Keys to learning in specific subject areas of engineering education – an example from electrical engineering

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Abstract

"Most previous educational research on university teaching and learning has looked for generic principles, which could then be used to inform practice"[6]. Research in engineering education has for example dealt with the alignment of assessment to the curriculum or progressive teaching/learning environments. Through research in specific subject areas it has been shown that there are specific "ways of thinking and practicing (WTP) in each subject area" (ibid).

In science education the focus has been on students' views of single concepts. One of the common objectives in science and engineering education is "to learn relationships".

In our research we have been investigating what we call complex concepts, i. e. concepts that make up a holistic system of "single" interrelated concepts. As in many disciplines we find "threshold concepts"[9], concepts which are *transformative, irreversible, integrative* and *troublesome*[11]. These concepts are often recognized by teachers in a field, but we also suggest that it is possible by research to find "*key concepts*", but not in the sense that the term is often used in some educational contexts, as interchangeable with 'core' concepts, and meaning simply that the concepts are an important part of the prescribed syllabus. Here we use the term as a more precise metaphor to mean that the concept in question acts like a key to *unlock* the 'portal' of understanding. We use variation-theory [8] in order to find "*key concepts*", critical aspects that can act like a key to unlock the portal of understanding.

In our paper we will describe how we have designed labwork in an electrical circuit course, taking the ideas behind *threshold concepts* and *key concepts* into our specific topic Transient Response as one example of how research into specific subject areas is made possible through qualitative research.

Keywords: threshold concepts, variation theory, capability-driven curriculum, electrical engineering education

1. INTRODUCTION

Research in engineering education is a growing field, especially since the number of students going into the area in many countries is decreasing. Some areas which have been the focus are aligning assessment to curriculum, new teaching methods, generic skills and program development. All of these areas have been, and still are, of great importance. But, the learning is always a learning of something[8], and to switch from content-driven curriculum design, to a design where content is not discussed at all is to go from one ditch to the other. Bowden[3] suggests capability-driven curriculum design, where content and capabilities are not separated, different pieces of content not taught as isolated islands, but where relations between the different pieces of knowledge is in focus. To adopt this view, "you need to determine the programme goals first (the intended capability outcomes), then the course goals, then the necessary learning experiences and, only then, the teaching plans" [3](p. 45).

In variation theory there is a distinction between 'the intended object of learning', 'the enacted object of learning' and 'the lived object of learning'[12][12], i.e. between what is planned, and what is actually opened up to the students, and what they really learn. Thus by studying what the students do during lab-work it is possible to see how the intended and the lived objects of learning correspond, i.e. whether the goals set up are possible to

meet, or changes need to be made. As well what the students see as what they do not notice are results to use in the development of new instructions.
In many fields of higher education it is possible to recognise ‘threshold concepts’[9][10], concepts that are *transformative*, *irreversible*, *integrative* and *troublesome.* These concepts are of special importance, since a deep understanding of them is necessary for learning other concepts. Examples investigated are e.g. recursive functions in computer engineering[2], and opportunity cost in economics [7][7]. All of these are difficult to learn, and if not learned in a deep way, they hinder the students from learning following topics. In our research we have found ‘transient response’ to be a threshold concept, but we have also found the ‘critical aspects’, aspects necessary to vary systematically, through variation theory. We have therefore suggested a distinction between ‘threshold concepts and ‘key concepts’[5], not in the sense that the term is often used in some educational contexts, as interchangeable with ‘core’ concepts, and meaning simply that the concepts are an important part of the prescribed syllabus. We use the term as a more precise metaphor to mean that the concept in question acts like a key to *unlock* the ‘portal’ of understanding, the ‘portal’ which opens up for learning of other concepts.
We have developed a model, ‘the model of learning a complex concept’, which we have used in three different ways, firstly to identify what is troublesome for the students, secondly to find out what needs to be changed in order to open up for learning, thirdly to identify the changes in students' actions in relation to our model [1].

In the paper we will describe how we have developed the model, and how we suggest it may be used in other areas of engineering education research.

2. METHOD – DATA COLLECTION

We have videorecorded the labwork carried out in a first year university course in electrical engineering. The first year (2002) there were 13 two-hour problemsolving sessions and 13 two-hour lab-sessions. The second year (2003) there were 9 four-hour integrated sessions. In both courses there were 13 two-hour lectures. Our focus has been the lab concerning transients, the next to the last lab, and by most students considered very difficult to understand, but also the lab where we saw the largest differences between the old and the revised course. This part of the curriculum was in the former course appointed 2*2 hours for problemsolving and 1*4 hours for labwork, and in the new course 2*4 hours integrated sessions, thus the same amount of time was appointed for this subject both years. The changes in the problems to solve during the sessions were very small but systematic [4] (see also the appendix for the examples). The instructions for the labwork integrated theoretical issues (mathematical), simulations, and measurements, aiming at pointing out some links that were not made by the students in the old course.

3. RESULTS – DEVELOPMENT OF A MODEL OF LEARNING A COMPLEX CONCEPT

Tiberghien and co-workers (e.g. [13], [14] and [15])categorize knowledge into two domains: the object/event world and the theory/model world. This dichotomy has proved very effective when analyzing and developing lab-instructions. She points out that it is important in education to make explicit the links between the theory/model world and the object/event world**.** When learning complex concepts there are as well more than one concept in the theory/model world, as there are more than one in the object/event world. Very often these concepts are taught in separate courses, e.g. differential equations in maths courses, but even when they are mentioned in the same course, the students may not ‘make links’, i.e. find relations between them, and the result is knowledge as isolated ‘islands’. Building on Tiberghien’s work we tried to identify which concepts that belonged to the object/event world, and identified the real circuit and the measured graph. We also identified the differential equation, the transfer function, the time domain function and the calculated graph as concepts in the theory/model world. The arrows are what the teachers would consider intended links to make. Often the teaching follows the circle, i.e. from the real circuit the differential equation is derived, then transformation by means of the Laplace Transform is carried out, from the transfer function the time domain function is derived by means of the inverse transform, and then a graph is sometimes derived. In the lab, the students measure the graph, and are asked to compare the calculated and the measured graphs. They are also asked to try to find out which mathematical expression that will give the same calculated graph as the one they have measured. This is done by means of a real time measurement program where it is possible to get graphs from measurements as well as doing “curve fits”.

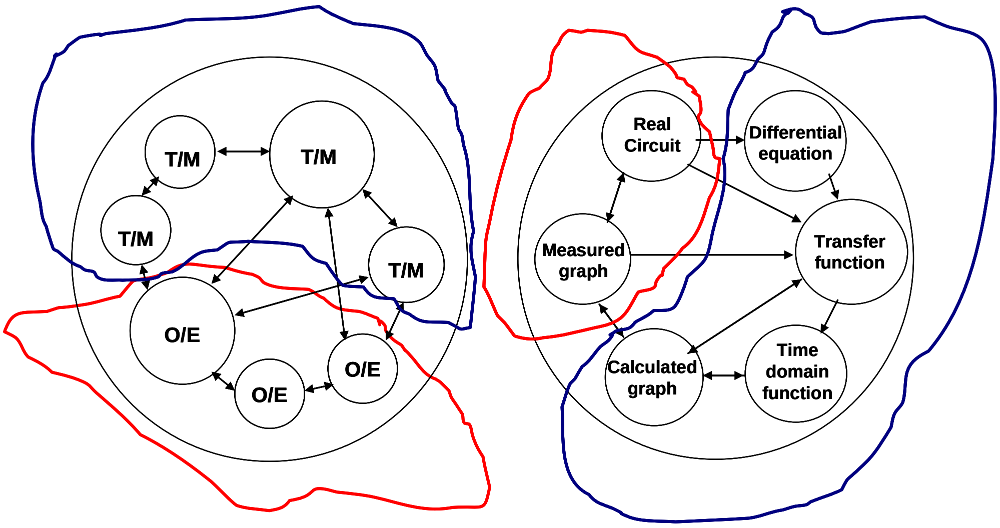

Figure 1. Our model – *Model of learning a complex concept* – and the model translated into the example in the Transient Lab

In the course 2002, the links that students actually made were very few, and all followed the circumference of the circle. Since the most difficult relations to understand are those where the boundary between the two worlds cross, few opportunities to link the worlds are opened up. The changes in the lab-instructions that were made were:

- Simulations of systematically varied examples (see appendix) of transfer functions were suggested – the link between calculated graph and transfer function was explored
- The students were explicitly asked to figure out the transfer function from the measured data (which in the lab-environment are presented as a graph) – the link between the measured graph and the transfer function

In 2003 the revised instructions were used and the conversation was totally different. Of course students still ask questions, but the questions are more informed, especially towards the end of the lab.
An example of how the links can be explored through the students' conversations focuses on Tess and Benny, students 2003. Tess has been doing all the calculations, and Benny has worked on the simulations. After about 40 minutes they are supposed to wire up the circuit**,** and they read:

```
Tess:    "Wire up the circuit"                    (reads from instruction)
                                                  (turns her head towards B)
         It seems taken for granted
         what circuit he talks about
Benny:   Yea, we'd better read this again
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The gap in understanding may be illustrated by the circle which shows the relationships that the students now had been working on:

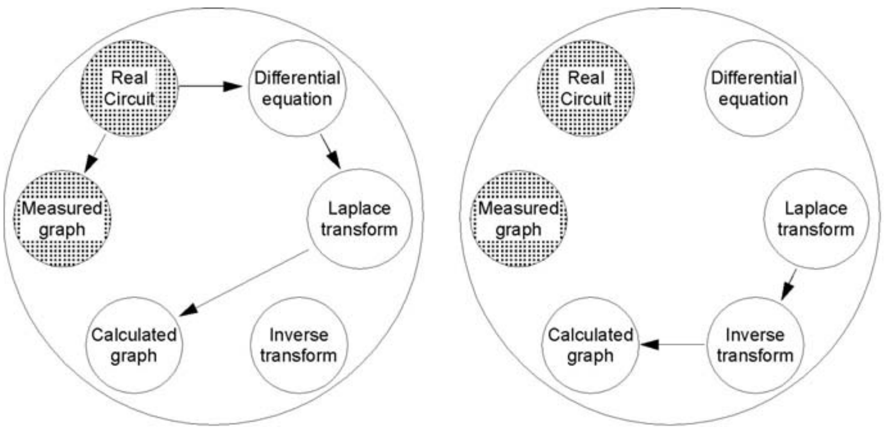

Figure 2. a) Benny's "lived object of learning" in this first part of the lab session
b) Tess' "lived object of learning" in this first part of the lab session

In this part of the session**,** Tess and Benny encountered different “objects of learning”. At this point, neither of them is thinking about the real circuit, because in order to do so they have to make links back: Benny from the graph and Tess from the mathematics.

One often recurring question during the first course is "Is this good enough for the report", a question which shows that the students do not know what to expect, and we can see from the students' discussions that this is due to the lack of links made between different objects of learning. In the new course this question is not raised at one single time, and we can refer that to the way the students do establish links between theory and the real circuit in the new revised course.

In the first course, many students do not know how to attack the problem at all. They ask for help e.g. what formula to use for the curve fit. As exemplified in the appendix, there can only be two types of solutions; a damped sinusoidal function or a function of the sum of two negative exponential functions. The teacher wants the students to find these equations by calculations and states: “Just calculate the poles to the expression and find the function to use”. The students notice this expression, although they do not understand it, which is indicated by two actions; firstly they repeat the quote from the teacher: “Just calculate the poles to the expression and find the function to use”, at several times during the rest of the lab, and they show a hesitation to start doing any calculations. This hesitation is in the new course totally gone; as soon as the students have tried a few simulations some of them start to do calculations, by use of notes from lectures.

4. CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

In this part we will discuss the relevance of the model, and how it may be used in other subject areas to inform course development, particularly lab-instructions.

4.1 Questioning the model

The transitions from the real circuit to the differential equation, and on to the transfer function, through the inverse transform to the time domain function and on to the calculated graph, can be considered ‘obvious’ or ‘self-evident’, but we have never seen anyone describing ‘the object of learning’ in such a way before. Therefore we conclude that the circular paradigm is not self-evident, but is perceived in that way because the links between the ‘islands’ are taken for granted, and are therefore not made explicit during teaching.

There is always a possibility that the ‘islands’ in the circle should be labeled differently, and that there should be other ‘islands’ in the circle. However, we claim that these are the ‘islands’ we can notice when listening to the students’ discussions. One question often stated, is whether the calculated and measured graphs should be one or two ‘islands’. A stated aim in the lab is to: “compare the measured and the calculated graphs”, or later on: “use the curve fit function in the program, enter the math expression, and vary the parameters until you get a curve that looks as your measured graph”. Thus also the teachers view the graphs as different categories.
Another question might be whether the real circuit and the circuit diagram ought to be two different ‘islands’, but in the lab we never see the students making any distinctions between the two. When they have questions about the circuit, e.g. in the question above: “What circuit?”, they only ask this because they don’t remember that they have seen a circuit diagram, and not that they would have problems interpreting what to wire up when the see the diagram.

A question that may be discussed and investigated further would be what kinds of relations that the links may represent. The links we have suggested are pragmatically derived from the students’ conversations, but they are of different types. The one between the real circuit and the differential equations is ‘physical modelling’, the next two are mathematical derivations, first using the Laplace transform and then the inverse transform. Next link is to draw a curve from the mathematical expression, and going in the opposite direction, derive the expression from the given curve (which is new to many students). The link between the calculated and the measured graphs is an interpretation, the students’ skills in recognising different parts of a graph stemming from different functions such as exponential and sinusoidal functions in combination. The last link is the one between the real circuit and the measured graph, which comprises skills such as the use of the computer as a data collection medium, as well as the knowledge about where to connect the measurement instruments.

Also a discussion on whole-part relationships would be useful, e.g. when considering transient response as one single island, where other islands could be frequency response, state equations, etc. in a course in control theory. Or, in a less advanced course to see that the ‘islands’ presented here are divided into sub-circles.

4.2 Unlocking the portal of understanding

The systematically varied examples (appendix) help the students to identify possible solutions to the mathematical problems they have to solve in order to carry out the lab-task. The most obvious outcome is that the students work with the problems more independently, their discussions are totally different – they know what to do. Here our model helped to find what was critical for learning, namely which links between the worlds to open up for. Especially to make the link between the graph and transfer function discernable through variation, helped the students to identify the typical curves. But by identifying these types, the students also received an indication of what to expect from calculations, as well calculations of the transfer function as the time domain functions, which they were to use for the curve fit. Thus their initial hesitation to do calculations gradually diminished. According to the ‘threshold concepts’-theory it is necessary to vary also the liminality, “Variation in how the portal, that is the liminal space itself, is entered, occupied, negotiated and made sense of, passed through or not … *liminal variation*”[10]. To open up the learning space by variation of the ‘critical aspects’, we also open up the ‘liminal variation’, so that the students may feel that the task is not an impossible one, but they feel encouraged to attack the problems they had.

4.3 Further use of the model

We are now transcribing data from another part of the course, where we also expect to be able to use our model, namely AC-circuits. However, we also suggest that this model can be used in evaluating other lab-courses especially when the labs are dealing with modelling of real world phenomena, i.e. enterprise modelling in information technology or computer aided design of mechanical structures, which will be our next projects.

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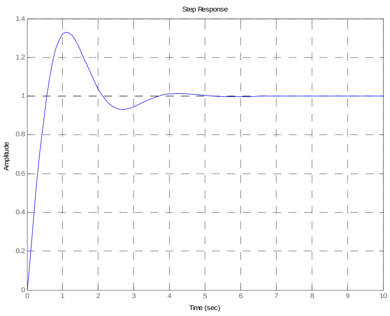
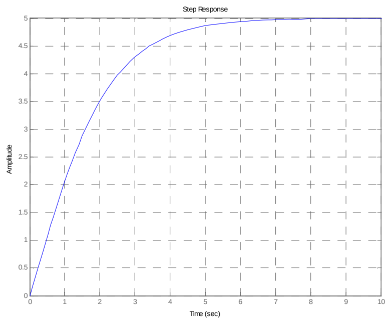
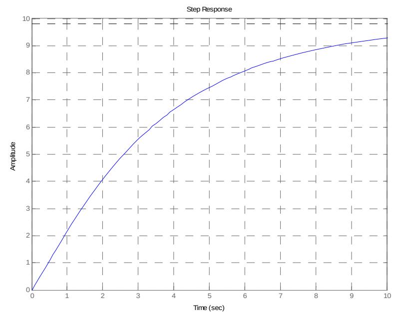
Appendix: Examples of systematically varied Laplace-functions to analyse, mathematically and graphically

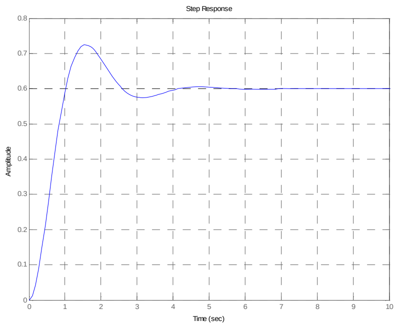
$$G(s) = \frac{2s+5}{s^2+2s+5} \qquad G(s) = \frac{2s+5}{s^2+2s+1} \qquad G(s) = \frac{2s+5}{s^2+2s+0.51}$$

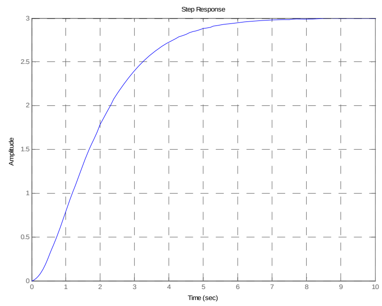


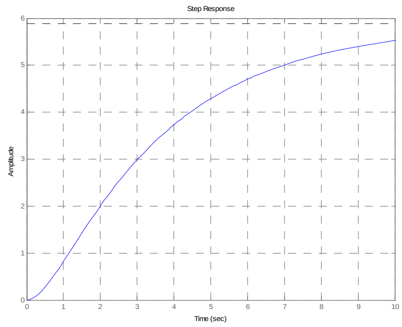




$$G(s) = \frac{3}{s^2+2s+5} \qquad G(s) = \frac{3}{s^2+2s+1} \qquad G(s) = \frac{3}{s^2+2s+0.51}$$







Important characteristics:

1) Solutions to the characteristic polynomial, i.e. the poles to the transfer function give different shapes to the curves:

$$s = -1 \pm \sqrt{1-5}$$
$$s_1 = -1 + 2j$$
$$s_2 = -1 - 2j$$

gives under-critically damped behavior

$$s = -1 \pm \sqrt{1-1}$$
$$s_{1,2} = -1$$

gives critically damped behavior

$$s = -1 \pm \sqrt{1-0.51}$$
$$s_1 = -1 + 0.7 = -0.3$$
$$s_2 = -1 - 0.7 = -1.7$$

gives overcritically damped behavior

2) Note the different start behavior that depend on the difference in degree of powers in the nominator and denominator polynomials

3) The Steady-State value depends on the transfer-function's limit-value when s approaches zero.