Investigating engineering students’ learning – learning as the 'learning of a complex concept'

Jonte Bernhard¹, Anna-Karin Carstensen², Margarita Holmberg³

¹ Engineering Education Research Group, ITN, Campus Norrköping. Linköping University, SE-60174 Norrköping, Sweden  
jonte.bernhard@liu.se

² School of Engineering, Jönköping University, Jönköping, Sweden

³ ESIME, Instituto Politécnico Nacional, Mexico City, Mexico

Abstract: In both engineering and physics education, a common objective is that students should learn to use theories and models in order to understand the relation between theories and models, and objects and events, and to develop holistic, conceptual knowledge. During lab-work, students are expected to use, or learn to use, symbolic and physical tools (such as concepts, theories, models, representations, inscriptions, mathematics, instruments and devices) in order both to understand the phenomena being studied, and to develop the skills and abilities to use the tools themselves. We have earlier argued that this learning should be seen as the learning of a complex concept, i.e. a “concept” that makes up a holistic system of “single” interrelated “concepts” (i.e. a whole made up of interrelated parts). On the contrary, however, in education research it is common to investigate “misconceptions” of “single concepts”. In this paper we will show the power of analysing engineering students’ learning as the 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 that students actually make are represented by arrows. The nodes in our model are found by looking for “gaps” 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. The more links that are made, the more complete the knowledge. In this study we report an analysis of a sequence of labs about AC-electricity in an electric circuit theory course. In for example electric circuit theory the “concepts” of current, voltage and impedance are interdependent. Rather, the central physical phenomenon is “electricity” represented by Ohms law as a generalization of the current/voltage/impedance/frequency-relationship of a circuit or circuit element. The results show the learning of “electricity” as a complex concept with students’ knowledge becoming more complete. Furthermore, according to our analysis “entities” that in later labs were fused into one were separate in the earlier labs. For example in a later lab we could note that “the physical circuit” and “the circuit drawing” had fused into a single “real circuit”. Our results suggest that the learning of a complex concept first start with 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. In line with the thesis of M. Holmberg we also argue that learning problems in electric circuit theory may be due to the common failure to appreciate that concepts are relations.

Keywords: Engineering education research, labwork, learning of a complex concept.

1. 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 the conference Physics Teaching in Engineering Education (PTEE) 2002 [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.

![Figure 1: Our earlier model describing steps involved in modelling in a lab [3].](image)

Although to make links is one of the most important aims we found in our studies that students struggled with the step “real” world $\rightarrow$ mathematical representation and with the step mathematical representation $\rightarrow$ “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.

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.

![Figure 2](image)

**Figure 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.

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.

2. 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 [15]. 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].

**Figure 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. The figure show Adams’ and Davids’ lived object of learning 29 minutes into the lab.
3. 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 figures 3–4 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 3. 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.

![Diagram showing links between circuit diagram, real circuit, measured graphs (time-domain), and phasor representation.]

**Figure 4:** Adam’s and David’s lived object of learning at the end of the AC-electricity lab.

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 4. 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 5. 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 result regarding functions in the time-domain in figures 3–4, is that Adam and David didn’t follow the instructions and decided that they could do this later at home.
Figure 5: Adams’ and Davids’ lived object at the end of the frequency dependency lab.

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 6 the “single concepts” circuit diagram and real circuit in figures 3–5 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.

Figure 6: Benny’s and Tess’ lived object of learning at the end of transient response lab [9].
4. 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 [16] 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 view is also closely related to the view expressed by F. Marton and M.-F. Pang [17]: “Perception is seen as discernment (and not construction, for instance), and our concern is primarily the differences between different ‘ways of seeing’ Above all, our answer to the question ‘What changes in conceptual change?’ is different from the answers suggested by other theorists. In our view it is the world experienced, the world seen, the world lived that changes. (p. 542)” The model of *learning a complex concept* describes how the world experienced by students changes.

Our results imply that it is not adequate to discuss knowledge as a dichotomy between theoretical knowledge and knowledge of the “real world”. The result, that the *measured graph, calculated graph* and the *time-function* (see figures 3–6) 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 [18] 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”. In a similar vein F. Marton and M.-F. Pang [17] “consider the
conceptual resources of science, economics, and the like as tools for making sense of the world around us, or tools ‘to see with’ (p. 543)”. The model of learning a complex concept describes how students use different tools, physical as well as conceptual, “to see with” and to make sense of the world with. K. Barad [19] 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