Black boxes in electronics engineering labs

Coppens, P. [1]
Ir., PhD researcher
KU Leuven, Faculty of Industrial Engineering and Biosciences; LESEC
Leuven, Belgium

Van den Bossche, J.
Prof. Dr. Ir.
KaHo St-Lieven; LESEC
Gent, Belgium

De Cock, M.
Prof. Dr.
KU Leuven, Department of Physics and Astronomy; LESEC
Leuven, Belgium

Conference Topic: Educational Research Methods

INTRODUCTION

Analogue electronics is a typical intermediate lab course building on and extending principles covered in the introductory Electricity and Magnetism course. Although there is extensive research on conceptual difficulties with basic electric circuits (see [1] for an overview, more recent examples include [2-3]), little is known about student understanding of more advanced electronics concepts (some examples are again in [1]). Moreover, only little research has been conducted on more advanced lab courses, as Hofstein and Lunetta observe [4].

We therefore started an in-depth investigation of student learning during an electronics lab session. We are interested in *what* students actually do and learn and *how* and *under which conditions* they develop an understanding of concepts during lab work.

In previous studies [1,5], we reported on the results of written pre- and posttests and interviews by which we tried to get insight in the understanding of concepts related to a lab session on *RC* filters. Findings of these studies and classroom observations of student activities asked for a reformation of the lab session in order to stimulate students to think more about concepts while performing experiments. Whereas in the foregoing papers, the emphasis was on the learning effect of the lab (measured by the tests and interviews), in this paper we focus on the student activities *during* the lab. Both in the original and in the reformed lab, several student groups were videotaped. Student activities and verbalisations are analysed using (a refined version of) the Category Based Analysis of Videotapes from Labwork (CBAV) approach as described by Niedderer et al. [6] to investigate whether the new lab had an impact on the type of student activities and conversation, their (relative) duration and correlation.

[1] Corresponding Author
Coppens, P

1 METHODOLOGY AND DATA

1.1 Description of the laboratories

In the original lab, students were given a (random) resistor and capacitor and were instructed to construct either a high-pass filter (HPF) or a low-pass filter (LPF). The lab manual contained detailed instruction both on the equipment and on the measurements to be done, and provided the students with an example of a measurement. The main focus was on how to read the oscilloscope, as this was a new device to most students. To gain insight in the functioning of a filter, students were asked to represent their measurements by a Bode plot.

In the reformed lab, we tried to force the students to think more conceptually about what they are measuring by providing them with a black box containing one (unknown) resistor and one (unknown) capacitor. Using the same equipment and measurement techniques as in the original lab, they have to find out the values of both components (resistance and capacitor), as well as how they are connected. The box also contains a switch, which adds either a resistor or a capacitor to the circuit. The second part of the lab assignment asks students to find out what happens when the switch is flicked.

The manual does not contain measurement examples anymore, although it contains a list of possible values for the components. A presentation given by the TA at the beginning of the lab still contained an example of both a measurement table and a Bode plot. The instructions on the equipment are adapted, but the broad lines were kept. A first run of the new laboratory learned that students are unprepared and struggle mainly with the use of the equipment, specifically with reading of signal parameters (amplitude and phase shift) on an oscilloscope screen. Therefore, students are asked to prepare for the session and hand in their preparation at the beginning of the lab. The preparation is twofold. A simulation of an oscilloscope screen was developed to allow students to exercise scope reading. In the second task they get a (small) set of measurements which they have to represent as a Bode plot. The preparation is not graded, although students are not aware of this. Both tasks together took the students 15-20 minutes to finish.

1.2 Dataset

In 2013, 3 pairs of students were videotaped while performing the original lab. The laboratory was part of an intermediate course in electronics for 2nd year engineering students at a university college in Belgium. None of the authors was affiliated with the college. Informed consent was obtained from the students before filming.

In 2014, the reformed lab (black box approach) was implemented. Three pairs of students who did not make the preparation were videotaped, while two pairs who did were followed. All labs lasted 2 hours, of which the first 20 minutes were used by the TA to give a general introduction.

Every videotaped pair was one out of around 10 pairs in every class.

1.3 Analysis method

In order to study the student activities and ‘thinking’ that might contribute to better learning during labwork, we look for categories to describe these activities. As in [6], we assume that talking about ‘content’ (physics, electronics) means to verbalise important knowledge in the different contexts of labwork and that we can consider it as an indicator for cognitive processes contributing to learning concepts.

All videotapes were divided in time intervals of 30 seconds, which were subsequently categorised. We followed the so-called CBAV approach of [6], which uses two (parallel) types of categorisation: the *context*, which describes the student’s *activities*; and the *verbalisation*¸ describing their *talking and thinking*. In a first analysis of one of the videotapes, we used the exact same categories as in [6], but this resulted in a low agreement (low Cohen’s kappa) between two different raters. After analysing the differences between both raters in more depth, the original categories were refined and some new categories were added. The result was written down in an extensive codebook, used to ensure a more consistent scoring of the lab videos. Both original raters coded a second videotape of a lab session with the new scheme and again Cohen's kappa was computed to verify inter-rater reliability. The results are in *Table 1*. The codes used are summarised in *Table 2* and

Table **3**. New codes are marked with an asterisk (*) and, where appropriate, the corresponding CBAV category is referred to in the last column.

The new coding scheme resulted in a higher agreement for the verbalisation, as can be seen in *Table 1* below. The disagreement about verbalisation is still higher than the one about the context, although it is better than in the original coding scheme. For the context, there is a bigger disagreement for one of the students than in the original scheme, but the drop is not as big as the increase for the verbalisation.

Table 1. Cohen's kappa for different coding methods

	CBAV	**New scheme**
Student 1 context	0.7572	0.6791
Student 2 context	0.6601	0.6675
Student 1 verbalisation	0.3632	0.5202
Student 2 verbalisation	0.3228	0.4778

Table 2. Overview of context categories

Code	**Name**	**Explanation**	**Example**	**CBAV**
O	Other	Things unrelated to the lab	Chat about last night's party	O
***PO**	Practical organisation	Organise the follow-up or preparation of the lab	Decide when to meet to write the report	/
3P	Third person	A third person intervenes in the observed pair	The TA comes by to answer a question from the students	3P
LG	Labguide	Students look something up in their labguide, book or online	Check the labguide to see if their set-up is correct	LG
***BB**	Blackboard	Someone explains something to the entire class	The TA tells where to find the right knob on the oscilloscope	LG
PP	Paper and pencil	Writing and/or typing	Preparing tables to measure	PP
MA	Manipulating apparatus	Using lab-equipment	Building up the circuit	MA
ME	Measurement	Performing a (series of) measurement(s)	Reading the amplitude and filling it in in the spreadsheet	ME
CB	Building computer model	Constructing a model in simulation software	Making a SPICE file of the circuit	CMB
CS	Running a simulation	Running an already constructed computer model	Running a simulation in Multisim	CMU
CL	Calculation	Process measurements	Constructing a Bodeplot	CL
***DD**	Data discussion	Students talk about their measurements	Discussing at which frequency to measure next	/

Table 3. Overview of verbalisation categories

Code	Name	Explanation	Example	CBAV
TK	Technical knowledge	Knowledge about apparatus or software usage	Try to find a button on the oscilloscope	KT
CK	Content knowledge	Knowledge about the (engineering) content	Argue whether a circuit is HPF or LPF based on its	KP
TC	Technical and content intertwined	Using technical and content knowledge intertwined	Realising the oscilloscope has to be connected in parallel	KTP, KTPi
MK	Mathematical knowledge	State content knowledge via mathematical equations	State the equation for the cut-off frequency	KM
GD	Geometrical description	Describe data (or other) in a geometrical way	"The amplitude is lower at this frequency"	KMM
CD	Content-based description	Describe data (or other) based on content	"The phase is 45°, so this is the cut-off frequency"	KMP/KMT
***ED**	Example-based description	Describe data (or other) based on an example	"The graph doesn't look at all like the one in the manual"	/
***MR**	Measurement reading	Reading or discussing the exact measurement value	"The amplitude is 5V"	/

This approach allows for an in-depth analysis of student activity and reasoning, but is only possible for a limited number of groups as it is very time consuming. The results can therefore not be generalised. The method has several advantages compared to more quantitative techniques such as surveys and written tests however. First of all, it is an observation of the students in their 'natural habitat', allowing for very authentic observations. Also, the scope is as broad as possible, making sure a wide range of topics are addressed. The latter is not possible via quantitative analysis techniques, which typically have a very narrow scope. Other studies that used a similar type of approach include [6-10].

1.4 Data representation

For every type of lab, the fraction of time spent on a certain activity or verbalisation was averaged across all pairs, shown in *Table 4* for the verbalisation and *Table 6* for the contexts respectively. These fractions do not include the 20 minute introduction by the TA. So a proportion of 10% is equivalent to roughly 10 minutes (and not 12). A fraction was calculated by counting the total number of timeslots in a group belonging to a certain category and dividing it by the total number of timeslots in the whole group. This means that every timeslot is counted twice: once for every member of a pair.

This average fraction was then compared to the other groups by means of a Z-test. The p-values of the tests can be seen in *Table 5* and *Table 7*, where an asterisk (*) means the difference is significant on a 5% level. To gain more insight in what verbalisation occurs during what activity, a cross table is also made per group. These can be found in

Table ***8*** and *Table 9*. The rows of every cross table contain the context and the columns are the verbalisations. Every cell (i,j) of the table shows what percentage of the total time spent on activity (context) i was verbalised as verbalisation j. So if row BB, column TK is 50%, this means that when the TA was giving an explanation to the whole class, it was about technical knowledge in 50% of the cases.

2 RESULTS

2.1 Video analysis of the original labs

The results of the original lab can be seen in the crosstable shown on the left of *table 8*. They appear to be rather good, i.e. spending a lot of time discussing their results based on content and even managing to simulate the circuit during the lab. But this is mainly due to the performance of one group, where one student was a third year student who did not manage to follow this course a year earlier. When this group is not taken into account, the results are different, as can be seen on the right of *table 8*. The other tables (*table 4* till *table 7*) use the data of the two other groups (not taking the third year student into account).

In the videotapes of these labs, we observed a number of issues with students' activities. First, students tended to follow the parameters in the example of the manual, even when the filter they made themselves was very different from the example. For instance, they tended to copy the same set of input frequencies, although the grid used in the manual was adjusted for the cut-off frequency of the example, which was usually different from the one in the students' filter. Also, because they knew what the cut-off frequency was (as they know the values of the resistance and capacitance), they tended to reason based on this knowledge and 'adjust' their results. For instance, they measured at regular 100Hz intervals, but included a measurement at the exact cut-off frequency, precise within 1Hz.

Furthermore, they struggled a lot to correctly read the oscilloscope, despite instructions in the manual. As a result, they spent most of their time performing measurements or (trying to) adjusting the settings of their equipment. Most students were unprepared for the lab, despite having the manual available well before. This resulted in the students hardly discussing their measurements while performing them and not managing to make a plot of their results during the lab time nor running a simulation. They did both of these things afterwards at home.

2.2 Result of black box approach without preparation

The crosstable for these three groups can be found in *Table 9* on the left. Also in the reformed setting, the students still struggle with the equipment and as a result spend most of their time performing measurements. However, they are discussing them slightly more (though not significantly more) and also manage to plot them (noticeable is the significant increase of time spent calculating). This is most likely due to the fact that now they need to know the phase shift in degrees and/or the gain in dB to be able to understand what is in the box. None of the groups managed to perform the second set of measurements with the added resistor or capacitor however.

While discussing the data (and to a lesser extent while measuring), the students are referring to the examples significantly less, but are instead describing their data based on content more often than in the original lab. They also seem to be discussing the subject matter (the 'theory') more than the students following the original lab. But when inspecting the cross table to see when this happens, it is clear that it is usually the TA talking about conceptual knowledge, either to the pair in private or in general to the entire class and not while the students are discussing their measurements.

2.3 Result of preparation

The crosstable for these two last groups can be found in *Table 9* on the right. Again, students spend most of their time performing the measurements. But this time, but both groups managed to finish the second part of the lab (flicking the switch). They also managed to make a plot for the first part of the assignment. So they have become much more efficient at performing their measurements, spending less time on the first part of the lab.

Again, students spend more of their time reflecting on data compared to the original lab and now the increase *is* significant. As was the case with the black-box lab without preparation, they are not discussing their data referring to the example of the TA or their textbook as much anymore. However, they are actually talking more about content knowledge among themselves (and not only with the TA). This happens mainly while they are discussing what happened after they flicked the switch. While performing their measurements however, they are describing what is happening in a more qualitative way. This is mostly when comparing a measurement to an earlier one and making a comment like "*the amplitude is lowering".*

The high percentage of time dedicated to using the equipment can be explained by the fact that one of both groups even managed to finish all their measurements in 25% of their total time. Afterwards, they spent a lot of time on an extra question, which asked what happened when an oscilloscope was measuring in *AC*-mode instead of the *DC*-mode they had been using.

Table 4. Total verbalisation for all groups

	TK	CK	TC	MK	GD	CD	ED	MR	/
Original	25%	4%	2%	8%	6%	4%	6%	34%	15%
Unprepared	25%	6%	3%	7%	7%	7%	2%	32%	17%
Prepared	20%	5%	2%	5%	12%	9%	7%	30%	17%

Table 5. P-value of Z-test for difference in fraction for verbalisation

	TK	CK	TC	MK	GD	CD	ED	MR	/
Original - Unprepared	0.9920	0.0477*	0.1052	0.4295	0.6312	0.0536	0.0004*	0.3843	0.3030
Unprepared - Prepared	0.0091*	0.6527	0.5552	0.0238*	0.0004*	0.0455*	0.0000*	0.5823	0.8966
Original - Prepared	0.0244*	0.1211	0.2713	0.0000*	0.0008*	0.0006*	0.2543	0.1902	0.2713

Table 6. Total context for all groups

	O	PO	3P	LG	BB	PP	MA	ME	CB	CS	CL	DD
Original	1%	1%	5%	10%	3%	8%	29%	33%	0%	0%	3%	7%
Unprepared	1%	2%	7%	8%	2%	7%	20%	36%	0%	0%	7%	9%
Prepared	5%	5%	3%	10%	2%	3%	20%	35%	0%	0%	6%	11%

Table 7. P-value of Z-test for difference in fraction for contexts

	O	PO	3P	LG	BB	PP	MA	ME	CB	CS	CL	DD
Original - Unprepared	0.6745	0.1031	0.2501	0.1260	0.6031	0.2263	0.0002*	0.2460	/	/	0.0001*	0.1868
Unprepared - Prepared	0.0000*	0.0017*	0.0000*	0.0658	0.2983	0.0026*	0.9601	0.5029	/	/	0.2187	0.2801
Original - Prepared	0.0000*	0.0001*	0.0105*	0.9124	0.1164	0.0004*	0.0000*	0.5892	/	/	0.0030*	0.0300*

Table 8. Cross table of all original labs left; without experts right

		VERBALISATION								
		TK	CK	TC	MK	GD	CD	ED	MR	/
CONTEXT	O	0%	0%	0%	0%	0%	0%	0%	0%	100%
	PO	0%	0%	0%	0%	0%	0%	0%	0%	100%
	3P	46%	14%	0%	29%	0%	7%	0%	0%	4%
	LG	46%	2%	2%	4%	2%	4%	24%	0%	15%
	BB	50%	50%	0%	0%	0%	0%	0%	0%	0%
	PP	22%	0%	0%	33%	3%	0%	0%	6%	36%
	MA	48%	2%	1%	3%	2%	2%	5%	7%	30%
	ME	4%	1%	2%	4%	6%	2%	1%	79%	1%
	CB	58%	0%	0%	0%	0%	0%	8%	0%	33%
	CS	0%	0%	0%	0%	0%	100%	0%	0%	0%
	CL	29%	0%	0%	25%	0%	0%	0%	38%	8%
	DD	4%	2%	0%	2%	29%	40%	19%	0%	4%

	VERBALISATION								
	TK	CK	TC	MK	GD	CD	ED	MR	/
O	0%	0%	0%	0%	0%	0%	0%	0%	100%
PO	0%	0%	0%	0%	0%	0%	0%	0%	100%
3P	64%	14%	0%	21%	0%	0%	0%	0%	0%
LG	34%	4%	4%	4%	4%	4%	28%	0%	19%
BB	50%	50%	0%	0%	0%	0%	0%	0%	0%
PP	28%	0%	0%	41%	2%	0%	0%	3%	26%
MA	47%	2%	1%	2%	3%	2%	4%	6%	31%
ME	3%	2%	2%	5%	7%	2%	1%	78%	1%
CB	/	/	/	/	/	/	/	/	/
CS	/	/	/	/	/	/	/	/	/
CL	0%	0%	0%	14%	0%	0%	0%	86%	0%
DD	0%	0%	0%	4%	42%	25%	25%	0%	4%

Table 9. Cross table of the new lab, with the black boxes. Unprepared groups on the left, prepared groups on the right

		VERBALISATION								
		TK	CK	TC	MK	GD	CD	ED	MR	/
CONTEXT	O	0%	0%	0%	0%	0%	0%	0%	0%	100%
	PO	0%	0%	0%	0%	0%	0%	0%	0%	100%
	3P	54%	14%	3%	3%	0%	6%	3%	6%	13%
	LG	20%	16%	6%	10%	0%	0%	6%	0%	41%
	BB	9%	77%	0%	0%	0%	0%	0%	0%	14%
	PP	36%	10%	0%	28%	0%	0%	6%	0%	20%
	MA	45%	3%	6%	5%	6%	1%	0%	1%	33%
	ME	5%	1%	2%	6%	7%	3%	0%	73%	2%
	CB	/	/	/	/	/	/	/	/	/
	CS	/	/	/	/	/	/	/	/	/
	CL	72%	3%	0%	5%	0%	0%	0%	18%	3%
	DD	2%	0%	0%	6%	31%	47%	12%	0%	2%

	VERBALISATION								
	TK	CK	TC	MK	GD	CD	ED	MR	/
O	0%	0%	0%	0%	0%	0%	0%	0%	100%
PO	3%	0%	0%	0%	0%	0%	6%	0%	91%
3P	67%	0%	11%	0%	0%	0%	22%	0%	0%
LG	4%	16%	6%	9%	0%	13%	20%	0%	32%
BB	0%	60%	0%	0%	0%	0%	40%	0%	0%
PP	26%	30%	0%	13%	0%	0%	0%	4%	26%
MA	58%	3%	5%	1%	13%	5%	1%	4%	10%
ME	6%	0%	0%	6%	13%	5%	4%	63%	3%
CB	/	/	/	/	/	/	/	/	/
CS	/	/	/	/	/	/	/	/	/
CL	24%	0%	2%	12%	0%	5%	0%	57%	0%
DD	1%	10%	3%	0%	32%	39%	14%	0%	1%

3 SUMMARY AND ACKNOWLEDGMENTS

The most important issue seems to be that students struggle using an oscilloscope for the first time. The analysis of the original labs as well as of the unprepared students in the black-box lab showed that students spend most of their time measuring. Students who have some experience reading a scope tend to spend less time on performing measurements, allowing them to complete the second part of the lab. This is clearly reflected in the significance of the differences between the groups: there is not a big change between the unprepared students and the original lab, but there are many categories where this difference is significant only when the students have prepared the lab. These students reflected more on their data while measuring (categories GD, CD and ED), presumably because they are more certain on the correctness of their reading. They also spend more time discussing their data from a content point of view instead of referring to examples provided by the TA.

As a general conclusion, it seems that students indeed tend to discuss more about concepts during the black-box laboratory. However, the increase in time spent discussing concepts is rather low, so it remains to be seen whether this increase in time spent on discussing concepts is reflected in the post-test results. Besides analysing the videotapes of the students, we also intend to analyse their reports once they are available. We also conducted a pre- and post-test to see if the black box approach helped on the long(er) term. A rough analysis of the preparation of the students showed that they still have some difficulty reading the simulated oscilloscope properly, so we will update the simulation to guide them more. In the first semester of the 2014-2015 academic year, we will try out the updated laboratory at a different college.

We would like to thank the students who allowed us to film them during the lab as well as the TA's to allow us to try out this idea.

REFERENCES

[1] Coppens, P., De Cock, M., & Kautz, C. (2012). Student Understanding of Filters in Analog Electronics Lab Courses. In 40th SEFI Annual Conference:Engineering Education 2020: Meet the Future. Thessaloniki.

[2] Stetzer, M. R., van Kampen, P., Shaffer, P. S., & McDermott, L. C. (2013). New insights into student understanding of complete circuits and the conservation of current. American Journal of Physics, 81(2), 134. doi:10.1119/1.4773293

[3] Timmermann, D., & Kautz, C. H. (2013). Student Understanding of Electric Circuits and their Representations. In SEFI Annual conference Leuven (pp. 16–20). Leuven.

[4] Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. Science Education, 88(1), 28–54. doi:10.1002/sce.10106

[5] Coppens, P., & De Cock, M. (2013). Exploring students' activities and learning in an analog electronics lab session. In 41th SEFI Annual Conference. Leuven.

[6] Niedderer, H., Tiberghien, A., Buty, C., Haller, K., Hucke, L., Sander, F., … Welzel, M. (1998). Category Based Analysis of Videotapes from Labwork (CBAV) - Method and Results from Four Case-Studies. Retrieved from http://www.cordis.lu/tser/src/ct2001w.htm

[7] Aufschnaiter, C. Von, & Aufschnaiter, S. Von. (2007). University students' activities, thinking and learning during laboratory work. European Journal of Physics, 28(3), S51–S60. doi:10.1088/0143-0807/28/3/S05

[8] Karelina, A., & Etkina, E. (2007). Acting like a physicist: Student approach study to experimental design. Physical Review Special Topics - Physics Education Research, 3(2), 020106–1 020106–12. doi:10.1103/PhysRevSTPER.3.020106

[9] Warren, A. R. (2008). Network Analysis of Social Interactions in Laboratories. In 2008 Physics Education Research Conference (AIP).

[10] Zwickl, B. M., Finkelstein, N., & Lewandowski, H. J. (2013). Incorporating learning goals about modeling into an upper-division physics laboratory experiment. American Journal of Physics, 1–19.