Analysing and modelling engineering students' learning in the laboratory: a comparison of two methodologies

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Abstract: Producing structured, meaningful and useful descriptions (representations) of students' learning in labs is not straightforward. Two possible approaches are compared here. Students' courses of action in labs of an electric circuit course were video-recorded, then the activities during the labs were described and analysed using "the learning of a complex concept" (LCC) methodology. Conversations during the full lengths of the same labs were also transcribed verbatim. Subsequent analysis indicates that transcription offers a more detailed representation of the learning and interaction that occurred. However, it is considerably slower than LCC methodology, which can also represent learning in the full length of a lab in some detail. Furthermore, the latter gave a better overview of the analysed labs than transcription and more readily facilitated representation of both learning complexities and linking theory to practice. In conclusion, both methods can play valuable roles in engineering education research, depending on the questions addressed.

Introduction

The two main problems social scientists face as empirical researchers are the equivocal nature of the theoretical realm and the complexity of the empirical realm. As researchers our primary goal is to link the empirical and the theoretical - to use theory to make sense of evidence and to use evidence to sharpen and refine theory. The interplay helps us to produce theoretically structured descriptions of the empirical world that are both meaningful and useful. (Ragin, 1992, pp. 224-225, our italics)

Ragin (1994, p. 55, our italics) continues by stating, “The end result of this dialogue [between ideas and evidence] is a representation of social life … presented along with the thinking that guided the construction of the representation”. A researcher investigating students' learning in labs is thus faced with the challenge to produce a structured description, i.e. a representation, of students' learning that is meaningful and useful. It is challenging because of the complexity of labs as an empirical world and because a lab-session lasts for several hours.

Conceptual inventories such as Force Concept Inventory (FCI: Hestenes, Wells, & Swackhammer, 1992), Force and Motion Conceptual Evaluation (FMCE: Thornton & Sokoloff, 1998) and The Signals and Systems Concept Inventory (Wage, Buck, Wright, & Welch, 2005) are well suited for quantitative comparisons of different curricula and interventions (e.g., Hake, 1997; Wittman, 2002). However, as explained by Berger, Lu, Belzer, and Voss (1994, p. 476): “even the best pre-post and randomized designs cannot provide an answer [about what is going on while students are learning]”. This requires a study of the “inside story”, i.e. what students actually do and say during a lab. In the following sections we discuss in more detail methodologies for analysing and representing “what is going on” in a lab, but first we briefly discuss the concept of learning used in this paper.
Learning as a practical achievement

Following Dewey (1938/1986), Peirce (1878) and James (1890) we see cognition and learning as related to capabilities for action (cf. Wertsch, 1998). As succinctly stated by Rorty (1991): “we should not view knowledge as a matter of getting reality right, but as a matter of acquiring habits of action for coping with reality”. Indeed in his latest book Ference Marton (2015, p. 114) points out that he is “studying abilities, in the sense of what people can learn to do”. In a similar vein, Lavelle (2009, p. 88) maintained that in the “pragmatic” epistemology of engineering “practical usefulness” is valued.

Another important concept is “intentionality”, stemming from ideas presented by Brentano (1874/1995), and part of the theoretical frameworks of pragmatism (e.g. Dewey, 1938/1986), phenomenology (e.g. Ihde, 1986) and phenomenography (e.g. Marton, 1981). Intentionality emphasizes that there is no detached thinking, seeing, sensing or learning. We always think of something, and learning is always related to something etc. Conceptions are depicted as person-world relationships. Conceptual change in these perspectives can be achieved by changing a persons’ relationship to some aspect of the world, i.e. a context (Linder, 1993; Marton & Pang, 2008). This will develop a learner’s “functional understanding” in relation to some aspect of their life-world, fostering the “capability of handling novel situations in powerful ways” (Marton, Runesson, & Tsui, 2004, p. 5). A consequence is that experience (and hence learning) is seen as a whole, a gestalt. As expressed by Dewey (1938/1986, p. 72) “we never experience nor form judgements about objects and events in isolation, but only in connection with a contextual whole”.

A theoretical construct introduced by Marton and co-workers (e.g. Marton et al., 2004) is the object of learning. This is not a “thing”, but the set of relationships, concepts, theories, capabilities etc. that students learn or are supposed to learn. Such an object can be further categorised as an intended, enacted or lived object of learning. An intended object of learning consists of the subject matter and skills that students are expected to learn. An enacted object is what is made possible for the students to learn by the design of the learning environment and the teaching. Finally, a lived object of learning is what the students actually learn, i.e. the way they see, understand, and make sense of the object of learning and the relevant capabilities that they develop.

Studying learning in the engineering education laboratory

In order to study the learning process in a student’s environment it is necessary to make some kind of observations, i.e. we need to record his/her activities in an appropriate medium (e.g. written field notes, tapes or videos). Recording an interaction on video has a major advantage as it provides a permanent record that can be re-viewed multiple times, re-analysed and discussed with other researchers (Jordan & Henderson, 1995). Thus, the analyses presented here (of students’ interactions in engineering education lab-sessions, described below) are based on video-recordings. Throughout such analyses it is important to remember that although a video can provide a record of an interaction that is “objective” in some respects, it still only captures selected parts of the interaction.

In the records we are analysing “details of social interactions in time and space [in] the naturally occurring everyday interactions among members of [a community] of practice” (Jordan & Henderson, 1995, p. 41). We are especially interested in how students “utilize the resources of the complex social and material world of actors and objects within which they operate” (ibid., p. 41) during labs. For both analysis and presentation of evidence in scientific papers or conferences the actions recorded on video need to be represented by some kind of representation, for example a transcript or graphical model. We have recently developed a method for analysing, modelling and representing students’ courses of action in labs, which is tentatively named the “learning of a complex concept” (LCC) model (e.g. Carstensen, 2013; Carstensen & Bernhard, 2004). Here, we illustrate this methodology by presenting an LCC-analysis of students’ interactions in a set of labs, and a comparative transcription-based
analysis of the same interactions. The kinds of analyses and modelling (of the same empirical material) that the two methods afford are then evaluated and discussed.

**Method**

**Setting and data collection**

The study reported here is part of a larger project to develop active-learning conceptual labs in engineering mechanics and engineering electric circuit theory (Bernhard, 2010). The investigations have included studies spanning several academic years on lab-work carried out in a first-year university level course in electric circuit theory for engineering students, as described in several previous papers (e.g., Bernhard & Carstensen, 2002; Bernhard, Carstensen, & Holmberg, 2009; Carstensen & Bernhard, 2009). The sources of the data analysed and discussed in this paper are video-recordings of one group (two male engineering students) who took the course in spring 2003, during two AC-electricity labs. The topic of the first lab was learning to use phasors (the \( j\omega \)-method) for analysing and representing currents and voltages in AC-circuits. The topic of the second lab was analysing the frequency dependency of currents and voltages in AC-circuits and representing them using transfer functions and Bode plots. During these labs a computer-based system is used to control the signal generator and to collect and present data. The records presented here were made using a digital camcorder with a wide-angle lens. The camcorder was placed on a tripod and adjusted to get a good view of one group of students’ activities during labs, and a table-mounted microphone was used to capture their conversations. It should be noted that the recordings were made during the regular labs and hence the setting is naturalistic. Prior, informed consent was obtained from the students following standard ethical procedures. The recorded interactions were then analysed using the two methodologies, as described below.

**Method 1: Transcription**

The transcription process, outlined in Figure 1, served as both a “reference method” in evaluation of the LCC method and a contextual backdrop to illustrate the LCC analytical procedure, as illustrated using selected excerpts from transcripts in the following sections.

![Figure 1. Outline of the transcription process (ten Have 2001). Reduction and condensation of oral communications occurs in italicized steps. If the students’ speak in English the steps in square brackets are of course not necessary.](image)

Original transcriptions were made verbatim in Swedish, omitting prosodic and linguistic features such as rhythm, intonation and voice quality. A simplified version of standard conversation analysis conventions (as described for example by Hutchby & Wooffitt, 1998; ten Have, 2007) were used when creating the transcriptions, most importantly:

- A *single left bracket* indicates a point where overlapping speech starts.
- An *equals sign* indicates that there is no gap between two turns.
- A *dot in parentheses* indicates a “gap” within or between utterances.
- *Colons* indicate prolongation of the immediately preceding sound.
- Double parentheses contain transcriber’s descriptions or comments.

In our case translation from Swedish to English was necessary. As noted by Linell and Persson Thunqvist (2003, p. 415) “translation of naturally occurring talk-in-interaction is a difficult task, and it is impossible to make the transcriptions match the originals at all points”. Here, the focus when translating has been on conveying the meaning of students’ talk, rather than attempting to present a “true” word-by-word translation including intonations, dialects and genre.
Method 2: Learning of a complex concept analysis

As mentioned above we have developed a model named learning of a complex concept (the LCC model), in which “single concepts” are illustrated as nodes that may be connected by links. The nodes in our model are found by looking for “gaps” (Wickman, 2004; Wickman & Östman, 2002) in the actions and conversations of students as recorded on video. Gaps occur, according to Wickman (2004, p. 328), “when people encounter something … during talk or in action … noticing that a relation is needed … to go on”. Gaps are explicitly manifested “when students express a question or hesitation” (Wickman & Östman, 2002, p. 616). The nodes (illustrated by small circles; “islands”, in figures) are identified as things on either sides of gaps. A gap being “bridged” by the students making a link between two nodes is represented by an arrow. At the end of a lab the “single concepts” identified and the links students’ make are integrated into a conceptual whole, a complex concept (complex is used here in the sense stemming from the Latin complexus, i.e. a composite whole made up of connected parts). This methodology is a further development of the practical epistemologies developed by Wickman (2004), based on Wittgenstein’s later philosophy of language (Wittgenstein, 1953/2003, §154), holding that understanding should not be thought of as a mental process but as knowing “how to go on”.

Figure 2. Outline of the LCC-modelling process, in analogy with the transcription process illustrated in Figure 1.

The process of analysing a learning sequence by the LCC-model (see Figure 2) has many similarities with the transcription process presented in Figure 1. However, in the LCC-model the reduction is more intense, hence the data are more condensed.

Transcription and LCC-methodology both involve analysis of real, observed events. The links and nodes (single concepts) that appear in the LCC-model are empirical entities based on what the students do and say during the lab, i.e. an analysis of practice. Thus, they are not derived theoretically or pre-determined categories, but we named the nodes, acting as researchers to allow construction of an overview of the learning-related phenomena.

As the best way to describe methods is to show how they actually work in practice, the results section below provides more detailed and illustrative descriptions.

Results

Generally making transcripts took considerably longer than the initial LCC-analysis. In accordance with estimates by Jordan and Henderson (1995), and our previous experience of transcribing student’s interactions in various labs, 10-20 h was required for transcribing each hour of interaction in this case. The transcript of the first (four hours) AC-lab consists in the present stage of refinement of 3046 turns detailed in 87 pages (at 1.5 line spacing). In sharp contrast, preparing the raw notes for the LCC-modelling took approximately three times the original length of the lab (i.e. 12 hours).

We shall now consider details of representing students’ activities and talk in labs, beginning with the first AC-electricity lab. In the first part of this lab only resistive elements are included in the circuit. In the first excerpt the students are trying to understand how the circuit should be connected. Adam and David are pseudonyms and not their real names. Turns are numbered consecutively from the beginning of the lab. The excerpts are identified by tape number and starting time.

Excerpt 1 Tape 1: 6 min 58 s (Figure 3a)

118. Adam: where should we have the ground did you say?

119. David: yes (.) no where should the ground be
Adam: it does not matter

David: now it becomes fuzzy. I don’t see ((points at something in the circuit diagram in the instructions))

David: no when. what is

David: I don’t get it

Adam: there maybe you could set it ((Adam points at a position in the circuit diagram in the instructions))

David: but what is it? and these? does it represent a voltmeter?

Here we can see that the concepts of real circuit and circuit diagram enter into the discussion. However, David and Adam are not sure how they should interpret the circuit diagram in the instructions and turn this into an action of making real connections in the real circuit. Hence, we here have a gap. The real circuit is categorised as belonging to the object/event-world (shaded in Figures 3-6) and the circuit diagram belongs to the theory/model-world (un-shaded in Figures 3-6) in the terminology of Tiberghien (e.g., Vince & Tiberghien, 2002). The first step in the analysis is shown in Figure 3a. After some turns a link is established, as shown in excerpt 2 and Figure 3b.

Excerpt 2 Tape 1: 8 min 20 s (Figure 3b)

David: now we should see ((points at something in the circuit diagram)) it shall go through ten ohms. yes but that’s suitable ‘cause it already goes there

David: no high voltage

Adam: non: otherwise it would kick back here

Adam: not turned on

David: yes precisely

David: okay

Adam: non: we should (. . .) should connect the sensors also

David: yeah (. . .) of course

David: umm (. . .) it’s only (. . .) it’s only to say which sensor you have (. . .) named what (. . .) for example which is a

Adam: yes (. . .) it is the one across r

David: here is the resistor ((connects the voltage sensor across the resistor))

Figure 3. The “complex concept” corresponding to: a) excerpt 1 and b) excerpt 2

After connecting the sensors to the circuit, the next step is to prepare the software to collect data and generate graphs (By the student called: “measured graphs”). In excerpt 3 the students are about to make a link between the real circuit and a graph showing data they have collected, displayed as a dashed line in Figure 4a.

Excerpt 3 Tape 1: 10 min 25 s (Figure 4a)

David: now we shall see ((points at something in the instructions)) so we shall have an appropriate (. . .) for is this the sampling frequency for measurement or is it the sampling frequency for something else?

Adam: we’v got to have this on the output

David: but sample rate (. . .) it’s to the right

Adam: oh well yes (. . .) it feels somewhat too little, too little

David: oh well it depends on what it means (. . .) what is that, the sampling frequency for the measurement?

Adam: yes it must be

David: mm (. . .) so it’s good

Adam: yes oh well yes (. . .) now we should create graphs
Finally in turns 211-213 (more apparent in the video than in transcripts) a link is established between the real circuit and the measured graphs.

Excerpt 4 Tape 1: 10 min 57 s (Figure 4b)

208. David: we shall not measure any current (.) it is the three voltages we shall measure here
209. Adam: but how did we do (.) there
210. (.).
211. David: and then (.) then we drag to the graph here
212. (.).
213. Adam: so there it is

It can be noted that the links, i.e. arrows, in the LCC-model are verbs, i.e. they correspond to actions, and the single concepts are nouns.

Figure 4. The “complex concept” corresponding to: a) excerpt 3 and b) excerpt 4

After making the link between the real circuit and the measured graphs in excerpt 4 Adam and David struggle to make sense of the lab for another 18 minutes. At 29 minutes their lived object of learning can be represented by the diagram in Figure 5a. There is still a gap between the graphs and the phasor representation. A link is about to be established and the linking gains momentum 34 minutes into the lab. However, this link is first fully established after another 8 minutes into the lab. In the transcript this is a process represented by 82 turns and is thus unfeasible to include in this paper.

Figure 5. The lived object of learning: a) 29 minutes and b) 42 minutes into the lab

The lab continues and the links Adam and David have established and the “single concepts” that have appeared after four hours of lab work can be synthesized into a complex concept, as illustrated in Figure 6a. It can be noted that differential equation has appeared as a “single concept”, but the students made no links to it.

The complex concept resulting from a similar analysis of interactions in the next AC-lab (focused on frequency dependency) is shown in Figure 6b. As can be seen the picture is more complex.

Discussion and conclusion

In the introduction we discussed the importance of representing complexities of the empirical world in ways that are meaningful and useful (Ragin, 1992, 1994). As can be seen in Figures 6a and 6b, LCC-models can reveal the complexity of both students’ knowledge and learning in engineering labs, and hence difficulties associated with the common approach of investigating “misconceptions” of “single concepts” in education research. In our view this is problematic since these “single concepts” do not exist in isolation. Furthermore, in contrast to a (pure) scientist an engineer but must learn to deal with the complexities of the real world, rather than solely the idealisations commonly applied in (pure) science. Hence, we argue that the LCC-model allows for the modelling of learning close to the practical epistemology of engineering.
The more condensed format of the LCC-model gives a better overview of the learning process than transcripts (in which the bigger picture can be lost in the details). This is illustrated by Figures 6a and 6b, which provide much clearer overviews of the two labs than 6000 lines of transcripts. For example, Figure 6a shows that differential equation emerged as a “single concept”, but the students made no links to it (and were not requested to do so). However, functions in the time-domain does not even appear as a non-linked “single concept” in our representation, although the lab instructions requested the students to establish links to such functions. Similarly, in the LCC-model for the frequency dependency lab (Figure 6b) calculated graphs in the time domain and functions in the time-domain appear as unlinked single concepts, despite requests for links to be made in the instructions. Thus, the LCC-method allows direct comparison between the intended object of learning, as expressed in the instructions, and students’ lived object of learning during the lab. Hence it is possible to identify points where students have most “learning difficulties” since they correspond to gaps, especially lingering gaps, and non-established links. It might, of course, be possible to see such gaps and lack of links in transcripts too, but we suggest that they are less obvious in hundreds of pages of transcripts. Hence, the LCC-model offers convenient methodology for aiding further development of labs.

In terms of the LCC-model, learning can be described as the establishment of increasing numbers of links among component concepts, leading eventually to establishment of a whole complex concept, i.e. a gestalt. Thus, it is does not recognize simple dichotomies between knowing and not knowing, nor between theoretical and practical knowledge (cf., for example, Dewey, 1938/1986). Rather, the LCC-model reveals that in order to develop abilities, i.e. learning to do, links need to be established between theory/model and object/event “worlds”. However, a limitation of the LCC-model is that it does not show how links are established and how concepts fuse, for which detailed study of transcripts may be more informative. Furthermore, transcripts allow more flexible analysis and, for example, re-analysis of interactions, while the LCC-model is essentially designed solely to facilitate understanding of the complexity of learning in labs.

The LCC-model affords the analysis and representation of learning activities that take considerable time such as lab sessions, which may be prohibitively costly and time-consuming to transcribe (and the resulting transcripts may not be very revealing). Another method for analysing labs that does not take much time is category-based video-analysis (CBAV) (Niedderer et al., 2002). However, in CBAV pre-determined categories are used and the types of activities (e.g. manipulating equipment, calculating, talking to the teacher etc.) over time are noted and represented. Consequently, the process of learning in labs is studied from another viewpoint when CBAV is applied, and it provides little or no information on the links and connections students make during a lab session.
The LCC-model was originally designed for analysing learning and interactions in transient response labs (Carstensen, 2013; Carstensen & Bernhard, 2004), but we have shown that it can also be used for analysing these phenomena in AC-electricity and frequency dependency labs. The conceptual wholes (gestalts) formed by the students after the first (Figure 6a) and second (Figure 6b) AC-electricity lab show a progression. Carstensen (2013) has demonstrated, through LCC-modelling, that changes to the design of a transient response lab sequence resulted in a change in the lived object of learning. We argue that this demonstrates the utility and validity of using the LCC-model to investigate some aspects of learning in engineering education, and that it would be fruitful to test the LCC-model in other labs.

Koro-Ljungberg and Douglas (2008), Case and Light (2011), Bernhard and Baillie (2013) and Baillie and Douglas (2014), have all highlighted a need for greater methodological awareness and more sophisticated use of methods in engineering education research (EER). Acknowledging the importance learning and improving the use of existing educational research methods in EER, we maintain that it is also important to develop research methods for investigating learning in engineering education that are customised in accordance with its specialised objects of learning. Since the epistemology of engineering (Lavelle, 2009) differs from that of, for example science, methodologies from other fields of education research cannot always be imported. We see the LCC-model as one such contribution to the development of EER methods that are suitable for investigating some aspects of engineering learning, but we certainly do not claim that it is the “best” or “only” method.

References


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