8. LEARNING BY DESIGNING
A CASE OF HEURISTIC DIRECTED THEORY
DEVELOPMENT IN SCIENCE TEACHING

In teaching, science is often presented as a black box. Students are typically confronted with only the results of scientific research. They are not given any insight into what is actually happening in the black box which is the often tedious process of formulating and testing theories. Science presented in this way, characterized by Joseph Schwab (1962) as the “rhetoric of conclusions,” can easily lead students to an incorrect image of both the products and processes of scientific research. Students typically consider theories not as provisional solutions to problems, but rather as facts that are simply gathered from nature by scientists.

OPENING THE BLACK BOX

How can we give students a more adequate and complete picture of science? In order to do this, the black box must be opened to provide students with an insight into how a theory is developed and on what grounds it is accepted or rejected. This can be achieved by telling them about theory development (through autobiographies, scientific papers, etc.), but better still is to allow students to participate themselves in the process of theory development. This assignment is not an easy one for the teacher. In the typical classroom it is the teacher’s responsibility simply to explain the theory and subsequently test to see if students understand it. On the other hand, allowing students to participate in theory development, the teacher must first teach students how to formulate problems, how to create possible solutions and how to test these solutions. In this chapter, we will discuss the content and framework of a course in which teachers learn how to help students participate in the process of theory development.

We will first ascertain what we mean by theory development. On the basis of two lesson fragments we will illustrate and describe our view of theory development. The concept of a heuristic (search strategy) is central to this discussion. Such heuristics can generally be derived from the basic principles of a discipline and are thus specific to a particular discipline. We have developed a heuristic for teaching biology. We have called this heuristic a “design heuristic” because pupils use it to develop theories related to various biological systems by designing them from scratch — learning by designing.

Next we will describe how a teacher can prepare and supervise the process of heuristic directed theory development. Then, we consider how teachers can reflect on the premises and method of theory development together with the students. Preparation, supervision and reflection on theory development are illustrated using several examples from biology education. Finally, we focus on the effectiveness of our approach.

**THEORY DEVELOPMENT**

We will illustrate our conception of theory development by referring to two lesson fragments (Table I). In the first fragment, pupils are taught a theory in a traditional manner. In the second, pupils actually participate in developing the theory. The lessons are in biology with specific focus on the immune system. The pupils are in their final year of a high level, secondary school, biology course. The teacher has given a short introduction on bacteria and viruses before both lessons.

| Table I |
| Lesson fragments illustrating two instructional strategies |

**Lesson Fragment 1: Typical instructional discourse**

Teacher: White blood cells are responsible for eliminating bacteria and viruses. There are three types of white blood cells. I shall begin with the macrophages. Who thinks he knows what the word macrophage means?

Joost: Doesn’t macro mean big?

Teacher: Exactly. Macro means big and phage means an eater - a big eater, in other words! When a macrophage encounters a bacterium, it envelops the bacterium and subsequently digests it. We call this process phagocytosis. Where do you think that we can find this macrophage in the body?

Anja: In the blood - you just said that they are white blood cells!

Cees: I think near the skin that is where the bacteria enter the body.

Teacher: You are both correct actually. Macrophages can be found in blood, but also in tissues where bacteria enter the body, such as skin and lungs.

**Lesson Fragment 2: Discourse leading to theory development**

Teacher: We now know that bacteria and viruses can be harmful. How can a bacterium or virus be rendered harmless?

Klaas: With a sort of stabbing cell. This could stab through the bacterium.

Marjon: But then you still haven’t got rid of the bacterium.