To learn a complex concept is to keep more than one concept in focal awareness simultaneously

- an example from electrical engineering

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INTRODUCTION

In electrical engineering, as in most engineering areas, it is important to be able to model complex concepts and understand how these are linked together. The concepts concern different knowledge domains that need to be linked together. These links are not there just to learn, but need to be made by the students. By making links the concepts involved are possible to keep in focal awareness simultaneously, which is a necessary condition for learning.

1 GENERAL

To learn in a holistic way, requires that the student keeps concepts in focal awareness, i.e. is aware of the parts and relates them simultaneously [1]. It is important to be able to switch between the parts and the whole in order to learn. The purpose of lab-work in science and engineering is to link theory to the practice: the practice of experiments in science and the practice of design in engineering. However, this is very seldom made explicit in lab courses. [2] and when engineers enters their industrial career they “have to relinquish the theory knowledge from their university studies, since the students are not equipped with the knowledge how to use those theories in practice.“ [3, p. 82].

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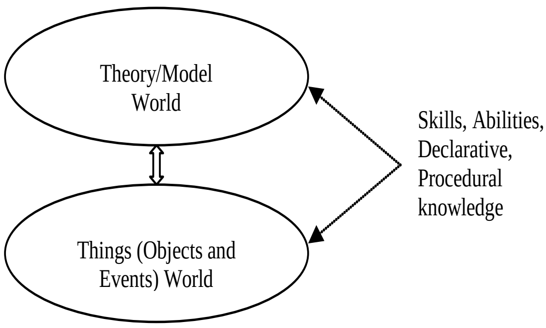
"In many fields of engineering the notion of a *model* is problematic and students can confuse the model with the phenomenon that is being modelled, with consequences that vary from area to area." [4, p.16], and Malmberg [3] suggests that students should learn to understand models, and to understand when to use different models. In line with Aristotle [5] he claims that to apply theoretical knowledge (episteme) to the practical knowledge (techné) is to make choices of which knowledge from both domains that are appropriate in the new situation (phronesis). In our research we show that this is to *make links* between the theory/model world and the object/event world.

2 METHOD

Building on Tiberghien [6] we have developed a tool to analyse "the learning of a complex concept", and used it to analyse the links made or not made by the students, in two labs in an electric circuit course in the first year of an electrical engineering program. We have video recorded the students during lab-work, and the analysis of the recordings led to our model, which could then be used to analyse what links that are necessary to make, what links students made and also to see what it takes to make the links that some students made and some did not. The difference in students' actions was the focus of this analysis.



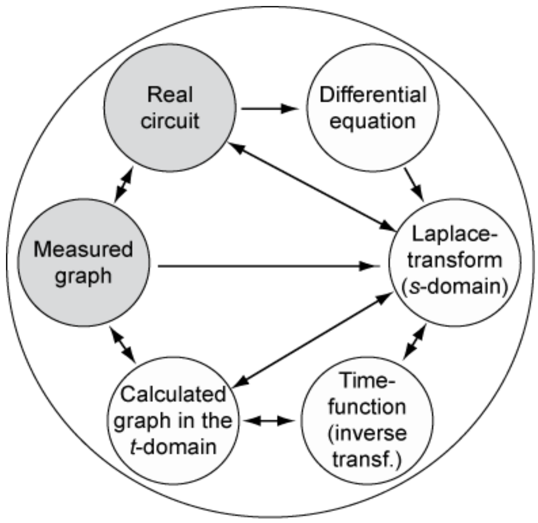


Figure 1a: Categorisation of knowledge based on a modelling activity [6]

b) The model of learning of a complex concept [7],[8]

Tiberghien has used "the theory of the two worlds" when modelling several different concepts in physics education in order to develop teaching sequences, where the links between the two worlds are made explicit. See e.g. [2] and [9]. We have taken this idea further working with more complex concepts, where several concepts as well in the theory/model world, as in the object/event world are modelled. First we modelled students' actions (including talk). We analysed what students did as well as what they did not do, i.e. what links (arrows in the figure 1b) they made between the concepts (islands in the figure above) as well as which links they did not make (which concepts that were not linked and thus arrows not drawn). Example of missing links were the arrows across the circle: the arrow between the measured graph and the Laplace transform (transfer function in s-domain), the arrow between the calculated graph and the Laplace transform and the arrow between the real circuit and the Laplace transform. The only links between the two worlds were thus the one between the real circuit and the differential equation, which very few students noticed, since they usually do not reflect on theoretical matters during labs, and the arrow between the calculated and the measured graphs, which were the focus of the practical task. This analysis led us to make two changes: To make students solve theoretical problems in the same sessions as the practical, so called integrated problem-solving sessions [8] and to add simulations into the lab-tasks. Both new tasks were very systematically varied according to variation theory [10]. Now we have taken this further and analysed the links more thoroughly.

3 RESULTS

By analysing the students actions it was obvious that the links between concepts in a complex concept are constituted by something to do, either measure, simulate or calculate, and that what is usually called “apply mathematics” is not just to apply, but to keep particular concepts in focal awareness simultaneously. We have explored the links in one of the labs the transient response lab thoroughly in a recent paper [11]. Here we will compare what it takes to learn the two concepts by comparing what actions that are taken. What choices of actions make students focus on concepts in a way that makes them see the whole complex concept and not just the parts?

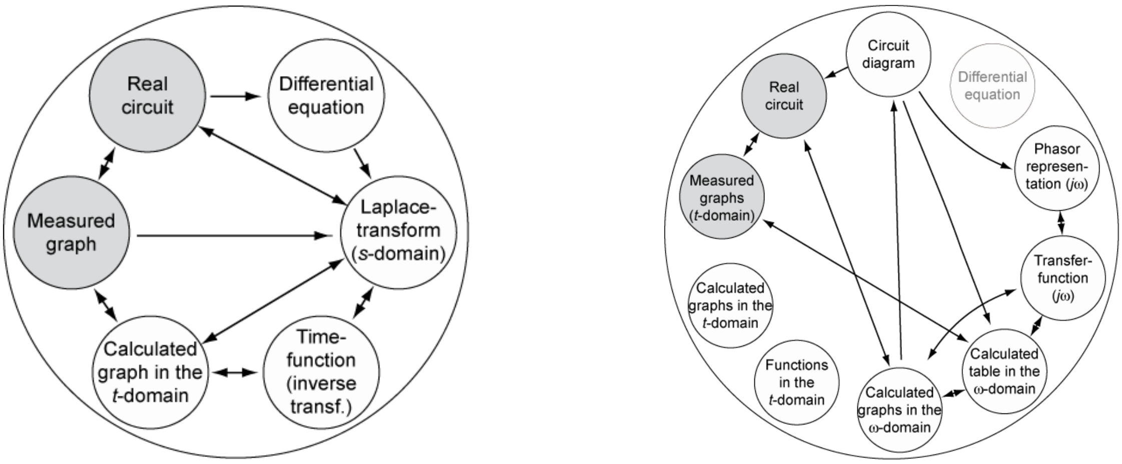


Figure 2a) Benny’s and Tess’ lived object of learning at the end of transient response lab [10] [11]

b) Adams’ and Davids’ lived object at the end of the frequency dependency lab.[12]

Figure 2 shows the lived object of learning, i.e. what the students become aware of and thus change their ways of seeing [13] [1]. In the transient response lab (figure 2a) none of the arrows across the circle were noted when analysing the old course. Most of the groups concentrated on the link between the measured and the calculated graph, which was the explicit task of the lab. However, it was expected that students should bring knowledge from the lectures, e.g. the different types of functions that would be appropriate to use for calculation of graphs, but this was not the case. In the new course students first simulated systematically varied transfer functions, and explored the calculated graphs (the arrow from the Laplace transform to the calculated graph), they were able to keep these in their awareness when making the measurements (first connecting the circuit, then measuring, receiving the measured graph, thus the arrows from the real circuit onto the measured graph). This made it possible for the students to compare the measured and the calculated graphs (called make a curve fit), and find out which functions that were appropriate (the arrow between the measured and the calculated graph). Thus to realize that only a subset of learned mathematical functions would be appropriate for this type of measurement came into focal awareness. The awareness of possible functions also made it possible for them to do the required calculations – to go from the transfer function to the time function and onto the calculated graph. Thus all the concepts in the circle was held in the students' awareness simultaneously and made it possible for them to see the transient response in a new way, i.e. they had learned the whole concept - transient response

In the frequency dependency lab (Figure 2b) the tasks were ordered in a way that the students should make links between the calculated table of the amplitude and the measured table, make links between the calculated graph and the measured graph, and not only as in many other labs between the two graphs. In the old course the link between the two worlds was only the link between the two graphs, and thus again in the old course only the links on the circumference of the circle were possible to make for students.

4 CONCLUSIONS

The modelling that is required in order to "apply mathematics" is in one sense similar in the two labs, since it requires wellknown mathematical concepts. However teachers often complain that students cannot apply these, and both students and teachers talk about the poor mathematical skills. After analysing what different actions students need to take, and what concepts they need to focus on in order to take these, another picture occurs – it is important to make the students focus on the relevant combination of concepts when making the links, it is important to discern critical features of each link, and when they do, the mathematics is no longer the problem, even if it still may be lots of tedious calculations to do.

We can also conclude that it is important to give the students clues or hints about what kinds of results that are possible, in order to make them do the maths, in terms of threshold concepts – enter into the liminal space. These clues can be found by studying the discrepancy between the intended object of learning and the lived object of learning, terms used in variation theory. In the two labs described above it was important not only to make links on the circumference of the circle, but to facilitate for students to make more links that transcend the worlds. The direct links between the calculated table and the measured table, *and* the link between the calculated graph and the measured graphs were both important in order for the students to get a richer view of what frequency response is. To be able to choose which aspects to focus it is important that students are shown that there are choices to make, and that certain choices are more efficient than others. This is what modeling in as well design as in science is about. As well Malmberg [3] as Tiberghien [9] discuss when they talk about the modeling required – both the modeling of the phenomena (the theoretical constructs) and modeling of the tasks (what paths to take in order to make links) are important in order for students to keep related concepts in focal awareness simultaneously, thus learn a complex concept and gain the phronesis necessary to "apply theory to practice"

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