VISUALIZATION AND MULTIMEDIA IN SCIENCE EDUCATION

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Abstract

Pictures, images, graphs and diagrams can be powerful tools for instruction. With computer and multimedia they will be used more often and achieve a rising importance. Illustrations, still and moving pictures can also be designed more easily for special applications. At the same time the question gets more important, how they should be used to promote effective learning.

For its special features multimedia can be used effectively to facilitate the cognitive process of representing imaginable events, actions and ideas. Several applications will be shown and guidelines will be discussed. Especially:

- Directing students' attention in complex systems and focus on important components
- Consider limitations of cognitive load
- Support multiple coding (also by using various kinds of illustration and visualization)
- Use multimodality
- Using hypermedia to present a nonlinear and interactive system to develop adequate knowledge structures (also provide concept maps and mind maps to indicate the relationship among concepts)
- Offer guidance and promote depth of processing.

Findings and first results from online-tests will also be reported.

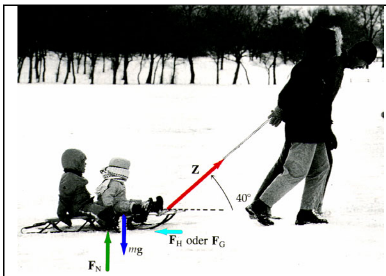
Overview

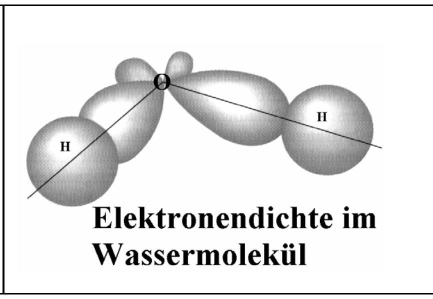
1. To begin with, I want to look at some functional aspects of illustrations.
2. Secondly, I want to point out, that action is necessary
3. Third, while there is great potential, but there are also several requirements to be met.

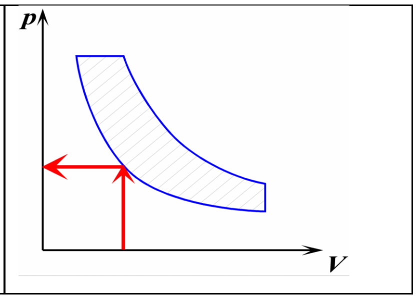
I also want to have a look at the kind of studies and investigations we intend to do.
I want to round off with some findings from preliminary studies.
Generally I will use the word "illustration" as a generic term for images, graphs, diagrams, still and moving pictures or just for any form of visualization.

1. Illustrations – functional aspects

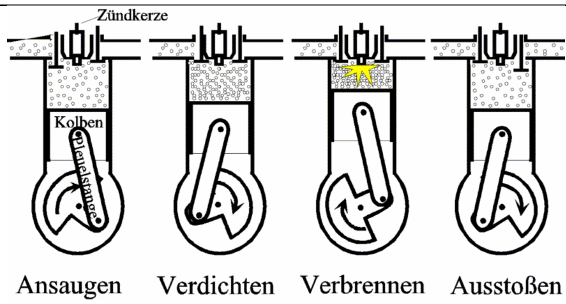
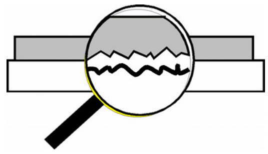
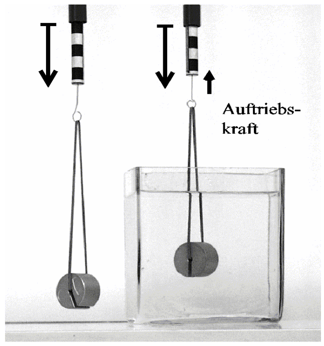
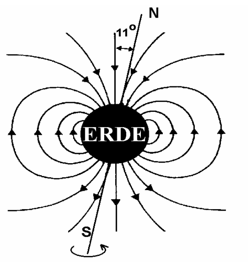
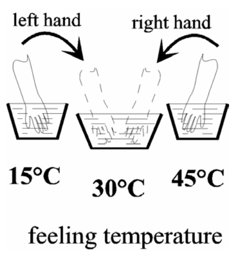
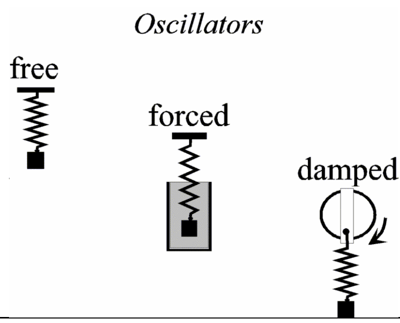
Illustrations can serve different purposes and various types of visual aids can be used to achieve different instructional goals.

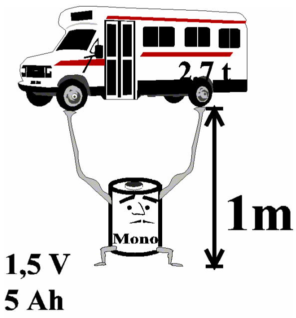






They can build a bridge between theory and phenomenon,
assist the process of imagery in science,
supply data in such a form that you are able to work with them.

They can show how things work – e. g. a combustion engine	
can be used to explain details - e.g. explain a model of friction	
assist us in describing physical concepts (use arrows in pictures to describe forces)	
Illustrate details of a phenomenon that cannot directly be seen	
simplify instructions – e.g. in order to describe hands-on-experiments	
illustrate the structure of a subject area	

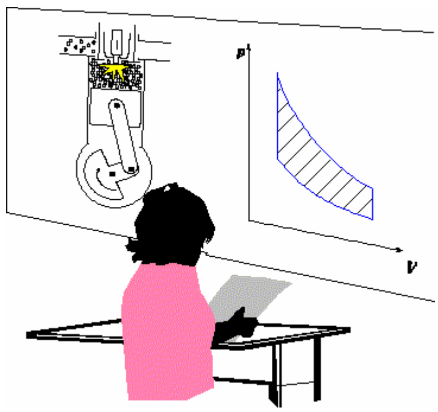
help to remember the results of calculations – by setting a visual remember.	

(For a more detailed discussion see Kircher, Girwidz, Häußler, 2001)

2. Need for action

Illustrations are more and more used in books and especially are and will be the dominant means of expression in modern media.

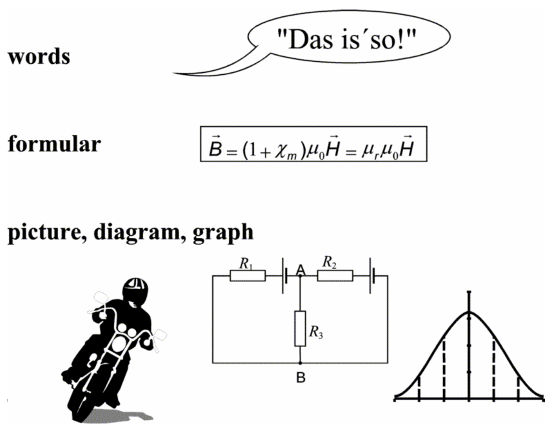
But there is a great difference between the technological possibilities and what we and our teachers know about using them in an effective way. This statement was made by Weidenmann (1998), and I think it is still up to date.
(Sales promotion is to be excluded.)



The development of modern media also necessitates changes that address thinking skills, especially concerning picture processing.

3. Potential and demands

Though pictures are easy to remember and have a lot of potential, they make certain demands on learners. Illustrations as well as words or formulas carry information in certain codes.
Visualization will only be helpful for learners if they are able to understand the symbols used. If non familiar forms are offered, the learners' ability to extract meaning from visual media will be limited.



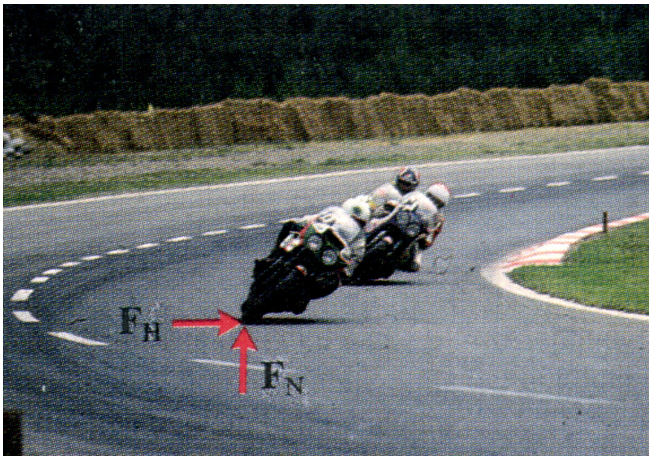
Therefore it makes sense to distinguish between different kinds of illustrations.
I will limit myself to 3 broad categories (suggested by Knowlton, 1966, Alesandrini, 1984, Issing, 1983, 1990, 1994):

(1) Illustrations showing superficial characteristics, like photographs;
(2) analogous pictures, showing things that cannot be seen in reality, like models of an atom;
(3) logical pictures like charts, graphs and diagrams.

Distinguishing between various forms may help to adapt to learners with different levels of ability and local conditions.

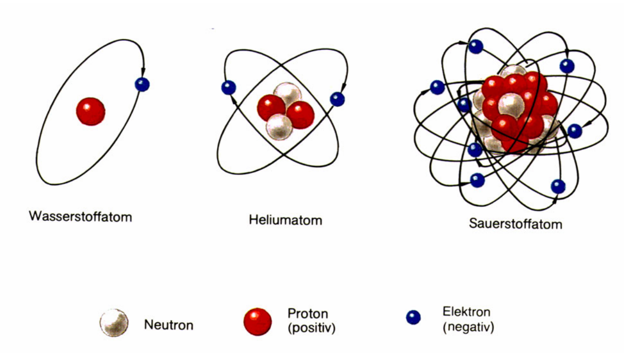
Pictures – reproductions showing superficial characteristics

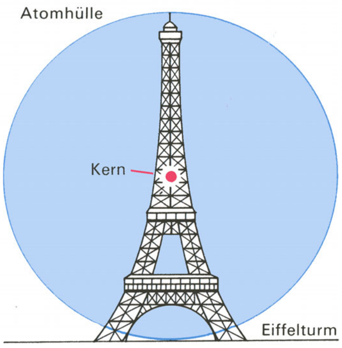
Reproductions (as well as some drawings) show more or less what can be seen in the real world. This is called surface identity. But they also convey information not referring to the intended topic. They may also stimulate emotions. Some male students may be fascinated by riding a motor bike. Perhaps they recognize that the second placed biker in the picture (Tipler, 1994, 107) is cutting the corner in a better way. They may ask whether he might overtake the first one.



In contrast to that, the teacher's intention is to discuss physical aspects. He wants to look at relevant forces. – Certain visual hints may be helpful.

Analogous pictures



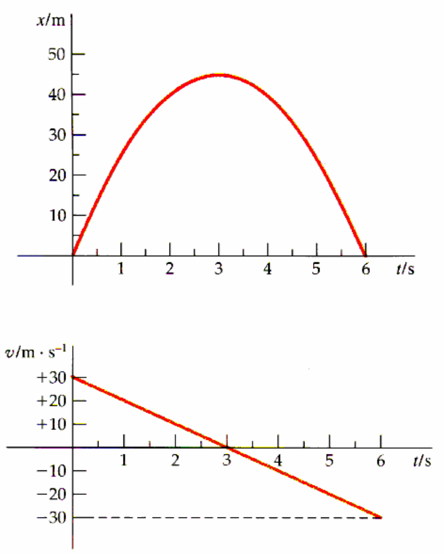


So called analogous pictures illustrate things you will never see in reality. They support helpful imaginations. But they can never mirror reality in all details. Therefore you also have to avoid the risk of giving rise to misconceptions – in this example concerning proportions. Such limitations have to be pointed out

This should not be omitted, even if you have to carry the "Eifel-tower" from Paris into your classroom and compare it with a cherry pit to give an example of proportions.

Logical pictures

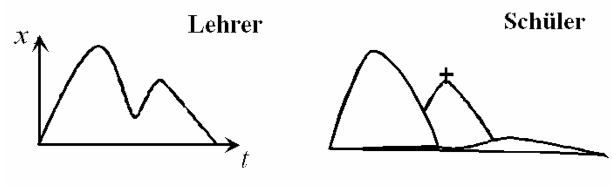
Logical pictures have the highest level of abstraction. They differ totally from sensory perception. Mental transformations are required to extract information for practical use.



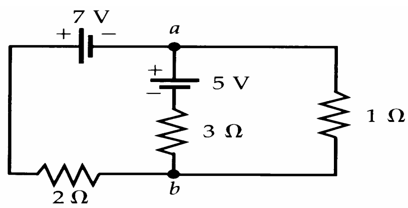
I want to point out a problem by presenting an example not taken from physics:
- What do you see? Don't worry, it is not a psychological test. It's just a map, view rotated by 90°. This shows that habit is quite an important factor when working with pictures and illustrations.

Various difficulties may occur:

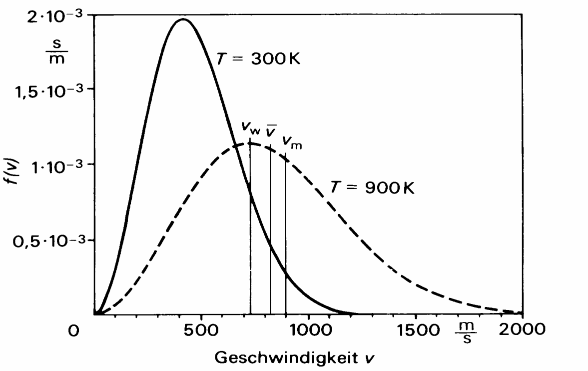
* Difficulty in coping with a presentation, as we've just seen – the teacher shows an abstract line graph – but pupils see two hills. (May be this example exaggerates a little bit, but there are problems in this field.)



* Symbols may look strange to students

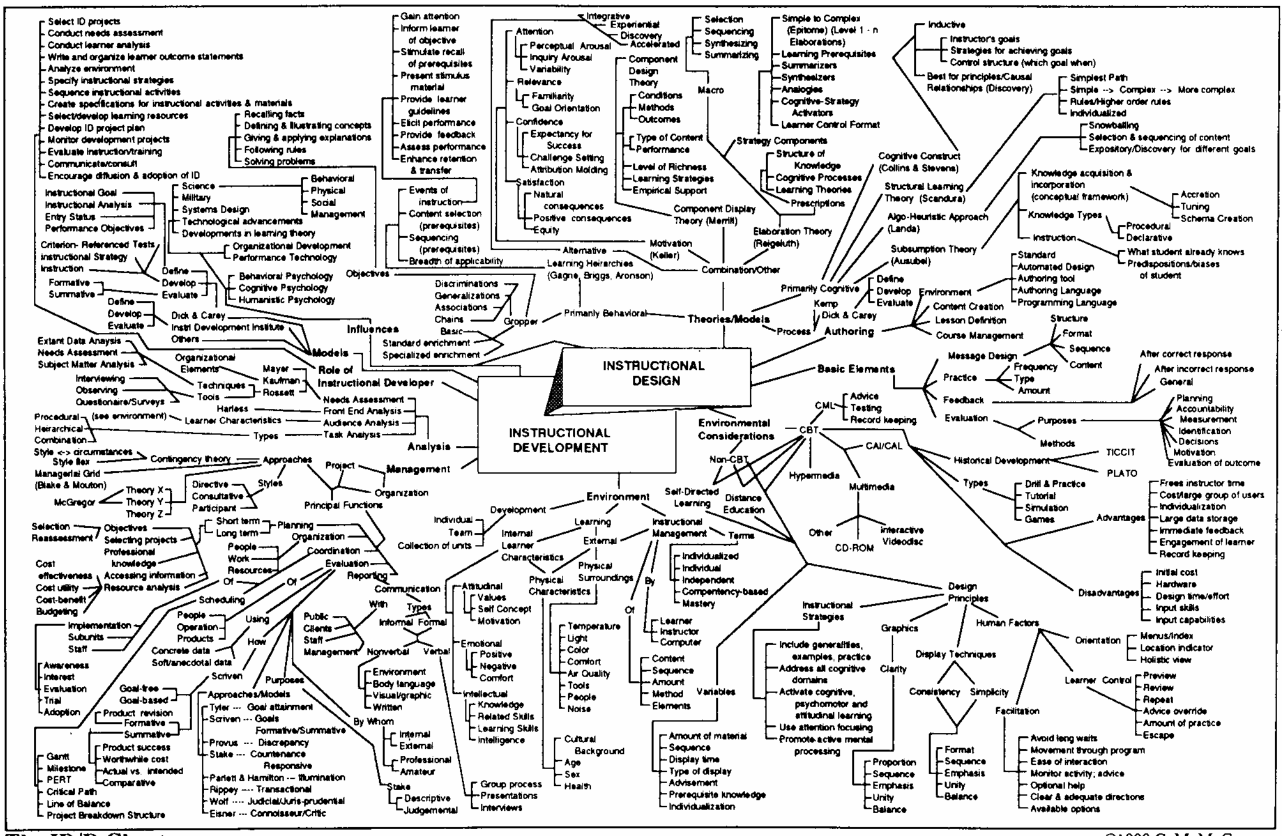


* May be working methods are not well known (this means extracting values, identifying characteristics, comparing developments shown in curves)



4. Empirical studies and investigations

Do children use adequate thinking skills and strategies in their picture processing? Results indicate that there are not only problems in processing information presented in diagrams. What are cognitive skills that are required? Are there key qualifications that should be trained? It should also be tested whether students internalize content and concepts embedded in a science multimedia computer program or use it merely as a game to be played. Conditions and possible support should be analyzed.
How can we investigate relevant factors and optimize applications especially using multimedia? No problem – just have a look at theories that reveal basic factors for instructional design (e. g. the ID-Chart, Connop,-Scollard 1991). You see, it is not even possible to read them all – not to mention to take them all into account.

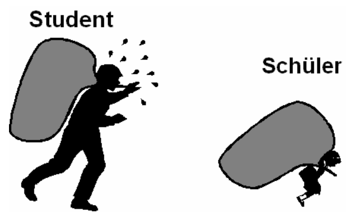


The ID/D Chart ©1990 C. M. M. Connop

(Connop, 1991)

Our concept is just to look at the most important factors. In sports and medical science these are called the "limiting factors".

I made some preliminary tests with students at the university to find out some limiting factors. The assumption is, that requirements that are not easy to cope with for students are bound to cause problems for pupils.



We intend to relate the findings to theories of learning with a view to using the insights gained for designing multimedia applications.

I will try to explain this by some examples from preliminary studies.

5. Examples, line of vision

Because of its special features multimedia can be used to facilitate the construction of mental models by working out imaginable events, actions and ideas. Different kinds of representations and authentic contexts can be helpful. There are some guidelines that should be considered, but in general these should also be studied more precisely:

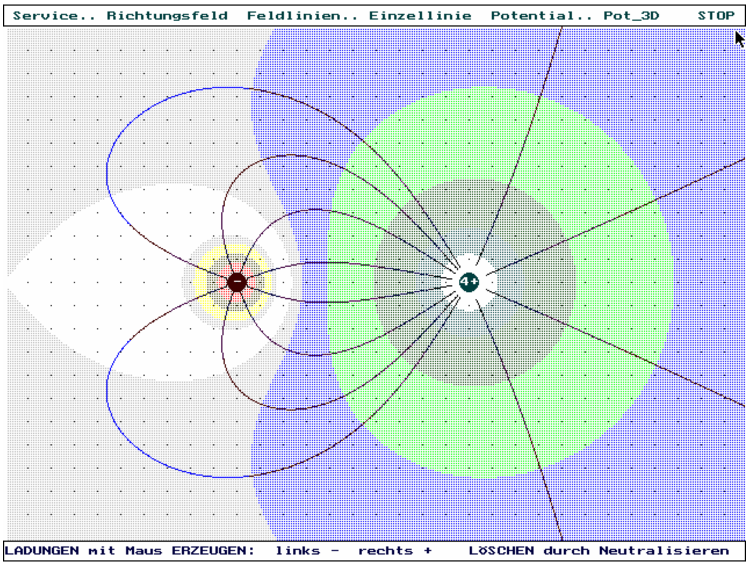
1 - Direct students´ attention within complex systems and focus on important components

First, let me show you an example, not taken from physics:

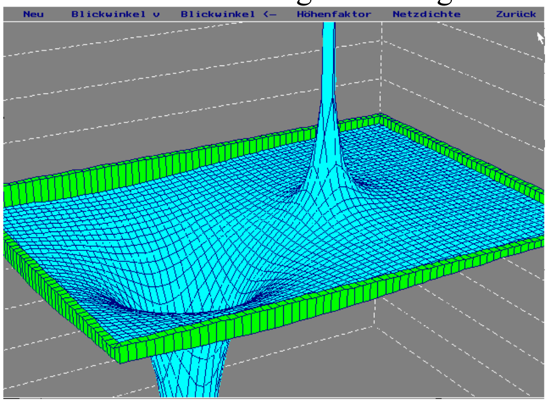
What are the details shown on a 10 euro note? If you are not sure about it, this is certainly not because you haven't had the opportunity to see it. But usually other things would absorb your concentration, may be the article you bought.

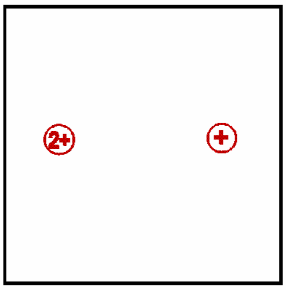
I had a similar experience with a program that draws characteristic of an electric field (lines of force, equipotential lines and so on). Students could create their own configurations of charges.

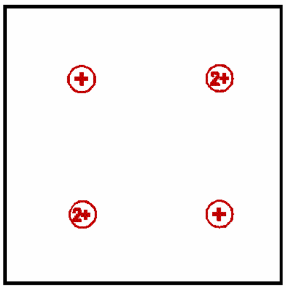
A special version of this program which logged all activities, I gave to students who came to a lecture at the university.



Learning with this program was not effective, at first. This was revealed by a test. Students had just created beautiful images with high towers and deep holes.

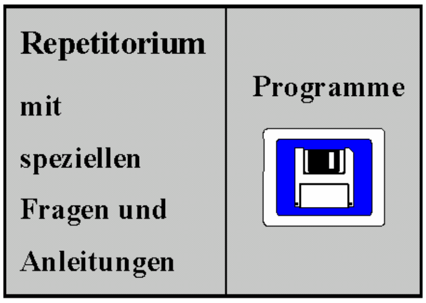






But after the test the log files showed a behavior that had totally changed. The work was really goal directed and students studied those configurations they had had difficulties with in the test before.

As a consequence we combined programs with a text that contained questions, proposals for work and additional information to support goal directed work.

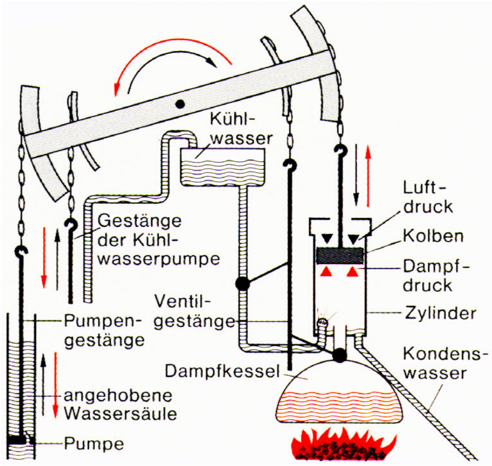


Also an online poll concerning short films showed a similar result. The suggestion made most frequently was: Give us still more assignments and ask more questions.

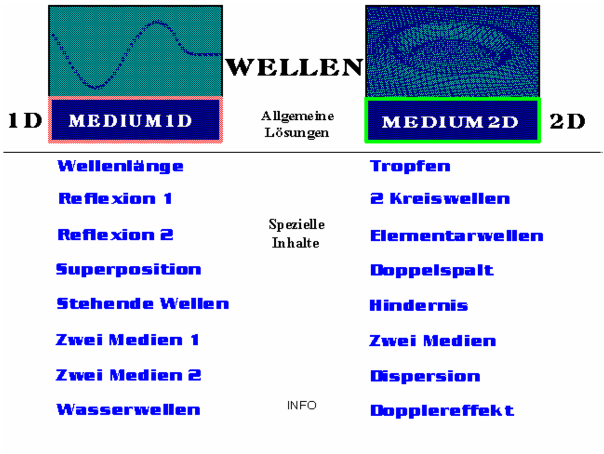
2 - Consider cognitive load (provide an adequate flow of information)

Eveis a ekil ton si daeh ruoy.

Would you please bear this sentence in mind and listen to me, too. But don't look as disappointed as this man, I will show you how to remember the sentence easily, later on.



But the problem points to the limitations of our working memory.
Cognitive load may also become a problem when pictures are presented. They can offer high density information (see picture from Stiegler, 1986, S.121). In particular they offer different kinds of information simultaneously in contrast to a text that promotes sequential processing. (By the way, that's a basic difference between text and image.)



How can we avoid cognitive overload?
One possibility is the single concept principle. This means focusing on one fact only.
There are some implementations relating to mechanic waves. For example "standing waves" can be regarded as a combination of one wave traveling to the right and one traveling to the left.
Another topic is the superposition principle, meaning that waves can propagate through one another without disturbing each other.

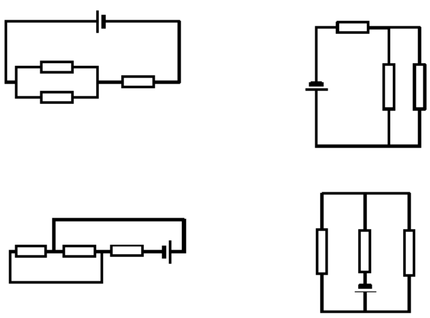
Certainly there are more possibilities to cope with limited cognitive resources. However further research is needed.

3 - Support multiple coding (also by using various kinds of illustrations and visualization)

Let us return to the sad looking man. In the meantime he has made an interesting discovery. Read the sentence backwards, from the end to the beginning. Now you won't have any problems remembering it.

 **Eveis a ekil ton si daeh ruoy.**   **Your head is not like a sieve.** 

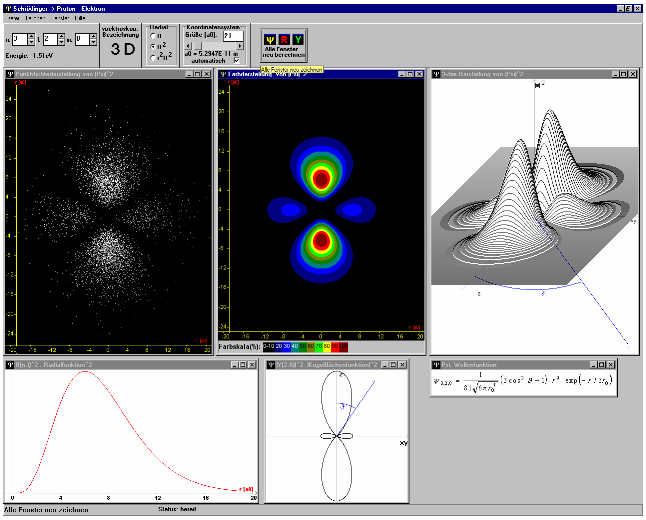
For problem solving it is often necessary to change the description and to be able to cope with different coding. – The key concept is multicoding of knowledge.
Just let me show you an application for school:



Novices would say that these are different electric circuits. By using very simple transformations the computer can show us that they only appear to be different. It is just the superficial structures that differ. For the physicist these are the same circuits.

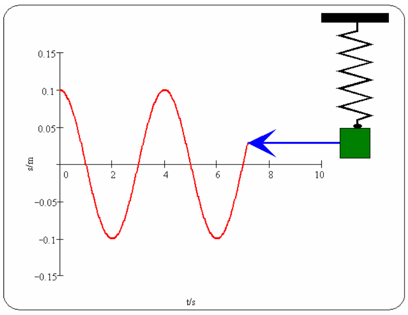
This example shows that knowledge should not be dependent on one kind of representation only.

This was also one of the ideas why we created this program. You can select different forms of description for an atom and also juxtapose and compare them.



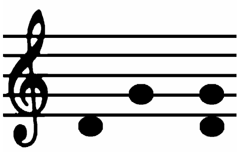
Multimedia-applications can also help to show how different presentations are connected with one another.

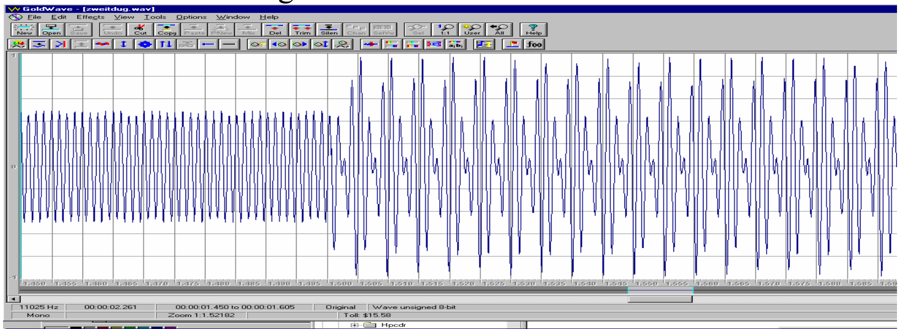
According to the "supplantation principle" (Salomon, 1979) a mental operation, that causes a problem for students, can be demonstrated by the machine. In this example the relationship between the movement of an oscillator and its registration in a line graph is shown.

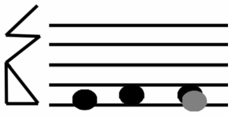


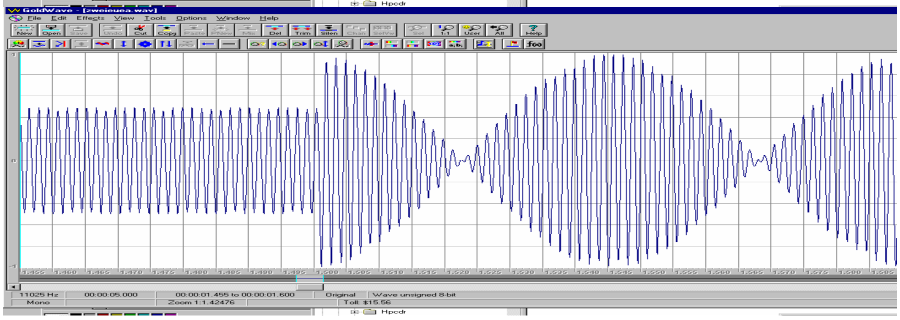
4 - Multimodality – using more then one sense for input

Utilizing multimodality means using several channels of information, ears and eyes for example. Today a soundcard belongs to the standard equipment of a computer. This offers attractive possibilities for teaching acoustics. So you can interrelate what you hear and how this is described on a sheet of music or in physics.
Now I play 2 notes, at first one after another, then both together. If your ears are o.k. you hear two notes (even though the loudspeakers are too small for this room).
The second example also consists of 2 notes, but the difference between them is small (only one half of a halftone). This is not used in classical music and you will soon hear why. (I even had to invent a new clef for this example.)
Our ears cannot resolve this combination into single notes and we hear what is called a "beat".

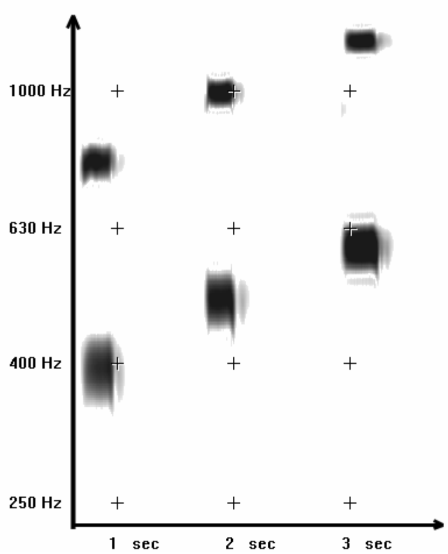








The diagram (a graphic presentation) can explain this. In the second case the changing of the amplitude can be <u>seen</u> clearly and can be <u>heard</u> as a beat.

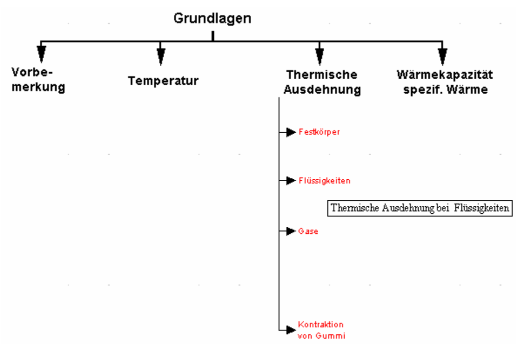


Conversely you can also play music and analyze it. In the next example you hear 3 tones played on a flute. A computer program can analyze the frequencies and display the frequencies over time in a diagram. I suppose you will be able to see some analogies between the presentation on the left and the sheet of music on the right.
Of course, in the strict sense there are some differences that should be discussed if we want to arrive at a deeper understanding of music. Still, such an arrangement, using multimodality, is a first step.

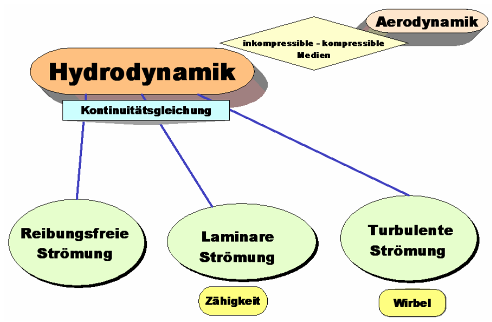
5 - Develop adequate knowledge structures

Let me speak about another important topic – structuring knowledge.
I presented several short films to students. They had to categorize the events observed. A catalogue of categories was given, adjusted to the lectures heard.
But the results were disappointing. Even the students pointed out the need for presenting still and moving pictures with attendant information that supports structured learning.
Different methods are possible:

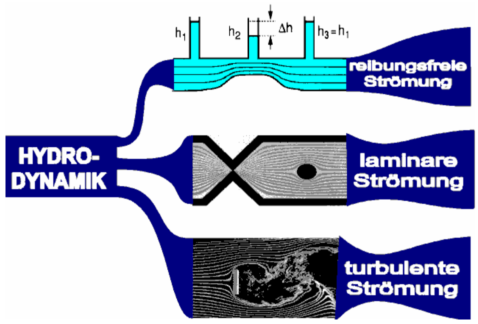
* Charts – may be they expand when the mouse pointer touches a certain field,



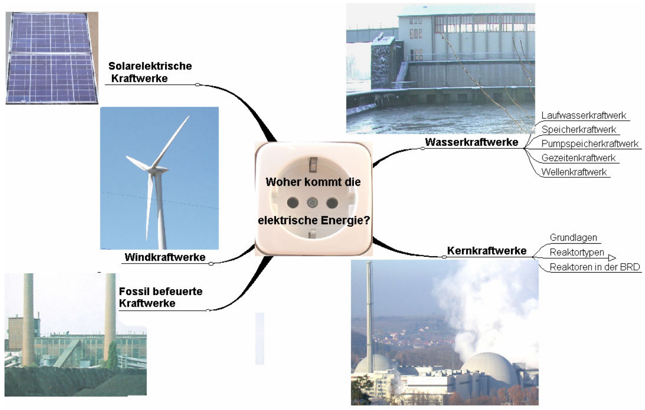
* Graphic arrangements



* Arrangements also using pictures taken from experiments



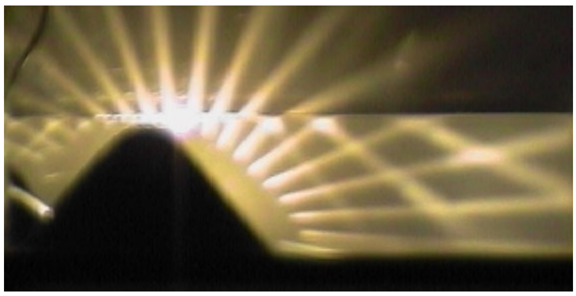
* Mind maps, may be supplemented by photos and films for showing examples.



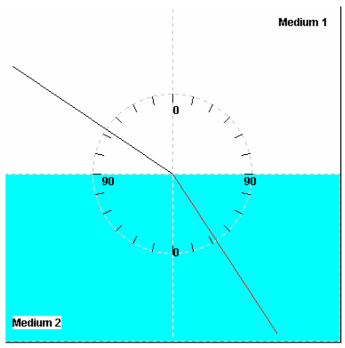
Promote depth of processing.

Multimedia can also assist a deeper processing. Among others discussing applications and connections has proven to be highly useful.

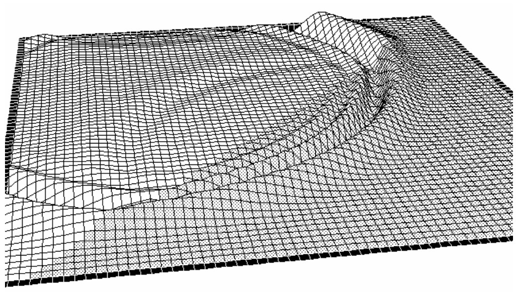
* Experiments real or simulated have to be done to derive laws.



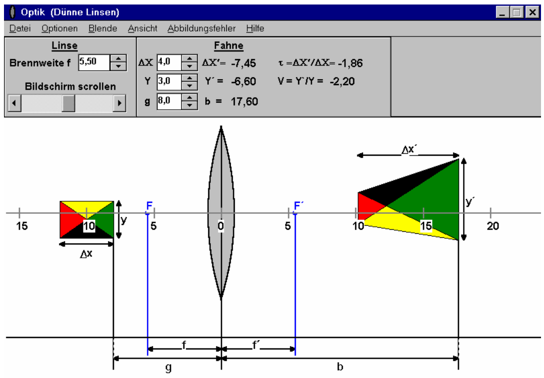
* Facts will be simplified at first (for example neglect reflection when regarding refraction of light).



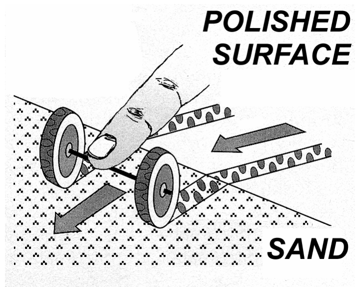
* Transfer to neighboring disciplines e. g. mechanical waves (water waves) can supply feedback and show whether basics are understood.



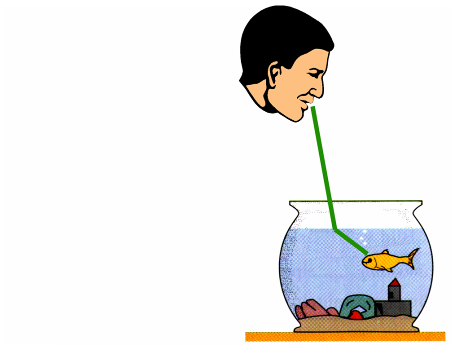
* Simulations and calculations for practice make knowledge applicable.



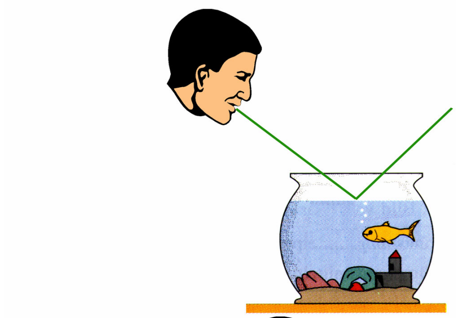
* Of course model experiments that reveal basic principles should not be missing. The experiment shown was suggested by Mach (in about 1920). It reveals that a change in velocity is fundamental for refraction. The vehicle goes from one area, where it can move with high speed into the sandy area. The left wheel will slow down first and the direction of motion will change.



* As soon as it is revealed that a change in velocity is fundamental, this knowledge should be applied when answering questions. You can also use pictures to make this attractive: "Why is it so hard to communicate with your ornamental fish? This is indeed, among others, also a problem of refraction. The velocity of sound in water is about 5 times as high as it is in the air. Therefore the sound is refracted like it is shown in this picture

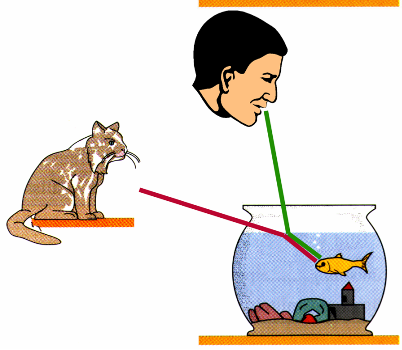


You have to speak from top down. (May be this appears unacceptable arrogant to the fish.) But if you do not, all your words will be reflected at the surface of water.



Actually the situation is still more complex. If the fish wants to see, who is speaking to him or her, he looks in the direction where the words seem to come from.

As the velocity of light in water is smaller than in the air the refraction is the opposite of that of sound and the fish can't see you. In the worst case, and this is, as you all know the normal state in physics, he sees a cat wanting to eat him. So his distrust towards you and your words will increase even more. (So you really should not try to speak to an ornamental fish.)



6. Summary

Of course our applications will be more serious (in most cases). We want to investigate important conditions for the use of illustrations, particularly:

- Direct attention
- Cognitive load
- Multiple coding
- Multimodality
- Structuring
- Depth of processings

I wanted to arouse your interest. Our project will start in autumn, it will integrate biology, mathematics and computational science and it will be aimed at 8th and 9th graders. We would be very pleased, if you are interested in such studies, and it would be nice to find possibilities to work together in this field.

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