has qualified the impact of psychometric intelligence on achievement differences. For a variety of subject matters, among them physics (Chi, Fetovich, & Glaser, 1981) it has been shown that the precondition for remarkable performance is deliberate practice during a long period of time rather than exceptional psychometric intelligence (Ericsson, Krampe & Tesch-Römer, 1993). Moreover, research on the cognitive processes of experts has shown that it is not the degree of abstractness in thinking that distinguishes them from novices, but rather the organization and the flexibility of their knowledge base. Experts organize their knowledge in chunks which are connected in complex networks and therefore allow efficient and flexible access. In contrast, novices have small islands of knowledge that cannot be easily integrated when faced with a particular problem.

Familiarizing teachers with the discussed psychological research may allow them a better understanding of their students' obstacles and appreciation of new approaches of science teaching such as facet based instruction.

A NEW VIEW TO PRIOR KNOWLEDGE: FACETS INSTEAD OF MISCONCEPTIONS

Early scientific views on the role of prior knowledge in concept formation were somewhat pejorative. The term "misconception" (Mc Closkey, 1981) was used to describe children's deficits, and the process by which they could be overcome was called "radical conceptual change" (Carey, 1985). The theory behind facet-based instruction takes a different view: Rather than focussing on the elimination of prior belief systems, one builds on these knowledge structures. It is taken for granted that knowledge cannot be correct or wrong per se, but that it can only be more or less appropriate for passing particular demands.

The following examples may illustrate that cognitive progress is characterized by adapting rather than by erasing prior knowledge. An indicator of cognitive development is the shift from using defining rather than characteristic features in concept formation (Keil, 1989). Characteristic features of the concept of "grandmother" are grey hair or wearing glasses, while defining features are being female and having children whose children have themselves children. Although adults can claim to know the defining features of a grandmother, Landau (1982) has shown that when being presented with a picture of a lady around age 70 and a lady around age 50, adults answered the question "Who is the grandmother?" by immediately indicating the older lady. Considering visible characteristic features is less time consuming than asking for information about the defining features which are not visible. Therefore in the experimental situation the subjects may have decided that by choosing the older lady the probability of making the right decision is higher than by choosing the younger lady. Moreover, a mistake would not have serious consequences. In contrast a judge who has to mediate in inheritance disputes would hardly rely on superficial features such as grey hair or glasses, and would rather clarify family relationships before deciding who is the grandmother.

The discussed result suggests that characteristic features can guide concept formation also after defining features are in place. The difference between adults and children, or more generally speaking, between experts and novices, seems to be that experts not only organize their concepts around defining features, but that experts have more complex concepts that contain characteristic as well as defining features. Moreover, experts know when to use certain kinds of knowledge, or, in other words, they show adaptive knowledge access, depending on the demand. I have heard people with a university degree in physics talking about "consumption of energy", which makes no sense within a scientific physical context but is useful in some everyday situations. Although I am far from being an expert in physics I myself claim to understand the principles of mechanics. Nonetheless, when I presented the problem depicted in Figure 2 in the in the Hunt and Minstrell (1997) paper to a poorly educated adult, who did not understand the meaning of "exert force on", I further explained "Ok, this means, who has to make more of an effort, the girl or the boy?" Prior knowledge is lurking everywhere.

Mastering the Piagetian conservation tasks has been interpreted as radical change in the dimension to be focussed on. In case of number conservation children have to understand that the expressions "more than" and "fewer than" refer to numbers rather than to other dimensions such as the spatial extension of objects. However, the following example may demonstrate that also for adults the use of the mentioned expressions depends on the context. Given two plates, one with three very large tomatoes, and the other with four very small ones, the question "On which plate are there more tomatoes?" resulted in further inquiries rather than an immediate answer. When I presented several adults with the two plates, all of them asked "What do you mean, the weight or the number?" In the supermarket one has to pay more for the three tomatoes than for the four ones because the price of vegetables depends on their weight. When one wants to decorate a cold buffet with whole tomatoes one has to focus on the number rather than on the weight. More experienced persons know that "more" and "fewer" can be used for any measurable unit and this knowledge allows them to choose among several alternative interpretations and thereby adapt their knowledge to the particular demand.

TEACHERS HAVE TO MAKE SURE THAT LEARNERS CAN RETAIN THEIR PRIOR KNOWLEDGE

The examples in the previous section suggest that concepts cannot be seen without their context of application. Instead of just telling learners that force means mass times acceleration, teachers have to clarify what kind of outcome can only be predicted when understanding force in this way. Already young children are willing to adapt their knowledge to demands if their prior knowledge is honored. I presented a bright first grader with questions concerning the concept of weight as they were mentioned in Carey (1991). The child answered in the same way Carey reports: he understood that a heap of rice has weight while he contested that a single rice kernel has weight. I further explained to the boy: "Imagine you are an ant. Somebody puts a rice kernel on your back. As an ant, would you still say that the rice kernel has no weight?". It turned out that the boy was sure that for an ant, the rice kernel has weight. During the discussion the boy understood that whether a living being feels the weight of an object depends on its size. However, he also started to understand that the expression "weight" is not only used in the context of subjective feeling but is also an objective property of all kind of material.

The core idea of facet based instruction is that teachers are not only responsible for the new knowledge they want their students to acquire, but also for the knowledge their students have already acquired. Only if the learners have the feeling that their prior beliefs are acknowledged they are open to new insights.

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