A tool to see with or just something to manipulate?

Investigating engineering students' use of oscilloscopes in the laboratory

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1 INTRODUCTION

The production of knowledge in science and engineering in modern society is technologically embodied. A central characteristics of learners' and professionals' experience of our world in engineering and in most sciences is that experience should not be seen as a direct experience *human – world*, but as an experience shaped by the use of physical and symbolic tools, *human – mediating tools (artefacts) – world*. This implies that the empirical production of knowledge in science and engineering is *technologically embodied* and perception is co-determined by technology. In science and engineering, instruments do not merely "mirror reality", but mutually constitute the reality investigated. Most important the *technology used* places some aspects of reality in the *foreground*, others in the *background*, and makes *certain aspects visible* that would otherwise be *invisible* [1-5].

Ference Marton et al. [6] describes learning as "developing the eyes through which the world is perceived". Given this fact an important issue for educational research is how students and professionals in a specific discipline acquire a "professional vision" [7] or "professional seeing" [6] by the use of mediating tools.

However, it is common in research regarding students' learning in the laboratory to see instruments and experimental devices as something is just manipulated [8, 9] with no or low cognitive value [10, 11]. On the contrary I have argued that the technology used in labs, indeed, can be used as tools for making sense [12] and that this can constructively be used in the design of labs [13]. However, at SEFI 2014 [12] I presented results that indicated that first year engineering students, when using an oscilloscope, indeed mainly were manipulating it with little connection to the real circuit investigated. This paper present a work in progress there the activities of third year electrical engineering students during a lab in a Radio Frequency (RF) electronics course have been studied and are compared to those of the first year students.

The purpose of this study were to investigate the differences between novices and more advanced students in the use of the oscilloscope as a tool for measurement and as a (cognitive) tool for understanding.

2 METHODOLOGY, SETTING AND SUBJECT MATTER

2.1 Subject matter: RF-electronics

Electric circuit theory rest on the assumptions that the circuit is much smaller than the wave length of the electric currents studied, that a cause has immediate effect everywhere in the circuit (i.e. the phase velocity is infinite) and that the real circuit can be described by a model with ideal elements with no physical dimensions (lumped elements) connected with zero resistance wires. For example Kirchhoff's voltage and current laws are based on the premise that these assumptions are true. For a 50 Hz alternating current the wavelength will approximately be 6000 km, i.e. three times the distance from my office in Norrköping to the SEFI-conference in Orléans.

However, in RF-electronics [14] these assumptions are no longer valid. With increasing frequency the wavelength decreases. For example, if a signal has a frequency of 10 MHz and the cable used has $c = 2.5 \cdot 10^8$ m/s the wavelength λ will be 25 m. Furthermore, reflection at the end of a transmission line can not be neglected. The reflection coefficient is (see figure 2)

$$\underline{\Gamma} = \frac{\underline{V}^-}{\underline{V}^+} = \frac{\underline{Z}_L - \underline{Z}_0}{\underline{Z}_L + \underline{Z}_0}$$

$\underline{V}^-$ is the complex reflected wave; $\underline{V}^+$ is the incident wave
$\underline{Z}_L$ is the complex load impedance; $\underline{Z}_0$ is the line impedance

The reflected signal can undergo an amplitude change as well as a phase change relative to the incident signal, which is represented by the reflection coefficient $\underline{\Gamma}$ being complex valued.

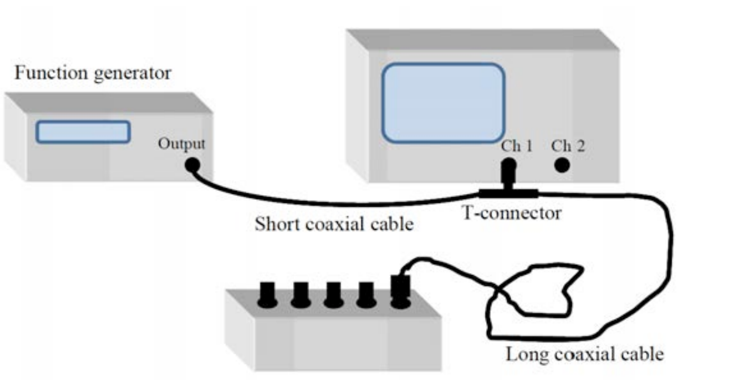

Fig. 1. The experimental setup the students analysed in the part of the lab discussed in this paper. The long coaxial cable is connected to an experiment box containing six different unknown circuits.

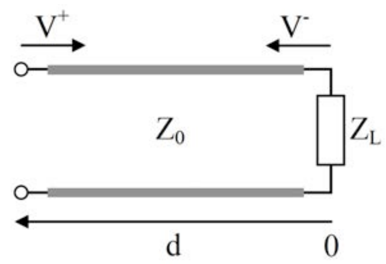

Fig. 2. Incident and reflected waves on the transmission line, i.e. the coaxial cable.

Furthermore, at high frequencies the behaviour of real resistors, capacitors and inductors deviates from the idealized models used in electric circuit theory [14].

2.2 Setting and data collection

Students' courses of action in one, four hour, course lab in a RF-electronics course were studied. The students were electrical engineering students in their fifth semester. Before this course the students had studied electric circuit theory (including transient response with Laplace transforms and periodic signals using Fourier analysis), electronics and wave physics.

The lab was the fourth lab in the course and the main purpose was to study transmission lines and terminations. The labs were performed in groups of 2–3 students. In the first part of the lab, using signals in the frequency range 100 kHz – 10 MHz, measurements were performed on different cables and with different (known) terminations. In the later part of the lab (see figure 1) a 15 m long coaxial cable were connected to an experiment box. The box contained six different circuits consisting of 1–2 lumped circuit elements. Using the oscilloscope and the function generator the students were asked to identify the circuit elements the circuits consist of. Students had access to an electronics and design software to validate their hypothesis.

The courses of action of two groups of students (two students in one group and three students in the other group) were recorded on video with separate cameras, placed on a tri-pod, for each group. Tabletop microphones were used to enhance recording of students talk. Recordings took place during a regular, scheduled, lab session, i.e. in a naturalistic setting, with other lab-groups present. This, and the cramped space due to the furniture in the lab-room, imposed restrictions on placement of cameras.

Selected parts of the video-recordings have been transcribed verbatim and translated from Swedish into English. The transcripts as well as direct viewing of the video-recordings have been used in the analysis together with students' written reports from the lab.

3 RESULTS

As mentioned earlier this is a report of a work in progress. In this section I will report on the results from the later part of the lab; the identifications of the six unknown circuits in the experimental box.

Compared to the first year students [12] it is apparent that these third year students used the oscilloscope quite differently. For the first year students the oscilloscope itself was the focus of attention and little connection were made to the actual circuit and its physical behaviour and the concepts involved. In this case we see an alterity relationship Human ⇔ Technology (⇔ World) [1]. Students struggled with making sense of the oscilloscope and learning to manipulate it.

On the contrary these third year students used the oscilloscope as a tool to see with. From looking onto the video recordings it is apparent that they have fluency in the use of the oscilloscope and they used it as a tool to investigate the behaviour of circuits and to make sense. Still much interpretation work is needed and hence it can be seen as an hermeneutic relationship Human ⇔ (Technology ⇔ World) [1]. Indeed the function generator, the cables, the oscilloscope and the terminating circuit elements form a complex and what is seen on the oscilloscope screen is dependent on the physical characteristics such as oscilloscope rise time as well as the physical characteristics of the rest of the object studied.

About two hours into the lab the groups started to investigate the experimental box with the unknown circuit elements. I will here report and discuss the work of the group consisting of Daniel, Samuel and Thomas (not their real names). They spent about an hour making measurements on all six unknown elements. During this hour there were much debate on how to interpret the graphs seen on the oscilloscope and both square waves and sine waves of various frequencies were used as incident signals. Space does not permit presentation of transcripts from this part; instead I will present some excerpts from the second pass.

In this passage the students had a second look at the circuits to finalize their analysis and conclusions. In the first pass the circuits consisting of reactive elements caused most confusion with problems to reach a unanimous interpretation.

They started the second pass with circuit 2 as is shown in excerpts 1 and 2 and in fig. 3–4. In the first pass Daniel showed residual thinking from electric circuit theory and electronics and was arguing as if it was a filter with an input and an output. In some sense it can be seen as true, but in this case we instead have one signal to the oscilloscope that is a superposition of the incident and the reflected wave.

Circuit 2 consists of a capacitor, i.e. $\underline{Z}_L = -j/(\omega C)$. This means that we have a reflection coefficient that is complex *and* frequency dependent. A square wave with frequency f_0 and amplitude *A* can be represented by a Fourier series ($\omega_0 = 2\pi f_0$):

$$v^+(t) = \frac{4A}{\pi}\sum_{n=1}^{\infty}\frac{1}{2n-1}\sin\left(\left[2n-1\right]\omega_0 t\right) = \frac{4A}{\pi}\left(\frac{\sin(\omega_0 t)}{1} + \frac{\sin(3\omega_0 t)}{3} + \frac{\sin(5\omega_0 t)}{5} + \cdots\right)$$

The implication is that the square wave can be seen as containing all frequencies and for low frequencies in the Fourier series the reflection coefficient $\underline{\Gamma}$ for the capacitor approaches the value +1 while for high frequencies the limit is -1. For intermediate frequencies in the Fourier series the reflection coefficient will be complex valued and frequency dependent.

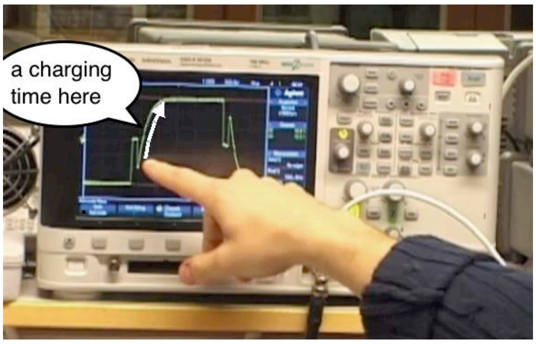

Fig. 3. Oscilloscope picture discussed in excerpt 1, turn 5.

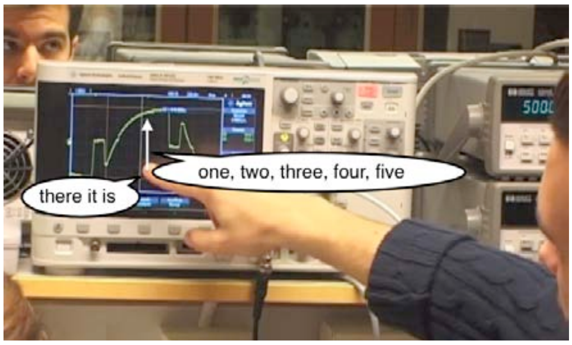

Fig. 4. Oscilloscope picture discussed in excerpt 2, turn 18.

Excerpt 1: Identification of the element as a capacitor (fig. 3)

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1.  Daniel: Thomas (.) I do not know what to say
2.  Thomas: I would say that it is a capacitor
3.  Daniel: m::
4.  Samuel: yes (.) just because you have
5.  Thomas: a charging time here ((points and moves the index finger as is
    shown in fig. 3))
6.  Daniel: we think that there is a capacitor
7.  ((9 turns discussing circuit numbering are excluded))
8.  Thomas: but if you look at the reflection (.) it does not make sense
9.  Daniel: at the same time you block a frequency there ((points to the
    oscilloscope))
10. Thomas: yea yea
11. Daniel: but it is only one frequency that is blocked
12. Samuel: but it is only one component
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13. Thomas: so I think it is about a recharging there
14. Daniel: look (.) here it comes and passes through

Although Daniel is not really convinced the students decide in excerpt 1 that circuit 2 is a capacitor. In turn 9 Daniel account for the fact that the square wave is built up by a sum over all frequencies, but is using filter terminology “blocking a frequency”. Once they have agreed on that the unknown circuit is one capacitor the students proceed quite straightforwardly to a determination of its value as is demonstrated in excerpt 2 and fig. 4.

Excerpt 2: Determination of the capacitance (fig. 4)

15. Thomas: then it will be well at this (.) yea
16. Daniel: you can even take the discharge (.) you see (.) it is the same only flipped (.) it is exactly symmetrical
17. Thomas: ((adjusts cursors in the oscilloscope))
18. Thomas: sixty three per cent (.) there it is (.) one two three four five squares (.) there ((distinctly counting by pointing; see fig. 4))

After finishing circuit 2 the students turn their attention to circuit 1 once more. In their first pass this circuit was much discussed. This was probably mostly due to the fact that this was the first unknown circuit they were analysing. In this second pass they quite rapidly noticed that the circuit was real-valued, i.e. the reflection coefficient had no imaginary part and hence the element was resistive.

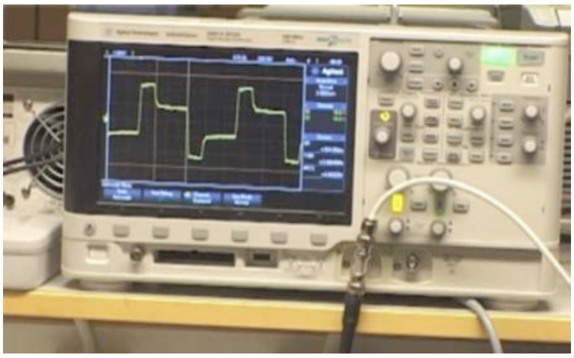

Fig. 5. Oscilloscope picture discussed in excerpt 3

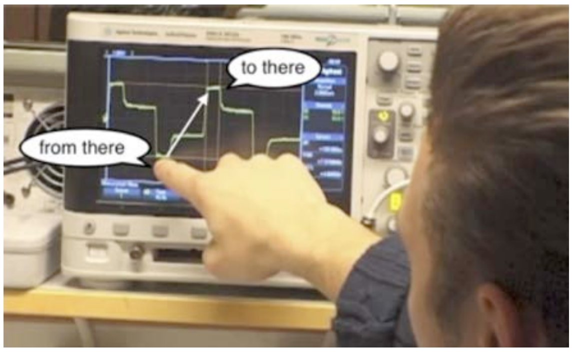

Fig. 6. Oscilloscope picture discussed in excerpt 4, turn 39.

Excerpt 3: Identification of the element as a resistor (fig. 5)

19. Samuel: should we run number one now
20. Daniel: m:::
21. (.)
22. Thomas: run
23. Daniel: that there is an obvious
24. Thomas: real
25. Daniel: =real yea

Although it was quite unproblematic for the students to identify circuit 1 as consisting of one resistor they discussed quite much on how to make measurements, as can be seen in excerpt 4. What should be counted as the peak is discussed in several turns.

Excerpt 4: Determination of the value of the resistor

26. Thomas: I can be measurement maestro
27. Daniel: they want to have what is up there as well
28. Thomas: °yes°
29. Daniel: what the base is (.) what you send in (.) now it is three (.) there we have
30. (.)

31. Thomas: so you want to have
32. Daniel: the peak (.) that is the peak
33. Thomas: yea precisely
34. Samuel: take peak to peak
35. Daniel: take peak to peak (.) you send in three hundred peak to peak
36. Samuel: you can take it (.) divided in two
37. Thomas: it is four point six peak to peak
38. Samuel: do you have two point three volt up there
39. Thomas: from there to there ((moves index finger as shown in fig. 6))
40. Daniel: m::

The students continued the lab with analysing the remaining four circuits and by validating their analysis by performing simulations and comparing with the experimentally determined graphs.

4 DISCUSSION AND CONCLUSION

As mentioned in the introduction a common view in STEM-education research is that equipment is something that is just being "manipulated" [e.g. 8, 9] and hence using experimental tools is seen as only requiring low-complexity level of cognition [11]. This is the consequence of the common view to see instruments and experimental devices as inherently having no cognitive value [10]. I have, indeed, shown that in some cases experimental devices have been used in such a way that they had little cognitive value [12, 15, 16].

However as is discussed by for example Don Ihde [1, 2, 4] and Ian Hacking [17] the value of instruments and experimental devices is that they contribute to cognition by mutually constituting the reality investigated and placing some aspects of reality in the foreground, others in the background, and makes certain aspects visible that would otherwise be invisible. Hence, a general conclusion on the cognitive value of technology is not possible. Instead different technologies has different affordances for learning and an instructor should choose the experimental technologies used in a lab wisely such as the appropriate aspects (for the learning aims of a specific lab) of reality will be foregrounded and visible for the students [15].

Furthermore, I have shown that the cognitive value of experimental technologies is dependent on instructional design and pedagogical context [16, 18].

In my previous study [12] the students were just manipulating the oscilloscopes and did not use them as tools for making sense. However, these students were novices. In the present study it is quite apparent that the students use the oscilloscope as a sense-making tool and that high complexity level cognition is involved. The results demonstrates that the capability to use it as a *cognitive* tool is gained by experience and training. Indeed, in a similar vein it was noted by Ian Hacking [19] that "you learn to see through a microscope by doing, not just by [passive] looking". Thus, it is important that the students are afforded possibilities to get experiences.

However, for example, Jordan et al. [20] have even argued "laboratory equipment … can serve to distract students from bigger ideas". Furthermore, it could also be argued that students do not need to become skilled experimentalist since with the rapid evolution of powerful computers as tools for modelling it is becoming more or less obsolete to do real measurements and experiments. Indeed modelling is an important tool in engineering [21]. But, compared to science (and hence also teaching and learning in science) there is a fundamental difference. Science works with simplification and idealized, isolated, objects while engineering works with complexity, real entities and artefacts [22, 23]. Thus experiments and hence experimental skills are, for example, needed to check the validity of models or to enable collection of data to enable the construction of empirical models.

The results further underlines that the active role of instruments and experimental devices [cf. 12, 13] for student learning and discourse cannot be neglected and that a material-discursive-analysis of learning is indeed needed. Accordingly, I maintain that it is problematic that the learning to use experimental technologies often are disparaged in favour of theoretical work and that many schools and universities are reducing the number of labs. To enable engineers to use "appliances of a technology … as tools of knowing" [24] and help them to develop a "professional vision" [7] deliberate and purposeful training is needed. Furthermore, to make improvements and re-design of, for example, labs and teaching materials feasible we need to further investigate the cognitive role of technologies to gain a better understanding. Moreover, the results points to the danger of drawing wrong or limited conclusions, such as neglecting the cognitive value of technologies, if only novices and younger students are investigated.

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