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INVESTIGATING THE MODEL 'LEARNING OF A COMPLEX CONCEPT' – THE PROCESS OF LEARNING IN A COURSE IN ELECTRIC CIRCUITS

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We have studied engineering students' learning in an electric circuit theory course using the model *learning of a complex concept* as an analytic tool. A *complex concept* is a *whole* that is made up of "single" interrelated "concepts". Student learning is analysed by studying the links students make between these "single concepts". The more links that are made by students, the more complete their knowledge becomes.

Keywords: lab-work, electric circuit theory, learning of a complex concept.

INTRODUCTION

In engineering and in physics education a common objective is that students should *learn* to understand theories and models and their *relation* to objects and events and *learn* to *apply* these models and theories. The ability to make links between mathematical models and measurement data, or graphs stemming from mathematical calculations and/or derived measurement data, is also often seen as the fundamental purpose of lab work [1, 2].

At PTEE 2002 in Leuven [3] we presented a study regarding engineering students' learning of AC-electricity. We especially studied how students learned to use phasor ($j\omega$) representations in representing and modelling stationary AC currents and voltages in electric circuits in the time domain. From our data we presented the model below in figure 1.

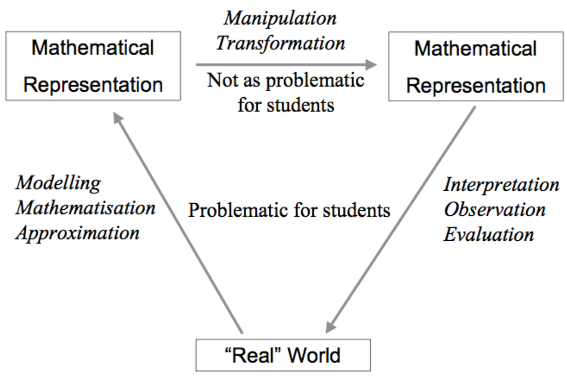

Fig.1. Our earlier model describing steps involved in modelling in a lab [3].

Although to make links is one of the most important aims we found in our studies that students struggled with the step *"real" world* → *mathematical representation* and with the step *mathematical representation* → *"real" world*. For example it was problematic for them to convert a measured signal to its symbolic phasor representation using complex numbers. However it was much less problematic for students to do mathematical manipulations and transformation within the symbolic domain.

Indeed, Tiberghien [2] proposed that the 'worlds' of theories/models and objects/events should be seen as the main analytic categories in the analysis of knowledge (see Figure 2a), and not the traditional dualistic categories - theoretical and practical knowledge. According to recent research students or novices have problems establishing the relations between the object/event world and the theory/model world. For example Vince and Tiberghien [4] found that "*establishing relevant relations between the physics model and the observable objects and events is a very difficult task*" and at a physics education conference at Tufts University the researchers present agreed on the following conclusion [5]: "*Connections among concepts, formal representations, and the real world are often lacking after traditional instruction.* ***Students need repeated practice in interpreting physics formalism and relating it to the real world***" (emphasis in original). Our previous results are very well in line the findings presented above.

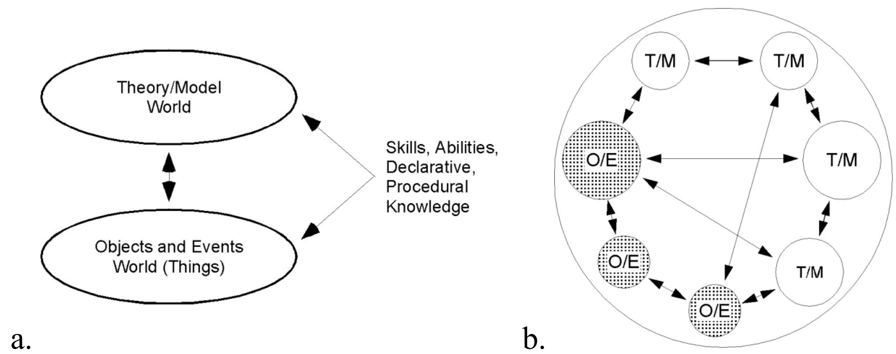

Fig. 2. a) Categorization of knowledge based on a modelling activity. b) Our suggested new model – the *learning of a complex concept*. The shaded circles are analytically attributed to the object/event world and the unshaded circles represent the theory/model world.

In line with this we have extended the model developed by Tiberghien and co-workers [2, 4]. We argue that learning should be seen as the *learning of a complex concept* (see figure 2b), i.e. a "concept" that makes up a holistic system of "single" interrelated "concepts" (i.e. a *whole* made up of interrelated *parts*). This model will be discussed in detail below.

An analysis of students' learning, using the model *learning of a complex concept*, in a lab about transient response has been reported in earlier studies by us [6-11]. In this paper we return to the topic of our PTEE 2002 paper [3], i.e. engineering students learning of stationary (i.e. sinusoidal signals) AC-electricity and frequency response of electric circuits. By using the model *learning of a complex concept* we are able to present a more fine-grained analysis of learning AC-electricity than was possible in our earlier analysis. This extension has also contributed to a deeper understanding of this model as will be discussed below.

METHODOLOGY AND SETTING

As mentioned above we have developed a model for *learning of a complex concept*. In this model "single concepts" are illustrated as nodes or "islands" that may be connected by links, while the links students actually make (identified by analysing the lived object of learning), or are supposed to establish (identified by analysing of the intended object of learning), are represented by arrows. The nodes in our model are found by looking for "gaps" [12] in the actions and conversations of students. A gap corresponds to a non-established link, and when a gap is filled and the students establish a relation between two nodes this is represented by a link (A generalised model is presented in figure 2b). This methodology is a further development of Wickman's practical epistemologies [12], which was based on Wittgenstein's philosophy of language [13].

The idea behind our model is that *knowledge is holistic*. Knowledge is built by learning the component pieces, the islands, and by learning the whole object of learning through making explicit links. Hence, the more links that are made, the more complete the knowledge becomes. It is important to note that we have analysed the *use* of concepts, models, representations and experimental equipment [cf. 14]. Hence, we do not study, or attempt to draw any conclusion on students' eventual mental models. We study what students *do*.

This study is part of a larger study. We have, during several academic years, studied lab-work carried out in a first year university level course in electric circuit theory for engineering students. Using digital camcorders students' courses of action were recorded. In the version (spring of 2003) of the course followed in this study labs and problem-solving sessions were merged into "problem-solving labs" (see references [6, 8, 9, 11] for details). In this study we present an analysis of one lab-groups' (2 male engineering students) course of actions in two 4 h labs in an electric circuit theory using the analysis model briefly presented above. The labs analysed are two labs about AC-electricity. The topic of the first lab was learning to use phasors ($j\omega$-method) in analysing and representing currents and voltages in AC-circuits. The topic of the second lab was analysing frequency dependency of currents and voltages in AC-circuits and represent these using transfer functions and Bode plots. The results from these two AC-electricity labs will be compared with the results from a 2×4 h lab sequence, from the same course and year, whose topic was transient response [6, 8-11].

RESULTS

In this chapter we will present the results from our analysis using the model for learning of a complex concept briefly described above. In figure 3 the analysis of two male engineering students' (Adam and David) courses of action in the first AC-electricity lab is presented. The situation 29 minutes into the lab is displayed in figure 3a. Adam and David have established links (however uni-directional) between the *circuit diagram*, *real circuit* and *measured graphs (time-domain)*. The students are about to establish the link between *measured graphs (time-domain)* and the complex-valued *phasor representation*. During the next 10 minutes the students struggle with this link and it is not fully established until 42 minutes into the lab. The links Adam and David have established and the "single concepts" that have appeared after 4 h of lab are displayed in figure 3b. It can be noted that *differential equation* have appeared as a "single concept" but no linking is made. Also it is noteworthy that although students were requested to establish links to *functions in the time-domain* it doesn't appear even as a non-linked "single concept" in our data.

In the frequency dependency lab the resulting picture is more complex. In this lab students are supposed to use concepts and representations related to the time- as well as the frequency-domain. Several links are established at the end of the lab, as displayed in figure 4a. Although *calculated graphs in the time domain* and *functions in the time-domain* do appear as "single concepts" no links are made, nor even attempts to do this. The reason for this, and the similar

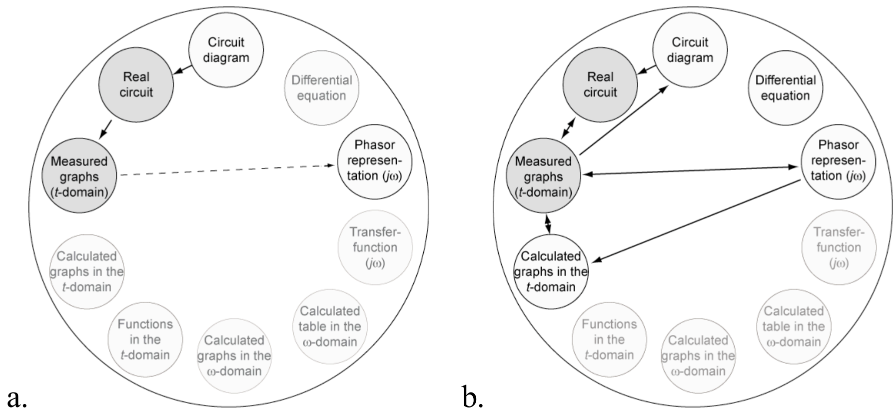

Fig. 3. An analysis of student learning in the first AC-electricity lab. Established links are represented by a solid black arrow and those in the process to be established by a dashed arrow. The "single concepts" that have appeared are represented by black circles and those that have not appeared by grey circles. a) Adams' and Davids' lived object of learning 29 minutes into the lab. b) Their lived object of learning at the end of the lab.

result regarding *functions in the time-domain* in figure 3a, is that Adam and David didn't follow the instructions and decided that they could do this later at home.

The lived object of learning found in the recordings of engineering students Benny and Tess at the end of the later lab about transient response is displayed as a comparison. As can be noted in figure 4b the "single concepts" *circuit diagram* and *real circuit* in figures 3a, 3b and 4a had fused into a single *real circuit*. The initiation of this fusion process can already be noted during the previous labs. In our analysis of videotapes we noted that during the first AC-electricity lab the "gap" between the *circuit diagram* and the *real circuit* became less and less apparent as the lab went on. In the frequency dependency lab the fusion process had gone so far that at many times it was difficult, in our analysis of students' courses of actions, to determine if the linking was made to *circuit diagram* or the *real circuit*. Our interpretation of this fusion process will be further discussed below in the discussion and conclusion section.

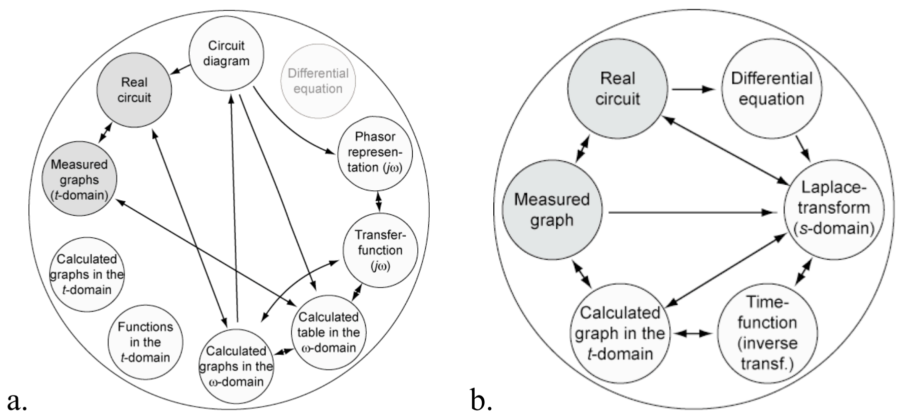

Fig. 4. a) Adams' and Davids' lived object at the end of the frequency dependency lab. b) Benny's and Tess' lived object of learning at the end of transient response lab [9].

DISCUSSION AND CONCLUSION

This study is another example of the feasibility to use the model of *learning a complex concept* as an analytic tool in studying student learning in labs. This model enables analysis of longer sequences of video-recordings that otherwise will be difficult to summarise and overview. It should be noted that the model is circular, and hence not hierarchical (as most models are), allowing for linking across the circle. The model *learning a complex concept* reveals and illustrates the complexity of knowledge.

On the contrary, however, in education research it is common to investigate "misconceptions" of "single concepts". In our view this is problematic since these "single concepts" do not exist in isolation. In for example electric circuit theory the "concepts" of current, voltage and impedance are interdependent. Rather, the central physical phenomenon is "electricity" represented by a generalised Ohms law modelling the current/voltage/ impedance/frequency-relationship of a circuit or circuit element. In the thesis of M. Holmberg [15] it was argued that some learning problems in electric circuit theory may be due to the common failure to appreciate that concepts should be seen as relations.

Our results imply that it is not adequate to discuss knowledge as a dichotomy between The result, that the *measured graph*, *calculated graph* and the *time-function* (see figures 4a and 4b) should be seen as separate "entities", was found empirically in our data. For an expert in the field these "entities" would in most cases be fused into one. On the contrary for students the links between these "entities" were among the most difficult to establish. In our data we found that the *circuit diagram* and the *real circuit* were fused into one common entity. This finding suggests that the learning of a complex concept first starts by establishing more and more links. As links become well established, "entities" that have been separate fuse into a whole. Our model suggests a method for finding "learning difficulties" since these corresponds to "gaps" and non-established links. As teachers and experts in a field we can miss to uncover these since for us the 'complex concept' has become a conceptual whole and we may no longer be able to distinguish the parts in the complex. Another conclusion is that it's not adequate to discuss knowledge in terms of a dichotomy between knowing and not knowing.

N. Bohr [16] has suggested that we should use the word "*phenomenon* exclusively to refer to the observations obtained under specified circumstances, including an account of the whole experimental arrangement" and he also argue "it is … impossible to distinguish sharply between the phenomena themselves and their conscious perception". K. Barad [17] have further extended the ideas of Bohr and she uses the term intra-actions instead of interactions to stress that these are relations *within* a whole. We suggest that our complex concept is an expression of phenomena in the sense of Bohr and Barad. When the learning of a complex concept become more complete and the elements of the complex fuse into a conceptual whole the links become internal links, i.e. intra-links, and interactions become intra-actions.

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References

[1] D. Psillos and H. Niedderer (Eds.), Teaching and learning in the science laboratory (Kluwer, Dordrecht, 2002).
[2] A. Tiberghien, “Labwork activity and learning physics - an approach based on modeling”, in Practical work in science education, edited by J. Leach and A. Paulsen (Roskilde University Press, Fredriksberg, 1998), pp. 176-194.
[3] J. Bernhard and A.-K. Carstensen, “Learning and teaching electrical circuit theory”, presented at the PTEE 2002: Physics Teaching in Engineering Education, Leuven (2002).
[4] J. Vince and A. Tiberghien, “Modelling in teaching and learning elementary physics”, in The role of communication in learning to model, edited by P. Brna (Lawrence Erlbaum, Mahwah, NJ, 2002), pp. 49-68.
[5] L. C. McDermott, “How research can guide us in improving the introductory course”, in Conference on the introductory physics course: On the occasion of the retirement of Robert Resnick, edited by J. Wilson (John Wiley & Sons, New York, 1997), pp. 33-46.
[6] A.-K. Carstensen and J. Bernhard, “Laplace transforms - too difficult to teach, learn and apply, or just matter of how to do it”, presented at the EARLI sig#9 Conference, Gothenburg (2004).
[7] A.-K. Carstensen, M. Degerman and J. Bernhard, “A theoretical approach to the learning of complex concepts”, presented at the ESERA 2005, Barcelona (2005).
[8] A.-K. Carstensen and J. Bernhard, “Threshold concepts and keys to the portal of understanding: Some examples from electrical engineering”, in Threshold concepts within the disciplines, edited by R. Land *et al.* (Sense Publishers, Rotterdam, 2008), pp. 143-154.
[9] A.-K. Carstensen and J. Bernhard, “Student learning in an electric circuit theory course: Critical aspects and task design”, European Journal of Engineering Education 34 (4), 389-404 (2009).
[10] A.-K. Carstensen, M. Degerman, M. González Sampayo and J. Bernhard, “Labwork interaction - linking the object/event world to the theory/model world”, presented at the PTEE2005, Brno (2005).
[11] A.-K. Carstensen and J. Bernhard, “Critical aspects for learning in an electric circuit theory course - an example of applying learning theory and design-based educational research in developing engineering education”, presented at the First International Conference on Research in Engineering Education, Honolulu (2007).
[12] P.-O. Wickman, “The practical epistemologies of the classroom: A study of laboratory work”, Science Education 88, 325–344 (2004).
[13] L. Wittgenstein, Philosophische Untersuchungen (Suhrkamp Verlag, Frankfurt am Main, 2003 [Original publication 1953]).
[14] G. Wells, “Learning to use scientific concepts”, Cultural Studies of Science Education 3 (2), 329-350 (2008).
[15] M. González Sampayo, Engineering problem solving: The case of the Laplace transform as a difficulty in learning electric circuits and as a tool to solve real world problems (Linköping Studies in Science and Technology Dissertation No. 1038, Linköping, 2006).
[16] N. Bohr, Atomic physics and human knowledge (John Wiley & Sons, New York, 1958).
[17] K. Barad, Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning (Duke University Press, Durham, 2007).