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# PUPILS CONNECTING OBSERVATIONS AND EXPLANATIONS IN SUCCESSIVE DEMONSTRATIONS

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**Abstract.** *The aim of this study is to find out how pupils will connect their observations and explanations from a demonstration. Seventh graders (117) were shown successively two demonstrations about floating and sinking. Pupils' observations and explanations were classified and compared with each other in the two demonstrations. The four observation categories were: Complete observation, incomplete observation, non-essential observation, and no observation. The five explanation categories were: Scientific explanation (density), alternative explanation (weight), situational explanation (temperature), spontaneous explanation (irrelevant, insufficient, wrong), and no explanation. Both the observations and the explanations were improved significantly in the second demonstration even that no teaching was done between the demonstrations. The ways used by the seventh graders in processing their observations and explanations have been examined from the viewpoint of perceptual learning, variation theory, and the memory models in cognitive psychology.*

**Key words:** *science education, observations, explanation, variation theory.*

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## Introduction

Making observations is one of the process skills like classifying, measuring, making inference, predicting, recording, planning or communicating (see cf. Johnston, 2005). Scientific observation is a method of inquiry that provides data for articulating explanatory hypotheses and models. It is a function of the current state of knowledge. Ahtee et al. (2009) have collected a concept map about the main characteristics of scientific observation. These contain among other things the observer's knowledge and skills as well as motivation and interest. In science, observations have an essential role in construction and verification of scientific models and are influenced by the observer's assumptions and domain knowledge (Haury, 2002). Observations are not categorical statements about the things and events but the observers' account how they have experienced and understood the observations. Furthermore, all observations are theory-dependent burdened with interpretations and assumptions (Hodson, 1986).

A scientific explanation consists of observations made from the phenomenon together with the initial conditions and the relevant laws. Parker (2004) emphasizes that generating meaningful causal explanations of scientific phenomena lies at the heart of both the scientific endeavour itself, and of effective classroom teaching. However, in everyday life observation is often simply seen as "looking at things". Ahtee et al. (2009) found from a questionnaire study that for the majority of the primary student teachers making observations seems to mean in the first place just noticing things or collecting data instead of paying attention to

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the cause behind the observations or how the observer's knowledge guides the observations. Ravanko, Hakkarainen and Ahtee (2009) found the same to be true also with the primary and lower secondary pupils whereas the upper secondary students specializing in physics had a more science related view about the position of observation in the process of scientific knowledge.

According to Horwood (1988) in ordinary science teaching and in science texts, the terms "describe" and "explain" and the activities of description and explanation are used in variable, inconsistent and confusing way even to the extent that students may simply take "explain" to mean "say something more about". Smith and Reiser (2005) suggest that in order to support student-directed observations students should be provided with structured tasks that facilitate complex analysis and reasoning around observed materials. These tasks should help students to understand that observation is not a goal in itself. Therefore it is important that while seeing different variations of a phenomenon pupils should start spontaneously to wonder and make questions about how to explain the observations. Wu and Hsieh (2006) point out that many lower secondary pupils have difficulty constructing scientific explanations for phenomena because the pupils have limited conceptual knowledge about the phenomenon to be explained. Therefore, they may form explanations based on their own ideas (Driver, Leach, Millar, & Scott, 1996). Furthermore, Kuhn (1989) has pointed out that many lower secondary pupils confuse explanatory claims with evidence and have difficulty making logical inferences.

In the general models of learning (e.g. Osborne & Wittrock, 1983) it is emphasized that people make actively their own interpretations and conclusions from the information obtained through senses. Pupils' selective attention and their own knowledge effect the formation of the meaning. Pupils have to become aware of the features that are essential to the understanding of the phenomenon under observation before it is possible for them to end with the facts that are critical in the scientific explanation. Because the pupils in the lower secondary school are novices even with the basic knowledge in physics they may pay attention to non-essential features in the demonstration. Our aim in this study is to help pupils to make essential observations while looking at a demonstration and thus learn to draw relevant conclusions. We chose flotation as the phenomenon to be studied because from primary school it is familiar to seven graders and because it contains many problematic features due to the concept of density (cf. Unal 2008).

It is well-known that lower secondary pupils have difficulties in understanding the concept of density. Shayer and Adey (1981) emphasize that the understanding of density requires the simultaneous command of two variables, mass and volume. Density is a property of matter and thus does not change in regard to the amount of the matter whereas the weight and volume of a piece of matter are proportional to the amount of the matter. Furthermore, when a piece of matter is heated its volume and density change whereas its weight remains the same. According to Smith, Snir, and Grosslight (1992) many seventh graders have not made even a preliminary qualitative differentiation between weight and density at a conceptual level.

The aim of this study is to find out how seventh graders will connect their observations and explanations from a simple demonstration. The concept of density was approached by looking at floating and sinking of same quantity of water with different temperatures in water. This was a completely new approach to the seventh grade pupils. The research problem was formulated as follows: How does a small change in the successive demonstrations effect pupils' observations and explanations?

**Processing Observations and Knowledge**

Bransford, Brown and Cocking (2000) describe in their book "How people learn" how internal representations can be built up through many opportunities for observing similarities and differences across the observed phenomena. Consequently the goal of these observing activities is to help students build internal representations – information stored in memory - which students can retrieve to generate inferences, solve problems, and make decisions. The nature of memory provides suggestions how observations are processed in the working memory and stored in the long-term memory.

The brain is not a passive consumer of information. Instead it actively constructs its own interpretations of information, and draws inferences from them. The brain ignores some information and selectively attends to other information. The stored memories and information processing strategies of the brain interact with the sensory information received from the environment to actively select and attend to the information and to actively construct meaning. The pathway to the construction of meaning e.g. from observing a happening does not start with that experience. Rather, it begins with selective attention of that experience, where selective attention is influenced by variety of aspects of long-term memory and cognitive processes. Selective attention results in selective perception. People attend to and perceive changes in stimuli. This implies that a person must have a model of the stimulation to perceive changes in it. Consequently, changes in sensory information are substantially influenced by relevant memory store and by cognitive processes. (Osborne & Wittrock, 1982).

**Information Processing**

Although, there are differences among theories of cognitive processing, most theories include sensory, memory, processing, and response components as a part of the overall cognitive processing system (see e.g. Gross, 2009). The sensory component is the site through which information enters the cognitive system in the form of coded messages before being transferred, after a very brief period (milliseconds) to the memory. Information is stored momentarily in the working memory as it is processed and transferred into the long-term memory. The amount of information that can be stored in the short-term memory as well as the length that it can be retained is limited. Information transferred and processed from the long-term memory can be retrieved again, but information transferred from the external environment is permanently lost unless rapidly processed, provided again, or reconstructed. A major instructional challenge, thus, is to present information in the form and amount that facilitates rapid processing in the working memory while at the same time not exceeding capacity.

The long-term memory is the site for both the storage and retrieval of all information that has been learned. Information is thought to be stored in highly organized associative structures or networks in the form of visual, auditory, tactile, olfactory, and semantic codes that assist in the retrieval and use of information. These storage structures vary among individuals in the amount or actual volume of information coded in the memory, in the structural connections making up the networks, and in the control strategies used to find and employ information.

**Theories about How People Perceive the World**

To experience something as an identifiable whole from its surrounding context, that something must be perceived as a gestalt, a thematic whole, which is discerned from its context (Gross, 2009; Marton, 1988). The gestalt laws describe to some extent what and how a person observes an object or a phenomenon. They tell some principles according to which the brain deals with the information obtained through senses. According to the law of similarity the more the objects resemble each other the more easily they are grouped together. Correspondingly, according to the law of proximity when the objects are close to each other they are perceived to be related. According to the law of familiarity a person combines the objects into groups that are familiar or have some meaning to him/her. However, the various laws are merely descriptive and not very precise.

Perceptual aspects of learning refer to how people perceive the world in relation to how they act. People do not act in relation to situations as such, but in relation to situations as they perceive, experience, and understand them. In his review about perceptual learning Goldstone (1998) considers four mechanisms. By attention weighting perception becomes adapted to tasks and environment by increasing the attention to important dimensions and features, and/or decreasing attention to irrelevant dimensions and features. Feature is a unitary stimulus element e.g. a certain colour and dimension is a set of ordered features like different colours. By imprinting, receptors are developed that are specialized for stimuli or parts of stimuli. By differentiation, stimuli that were once indistinguishable become psychologically separated. By unitization, tasks that originally required detection of several parts are accomplished by detecting a single constructed unit representing a complex configuration.

According to Marton and Booth (1997) a person's awareness contains all the entirety of all his/her

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experiences formed during the interaction between the person and his/her environment. To experience something the object has to be discerned, differentiated from the background. In order to discern a feature a person must experience variation in that feature. According to Marton, Runesson and Tsui (2004) the mechanism of selectivity originates from the contradiction between the huge amount of information that can be gained from a situation, and people's limited capacity for processing that information. Whenever people attend to something, they discern certain aspects, and by doing so pay more attention to some things, and less attention or none at all to other things. One person experiences a phenomenon in a certain way when s/he discerns certain things simultaneously. Another person experiences the same phenomenon in another way when s/he discerns other aspects. Both persons interpret the phenomenon according to the features that are critical to them.

When different people are observing a phenomenon they pay attention to different features. They use all senses in order to identify similarities and differences as well as patterns in and between objects and phenomena. When pupils are making observations they are expected to notice the features that are relevant for the scientific explanation. If a pupil does not succeed in making relevant observations it may be due to the fact that s/he is paying attention to a non-essential thing, or s/he does not perceive the central idea, or perceives it wrongly.

People see, experience and understand the things and events differently depending on their own experiences and awareness (Marton & Booth, 1997). These different ways to discern a phenomenon depends thus on the thing what people observe. In this study we try to find ways how to help pupils to make essential observations that lead to a scientific explanation. Therefore we need to know the critical features of the demonstration from the pupils' point of view.

At the same time, when a person becomes aware of something s/he will connect to it some meaning that is activated simultaneously in the working memory. The meaning is formed on the basis of his or her earlier knowledge or experiences (Marton & Booth, 1997). To construct meaning from sensory information it is necessary to generate links to what are perceived to be relevant aspects of information in long-term memory. The generated links are critical for the meanings that are constructed. The observations a person makes from an object or a phenomenon are not a copy of the object or the phenomenon but the person's interpretations. People have different knowledge and ways of thinking so that they form different conceptions (Marton & Booth, 1997; Marton, Runesson, & Tsui, 2004). Scientific observation is closely connected to procedural and conceptual understanding and in this way it is influenced by pre-existing knowledge and earlier experiences. Through processing, new knowledge and skills are formed. However, the working memory with its limited capacity set limitations to observations.

## Methodology of Research

### *Tasks*

During a science lesson two demonstrations were shown to the pupils. In the first one (floating) a transparent plastic bag half-filled with hot water from a tap in the classroom was let loose when placed perpendicularly to the surface of the cold water in a transparent basin. The difference in the temperatures was emphasized by asking some of the pupils to come and feel with their hands. Pupils wrote answers using whole sentences to two questions: What is happening in the demonstration? and How would you explain why it is happening as you observed? After the first demonstration the answer sheets were collected. Immediately after this the second demonstration (sinking) was shown. In it the basin was filled with hot water and the plastic bag with cold water, and the pupils wrote again their answers to the two above mentioned questions. The aim was to find the ways how the pupils experience these demonstrations.

### *Participants and Data Gathering*

The researchers showed the demonstrations during the physics lessons to seven teaching groups of seventh graders with the average age of 13 from five different schools. The total number of pupils was 117 varying from 13 to19 per teaching group. The data collection was carried out in the beginning of the spring term before the density conception was taught. During the autumn term chemistry is taught and teaching of physics is started with motion phenomena. The demonstrations shown were new both to the teachers and the pupils. Furthermore, the choice of school does not greatly influence science achievement in Finland (Reinikainen, 2007).

*Data Analysis*

The content analysis used is qualitative and it can be best described as a combination of inductive and deductive content analysis (Patton, 2002) consisting of careful identification of appropriate categories. First, pupils' answers to the first question (observation) in both of the demonstrations were read through many times in order to find possible categories i.e. to figure out what things fit together. When different categories started to be formed each category was again read separately, inconsistent answers were taken away or moved to other categories. Also this procedure was done several times. After this the categories were read together and given descriptive labels. All responses were carefully categorised together with their frequencies. The same procedure was followed with the answers to the second question (explanation).

In order to find out how the quality of the observations and the corresponding explanation depend on each other we determined how the answers were distributed between the observation categories and the explanation categories in the both demonstrations and calculated the significance in each case using the chi-square test. We determined also the Pearson product-moment correlation coefficient and its significance between the categories in the both demonstrations comparing how the pupils in each of the seven teaching groups chose these categories.

**Results of Research**

This section is divided into two parts. The first part presents the categories based on the written observations about the successive demonstrations and the changes in these observations. Both qualitative data and statistical results are given. The second part presents the explanations that the pupils gave in the first and second demonstration. Also the differences and stability of the explanations has been considered. In addition to the categories of observations and explanations, examples of pupils' answers are given.

*Pupils' Observations in the Successive Demonstrations of Floating and Sinking*

In both demonstrations four qualitatively different categories were found from the pupils' answers to the question 'What is happening? ': 1° Complete observation, 2° Incomplete observation, 3° Non-essential observation, and 4° No observation. Examples of pupils' answers are given in Table I and the number of the answers in the different categories is given in Figure 1. In the first category Complete observation, all essential things needed for the scientific explanation were mentioned i.e. the phenomenon (floating/sinking) and the two factors (hot and cold water). In the second category Incomplete, either the phenomenon together with one of the factors or only the phenomenon was mentioned. Respectively, in the last two categories either only a non-essential observation or no observation was mentioned. The category Non-essential was included especially to help us to follow the effect of these observations in the corresponding explanations. The category No observation includes both the answers in which the pupils mentioned only the preparation for the demonstration, some other phenomenon that was not present, or they did not give any answer to this question.

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**Table 1. Examples of the pupils' answers to the question "What is happening?" in the successive demonstrations of floating and sinking.**

| Categories | Floating | Sinking |
|---|---|---|
| Complete observation | *Hot water in the plastic bag floats on the cold water in the basin.*<br>*Hot water stayed on the surface of the cold water.* | *The cold water bag sank to the bottom in the hot water basin.* |
| Incomplete observation | *The hot water bag floats.*<br>*It floats on the surface of the cold water*<br>*The bag floats.* | *The cold water bag sinks downward .*<br>*The bag sinks to the bottom.* |
| Non-essential observation | *The hot water stayed in the bag.*<br>*The hot water bag fell on the surface of the cold water.* | |
| No observation | *The plastic bag containing hot water was put into the cold water.*<br>*Hot water melts into cold water.* | *The plastic bag containing cold water was put into the basin containing hot water.*<br>*The bag became empty when it was put into water.* |

In the first (floating) demonstration the phenomenon was not very clear to some of the pupils and they made only non-essential observations. About 10% of the pupils paid attention to the fact that the water did not run out of the bag, another 10% mentioned that the bag fell down on the surface of the big basin. In Fig. 1 the changes in the pupils' answers to the observation question from the first to the second demonstration are shown. The seven graders made better observations after the second demonstration, especially the non-essential observations have disappeared altogether and are replaced almost totally either with a complete or an incomplete observation. The numbers in the categories in the successive demonstrations differ very significantly ($\chi^2(2)$ (all categories with the last two ones combined) = 15.96, $p< 0.001$) even though two thirds of the pupils stay in the same category in both demonstrations. The linear correlation coefficient shows significant increase in the first and second category [$r_1= 0.953$, $p < 0.01$, $r_2 = 0.967$, $p < 0.01$]. The changes of the observations from the last two categories (C & D) in the floating demonstration to the two first categories (A & B) in the sinking demonstration also are very significant ($\chi^2(1) = 42.00$, $p < 0.001$). More than half of the pupils who in the first demonstration made wrong or no observation improved their observation but only six pupils improved their incomplete observation in the second demonstration to a complete one.

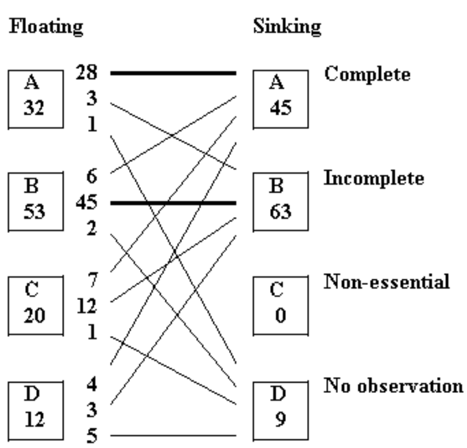


**Figure 1. The numbers and changes of the pupils' observations in the first (floating) and second (sinking) demonstration. The total number of pupils is 117. The thick line indicates statistically significant change.**

*Pupils' Explanations in the Successive Demonstrations of Floating and Sinking*

Five categories were found from the pupils' explanations in both of the demonstrations. They were: 1° Scientific explanation (density), 2° Alternative explanation (weight), 3° Situational explanation (temperature), 4° Spontaneous explanation (irrelevant, insufficient, wrong), and 5° No explanation. Examples of pupils' answers are given in Table II and the number of the answers in the different categories is given in Figure 2.

Only few pupils gave the scientific explanation using the concept of density correctly in the both demonstrations. The majority of the pupils used the concept of weight which is not correct but used frequently in everyday talk. The answers in which the pupils connected their explanation with the different temperatures of the water in the bag and the water in the basin are classified in the third category Situational explanation because the pupils just paid attention to the obvious feature in the situation without trying to connect it further. These pupils pay attention to the correct variable but they do not manage to go further with this idea. In the first demonstration nine pupils from 30 referred to hot and cold water, and the rest wrote something more indefinite like 'hot going up' or 'it is warm'. In the second demonstration the most typical answer stated that 'cold goes down'.

The fourth category Spontaneous explanation contains explanations that are irrelevant, insufficient or wrong. In the first demonstration the pupils' explanations were mainly irrelevant as they were connected to a non-essential phenomenon. For example, the falling of the bag was explained with gravity, and the floating of the empty bag with its lightness. Some pupils instead of giving an explanation just described what happened in the demonstration. An example of wrong answer is that surface tension causes the floating in the first demonstration or that 'hot water is heavier that cold water' in the second demonstration. The answers in which the explanation was connected to some other phenomenon like surface tension are more like a guess than an explanation.

**Table 2. Examples of the pupils' answers to the question "How would you explain why it is happening as you observed?" in both of the successive demonstrations Floating and Sinking.**

| Categories | Floating | Sinking |
|---|---|---|
| Scientific explanation<br>Density | *Hot water is less dense than cold water?* | *Cold water is denser than hot water.* |
| Alternative explanation<br>Weight | *Hot water is lighter.* | *Cold water is heavier.* |
| Situational explanation<br>Temperature | *Because the bag contained hot water and there was cold water in the basin.* | *Cold water goes always to the bottom just like hot air always rises up.* |
| Spontaneous explanation<br>Irrelevant, insufficient or wrong | *The gravitational force made it fall.*<br>*The bag is waterproof and the air inside the bag made it float.* | *Surface tension breaks down.*<br>*Because hot water decreased the amount of oxygen in the bag* |
| No explanation | *I do not know.* | *I do not know.* |

In Figure 2 the changes in the pupils' answers to the explanation question from the first demonstration to the second demonstration are shown. The numbers in the categories in the successive demonstrations differ very significantly ($\chi^2(3)$ (all categories) = 23.2, $p< 0.001$).There is very significant increase in the categories Scientific and Alternative explanation (Density and Weight) ($\chi^2(1) = 16.9$, $p< 0.001$) and Spontaneous explanation ($\chi^2(1) = 17.6$, $p< 0.001$). The linear correlation coefficient shows almost significant increase in the Alternative explanation and the Situational explanation categories ($r_1= 0.853$, $p < 0.05$, $r_2 = 0.821$, $p < 0.05$). An obvious feature also here like in the case of making observations is that in about a half of the cases the category stays the same in the both demonstrations. Those pupils who in the first (floating) demonstration gave the scientific, alternative or situational explanation changed their explanation less frequently than the other pupils ($\chi^2(1) = 20.5$, $p< 0.001$) who were trying to look for another explanation (see Figure 2).

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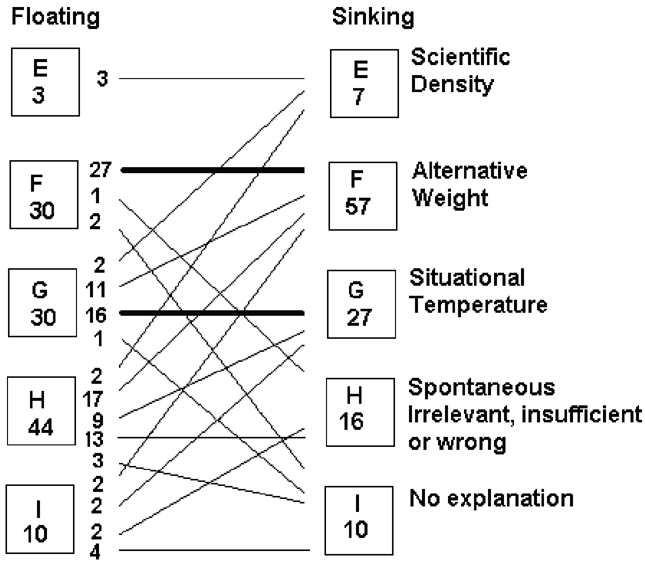


**Figure 2. The numbers and changes of the pupils' explanations in the first (floating) and second (sinking) demonstration. The total number of pupils is 117. The thick line indicates a statistically significant change.**

In the sinking demonstration the number of scientific (density) and alternative (weight) explanations doubled. Especially, 60% of the pupils who made only a non-essential observation in the first demonstration gave the alternative (weight) explanation in the second demonstration. However, the pupils who gave the alternative (weight) explanation in the first demonstration did not change their explanation to the scientific explanation. This is understandable as the concept of density demands the differentiation of the concepts of mass and volume as well as the understanding that density is characteristic to the material or combination of materials from which the object is made of, whereas "heaviness" is some kind of global notion learned through common experiences. Almost half of the spontaneous explanations given in the first demonstration have improved the biggest change being in the alternative explanations. One third of the situational explanations have improved and the majority of the pupils who in the first demonstration did not give any explanation now try to give at least some kind of explanation.

**Discussion**

In this study we have shown that a small variation in the successive demonstrations has a considerable effect as both the pupils' observations and explanations improved significantly. Marton, Runesson and Tsui (2008) emphasize that people act not to situations as such, but in relation to how they perceive, experience, and understand them. Pupils have many ideas in their mind with which they examine a new event. It is natural that looking at an event pupils pay attention to many features and thus different conceptions will be activated. However, the seven graders lack the expert's ability to distinguish between essential and non-essential observations (Bransford, Brown & Cocking, 2000). They are novices who have difficulties to identify the main phenomenon from the whole event and thus also to connect it to the proper theoretical aspects. When the pupils realized themselves on the basis of the second demonstration that their observation and the corresponding reasoning were not valid it was easy for them to abandon them and try to find a new explanation.

While making observations pupils often are content with one clear observation instead of focussing on possible causes or concentrating to think about properties and correlations (Kuhn et al., 2000). When the pupils make only essential observations they concentrate better on inventing relevant explanations. This means also that they may avoid the mismatch between the scientific explanation and their own explanation based on non-essential observations. It is well known that at the lower secondary school many pupils lose their interest in physics (cf. Hoffmann, 2002; Lavonen et al., 2005). In many cases this is due to the frustration that pupils feel when their thinking does not seem to work at all, when "*the world is not analyzable and worth trying to understand*" (Kuhn, Black, Keselman, & Kaplan, 2000). When pupils become themselves aware of the critical features, the demonstration will not be a frustrating event which they cannot understand.

Bransford, Brown and Cocking (2000) point out that when material is taught in multiple contexts, pupils are more likely to extract the relevant features of the concepts and develop more flexible representations of knowledge that can be used more generally. When pupils are making observations from an object they pay attention to several features and form different conceptions. Therefore it is important to show different variations from the same phenomenon that the pupils can concentrate on the essential ones. When different demonstrations are shown from a phenomenon, pupils will also get a more comprehensive picture from its behaviour and will be able to understand the justification of the scientific explanation. We argue that it is important that pupils start as early as possible with simple cases to find possible explanations to their observations and that they are shown many variations of the phenomenon so that they will learn and become familiar that they have to change their first trial and try to invent a different possibility.

Kang, Sharmann and Noh (2004) infer on the basis of their study related to seven graders' learning the concept of density that cognitive conflict should be considered in the process of concept learning. They warn, however, that cognitive conflict may only be one of the important factors to be considered in concept learning. As can be seen from Fig. 2 very few seven graders end with the proper scientific explanation but keep their weight explanation. When introducing the concept of density teachers should emphasize the differentiation of weight and density (Kang et al. 2004). Smith et al. (1992) found that children who differentiated weight and density in the tasks with solid materials had difficulties in understanding density in the context of thermal expansion. Therefore we suggest that an additional demonstration showing the fallibility of the weight explanation should be given to the pupils to be observed and explained. In this demonstration the hot water bag and the cold water bag should be let loose simultaneously on the surface of the lukewarm water in the basin. However, this time the hot water bag should be filled almost full whereas the cold water bag should contain much less water. The pupils will then be confronted with the dilemma that the heavy hot water bag will lay down on the surface whereas the lighter cold water bag will fall to the bottom. The complete understanding of this phenomenon will, however, demand from the seventh graders more new information than they could possibly assimilate at this stage like the understanding of the Archimedes' principle and the knowledge how the volume of water increases with temperature.

Our results are in accordance with the variation theory (Marton & Booth, 1997; Marton, Runesson & Tsui, 2004). When people make observations from a phenomenon they experience a connection between a certain feature and its meaning. They form an idea about the thing. This idea is a new state of awareness (Pang, 2003). Every phenomenon has its own critical features that distinguish it from other phenomena. In our demonstrations the critical feature is the density difference between hot and cold water. In order to be able to create a proper explanation one has to observe how the critical feature varies in the successive phenomena. Pupils differ according to what they know and what they are interested in and therefore they will pay attention to different things. Pupils will become aware of and form a conception about the object they are observing when they connect to a certain feature the meaning that is activated simultaneously on the basis of their earlier knowledge and experience. Therefore it is important that pupils are required both to make observations about what happens and to give their explanations why they think it happens because then both gestalt and information processing will be activated simultaneously.

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## Conclusions

On the basis of the memory models from cognitive psychology (Gross, 2009) and our own findings we have sketched models how pupils are processing information in making observations and explaining these observations (see Figure 3). Figure 3a gives a model how pupils process their observations from a phenomenon. Sensory memory gives an accurate account from the demonstration as experienced by the sensory system. Any information that is not attended to or processed further will be forgotten. Information from sensory memory is scanned and matched with information in long-term memory. If a match occurs it may be fed into working memory with a verbal label. In principle, there are three kinds of observations: essential, non-essential, and no observation at all. It may happen that the information coming through sensory memory activates relevant earlier experiences or knowledge in the long-term memory so that the pupil can e.g. by comparison extract the essential facts from the incoming information (see examples about complete and incomplete observations in Table 1). It may also happen that the observation is such that it activates irrelevant experiences or knowledge from the long-term memory and the pupil will end with a fact that is non-essential as to the phenomenon under observation (see the floating demonstration in Table 1). The selectivity in observations is caused by the fact due to the limited capacity of the working memory a person can manage only a small part of the huge amount of information involved in any situation. In the third case, the incoming information does not match with any other information in the long-term memory and the pupil ends with no observation at all (see examples about no observations in Table 1).

In Figure 3b it is shown how the information stored in the long-term memory is retrieved to the working memory to be processed with the incoming information containing essential observation. When there is a match with the proper physics law e.g. Archimedes' law the response may be the scientific explanation with the concept of density like in the topmost category in Table 2. When the everyday experiences match with the essential observation the response may lead to the alternative explanation (see Table 2). When no match is found in the declarative memory the pupils will end with the situational, spontaneous or no explanation (see Table 2). However, it has to be noticed that in fact very little is known about the precise functioning of the working memory and the long-term memory.

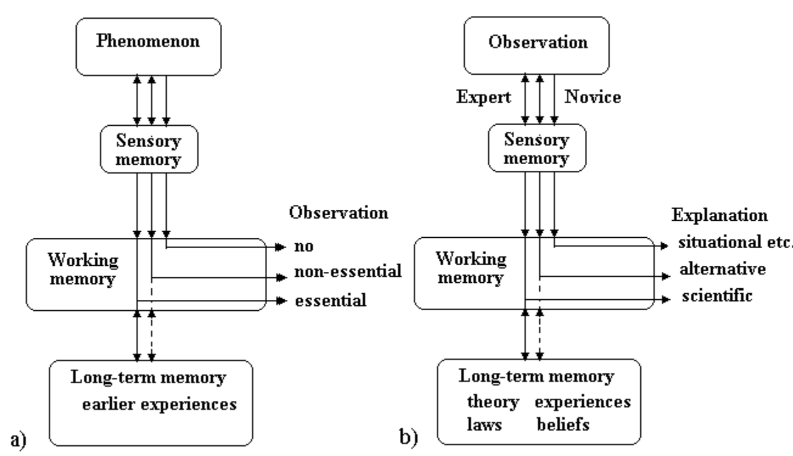


**Figure 3. Models how pupils are processing information a) in making observations, and b) in explaining the observations.**

The studies of experts and novices support the two-way flow of information between working memory and long-term memory (see e.g. Bao & Redish, 2003). An expert has more knowledge about the laws, theories and principles in physics than a novice, and this knowledge is also better organised.

An expert pays her/his attention to the relevant points and s/he reflects the information from the observations and the scientific knowledge in her/his memory and may end up with a scientific explanation. On the other hand, a novice's reflective thinking skills may also be insufficient and s/he does not compare her/his observations with the earlier knowledge. The novice may compare only some detail in the observation with a single piece of knowledge. Thus s/he may end even with an explanation that has no logical connection with the observation. All this means that in science learning it is important to give pupils opportunities to make observations and inferences based on them.

When pupils are making observations about a phenomenon new to them, they have to pay attention to everything as they do not know what could be relevant. However, all observations provide data for hypotheses. Understanding the role and restrictions of observations is thus crucial in learning the process from observations to explanations. The holistic view how information from observations is processed will help teachers to guide their pupils in science.

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