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Modelling and learning a complex concept – an exploration in light of some examples from electric circuit theory

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Introduction

A common objective in physics is "to learn relationships". However research in Science education has for a long time dealt with misconceptions of "single" concepts and research is often also done within a mental model-based perspective. We have earlier (e.g. Carstensen *et al.*, 2005) argued that we need to investigate what is called *a complex concept*, i.e. a concept that makes up a holistic system of "single" interrelated concepts (fig. 1b & 1c). In line with experientially based perspectives (e.g. Dewey, 1925/1981; Linder, 1993; Marton, 1986) we see conceptions as reflecting person – world relationships. Vygotsky (1978) and Cole (1996) have represented this relationship by a mediation triangle (fig. 2a) illustrating there is no simple relationship between subject and object. Similarly fig. 2b depicts there is a triadic relationship involving intentionality, and not a dyadic mirroring one, between sign and the object represented. In consequence with these views we hold a non-dualistic world-view or as stated by Dewey (ibid., p. 384) "experience … is neither exclusive and isolated subject or object, matter or mind, nor yet one plus the other".

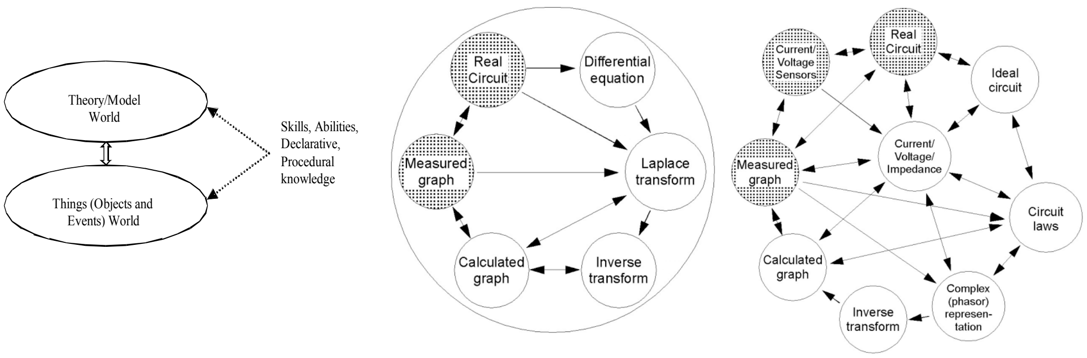

Figure 1: a) Categorization of knowledge based on a modelling activity (Vince & Tiberghien, 2002). **b)** Our model of learning of a complex concept translated and interpreted into the example in the Transient Lab. The shaded circles represent knowledge placed in the world of objects/events and the other circles the world of theories/models. **c)** The model interpreted in the first AC-electricity Lab.

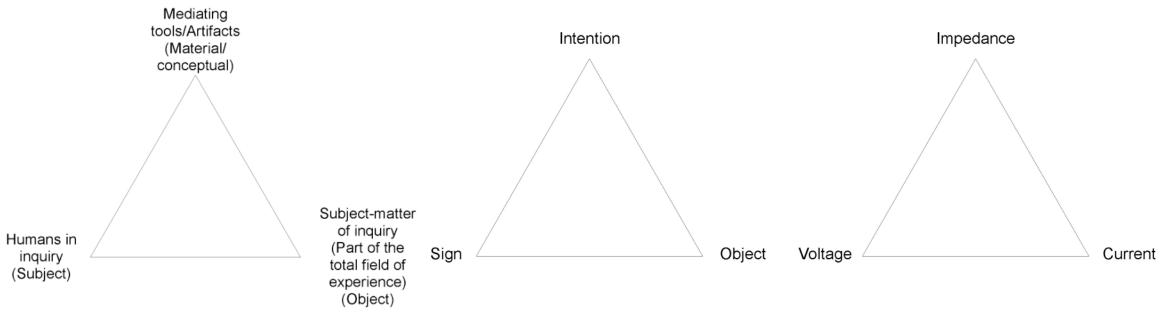

Figure 2: a) A model showing the concept of mediation adapted and modified from Vygotsky (1978) and Cole (1996): The triadic relationship between *subject – mediating tools – object*. **b)** Peirce's and Dewey's concept of representation and **c)** the concept of electricity as a triadic relationship.

Earlier we have also proposed the idea of *key concepts* – concepts that make up a "bridge to the learning of other concepts" (Carstensen & Bernhard, 2002, in press). Closely related to our ideas of key and complex concepts is the newly emergent theory of *threshold concepts*. A threshold concept represents a transformed way of understanding something without which the learner cannot progress. It entails a shift in learner subjectivity and makes an extended use of discourse possible. Threshold concepts are, according to Meyer and Land (2006), *transformative*, *irreversible* and *integrative*.

Also closely related to our study are the studies of Tiberghien and co-workers (see for example Vince & Tiberghien, 2002) regarding modelling and labwork. They make an analytic distinction between the "world" of objects/events and the "world" of theories/models (see fig. 1a). According to them understanding and establishing relationships between these "worlds" is of uttermost importance for conceptual understanding.

Method and sample

This study is part of a larger study. We have, during three academic years, studied labwork 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. The course were taken by 45-60 students each year. The different "concepts" taught in two different labs are, in fig. 1b and 1c, illustrated by circles and relationships are illustrated by arrows. These arrows can either represent the relationships the teacher wants the students to establish (intended object of learning) or the relationships actually made by different students (lived object of learning). We have found the items in fig. 1b and 1c by analysing what questions the students raise during labwork (Carstensen & Bernhard, 2003). Our methodology is a further development of Wickman's (2004) practical epistemologies based on work by Wittgenstein (1953/2003). See Carstensen and Bernhard (2004) and Carstensen *et al.* (2005), for a fuller discussion regarding the methodology.

Findings

In figure 1b and 1c are the findings from the analysis of two different labs presented. The alternating current lab is one of the first labs and the transient lab one of the last ones in a series. A common finding in both cases is that the relationships between knowledge placed in different "worlds" are more difficult for students to establish (cf. for example Bernhard & Carstensen, 2002, and Vince & Tiberghien, 2002, for similar findings).

The most striking difference between our results depicted in fig 1b and 1c is that in the alternating current lab the circle representing the current/voltage/impedance/frequency-relationship interpreted as being a hub in the middle that is central to lab, whereas the central object of learning in the transient lab is the larger encompassing circle – a gestalt of the frequency response of the circuit.

Discussion, conclusion and implications

Learning a complex concept can be seen as establishing more relations between the "islands" (Carstensen *et al.*, 2005). In the model in fig. 1c the central relationship is seen as the hub in a complex web of relations, whereas in fig. 1b the "islands" are seen as part of a larger circle, as aspects of a conceptual whole. A hypothesis, in such a model, is that as learning progresses the smaller circle fades and goes into the background and the larger circle establishes itself in the foreground.

The central physical concept in our analysis is "electricity", i.e. a current/voltage/impedance/frequency-relationship represented by the Ohms law triangle in fig. 2c. It depicts that the "concepts" of current, voltage and impedance are interdependent and do not "exist" in isolation. However it is common in science education and in science education research to treat "single concepts" as having their own existence. In line with the thesis of M. Holmberg (Sampayo González, 2006) we argue that the commonly reported learning problems in electric circuit theory are due the common failure to appreciate that concepts are relations (See also Linder, 1993, for a similar critique). Learning a complex concept, where several "single concepts" form a complex, is thus closely related to the idea of threshold concepts where the integrative aspect is a central characteristic. Therefore we propose that the idea of the complex concept can be used as an analytic tool within the theory of threshold concepts and can contribute to further development of theory and within empirical investigations.

We will further investigate these issues and since most phenomena in science and engineering can be represented as a complex concept, we argue that these issues are of general interest for research in science and engineering education.

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