Tools to see with
- Investigating the role of experimental technologies for student learning in the laboratory

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INTRODUCTION

Students' experience of the world in the laboratory is not a direct experience, human – world, but a mediated experience, human – tool – world, shaped by the use of physical and symbolic tools. Technology is used as agencies of observations, i.e. as tools for collection and processing of physical data. However, the role of experimental technologies for student learning in the laboratory is largely neglected in educational research. If technologies are studied at all, it is often seen as being synonymous with studying the role of computers.

In this paper work in progress investigating the role of experimental technologies for student learning in the laboratory is reported.

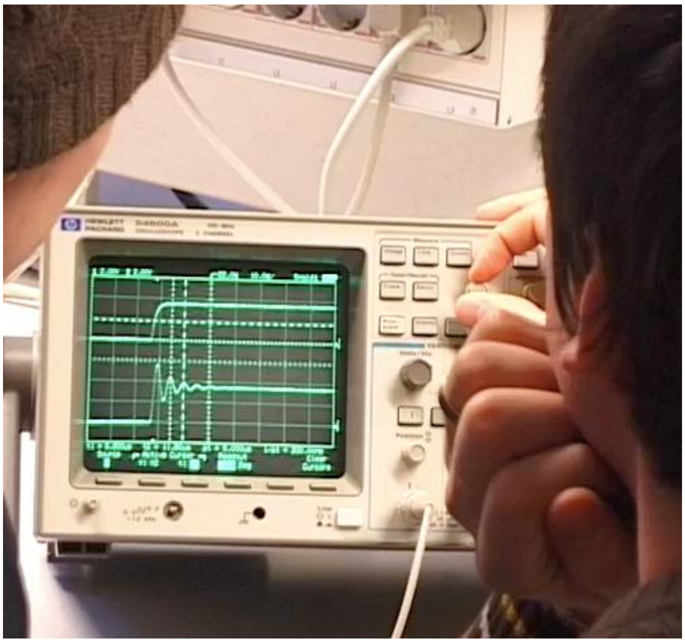


Fig. 1. Students "seeing" the behaviour of an electric circuit through an oscilloscope.

1 THEORETICAL BACKGROUND

1.1 Technology in the laboratory

The production of knowledge in science and engineering in modern society is technologically embodied. This is more than to say that science uses instruments (technologies), but it uses these technologies in unique and critical ways. According to Alfred North Whitehead [1, my italics]:

> "The reason we are on a higher imaginative level [in modern science] is not because we have a finer imagination, *but because we have better instruments*. In science, the most important thing that has happened in the last forty years is the advance in instrumental design … A fresh instrument serves the same purpose as foreign travel; *it shows things in unusual combinations. The gain is more than a mere addition; it is a transformation*".

Learning is described by Marton, et al. [2, p. 8] as developing a vision: "Arranging for learning implies arranging for developing learners' ways of seeing or experiencing, that is, *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" [3] or "professional seeing" [2, p. 11]. As mentioned above, 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, i.e. artefacts (spelled artifact in U.S. English). The concept of mediation and mediating tools could be represented diagrammatically as: *Human – mediating tools (artefacts) – world*.

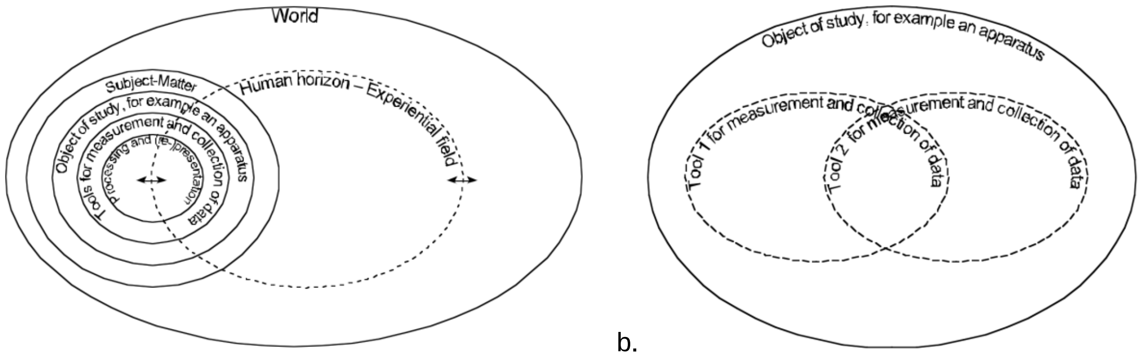
The structure of an artefact as well as learning to use an artefact changes the structure of human interaction with the world and hence is closely related to learning and hence one would expect that the role of technologies for learning should have been extensively investigated. However, with a few exceptions, this has rarely studied or problematized in STEM-education research and equipment is seen as something that is just "manipulated" [e.g. 4, 5]. Much of the theoretical framework is based on cognitivist and mentalist ideas that could be described as based on "the presumption that all psychological explanation must be framed in terms of internal mental representation" [6]. Hence, Kaptelinin and Nardi [7] argue that in cognitivist theories "technology is nearly invisible". Hucke and Fischer [8] expressively describes "object related" action (manipulating objects) as a low complexity-level of cognition while "concept related" (manipulating ideas) is high complexity-level. Jordan, et al. [9, p. 1011] even argues that "laboratory equipment … can serve to distract students from bigger ideas". This is in line with the "[traditional belief] that … instruments and experimental devices … *per se* … has no cognitive value" [10, pp. 423-424, italics in original], i.e. in traditional beliefs about science the technological means by which nature is perceived leaves no trace in our conceptions of nature [11]. Popper, for an example, restricted his epistemology to the "world of language, of conjectures, theories, and arguments" [12, p. 118].

A consequence of these views is that the role of instruments is often neglected or taken-for-granted and the emphasis is placed only on concepts and ideas. However, neglecting the role of instruments (i.e. technological artefacts) in science and engineering leads to naïve realism or to naïve idealism [13, 14]. It also leads to that educators will be 'blindfolded' in regard to critical features of the role of experimentation in a curriculum.

1.2 Mediated experience in the laboratory

Another view is offered by, for example, Dewey [15, p. 120, my italics] who pointed out that "appliances of a technology [such as] the lens, pendulum, magnetic needle, [and] level were [deliberately adopted in inquiry] as *tools of knowing*". Dewey introduces here the concept of mediation there artefacts are used as "tools of knowing". In pragmatism [16] as well as in "'postcognitivist theories' [such as] activity theory, distributed cognition, actor-network theory, and phenomenology … a major point of agreement … is the vital role of technology in human life [and a criticism] of mind-body dualism" [7].

As mentioned earlier mediated experience can be illustrated as *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* [e.g. 13, 17, 18, 19]. To promote students’ learning it is important to ensure that the learning environment enables them to focus on the object of learning and discern its critical features [20]. If focus can be put on the critical aspects of the object of learning there aspects will be foregrounded and come into the learners focal awareness and learning of these aspects will be possible. The fact that different technologies bring different aspects of reality to the fore is illustrated in figures 2a and 2b. In the word of Gibson [21] different technologies have different affordances for learning.



a. b.

Fig. 2. Illustration of the selective horizons of experimental technologies and humans in relation to human life-world.

Another set of tools for analysis is provided by Ihde [e.g. 13, 17] who have developed the following schematic distinctions regarding micro-perception in intentional mediated relationship between humans and their world [22, and 23, see also, for example, 24]:

Embodiment relations: (Human ⇔ Technology) ⇔ World

Hermeneutic relations: Human ⇔ (Technology ⇔ World)

Alterity relations: Human ⇔ Technology (⇔ World)

In embodiment relations we are not normally aware of the technology, it is almost a part of our body as it is for a blind man with a stick or for a person wearing glasses. This is symbolized by a parenthesis around (Human ⇔ Technology). In hermeneutic relations some kind of interpretation is involved, hence the term hermeneutic. Here the primary experiential terminus is with the technology symbolized with the parenthesis around (Technology ⇔ World). Both in embodiment and hermeneutic relations experience is transformed by the mediating technology used. In alterity relations humans are not related to the world via a technology, or to a world-technology complex, but to a technology and the rest of the world is more or less absent. It should be stressed that in the views of Ihde these are not distinct categories but parts of a continuum.

2 METHODOLOGY AND SETTING

2.1 Conceptual labs

Around 1995 I initiated a series of projects aimed of designing and implementing “conceptual labs” in primarily mechanics and electric circuit theory courses for engineering students [25]. A ‘conceptual lab’ is one that helps students to develop fruitful ways of linking concepts and models to objects and events [26]. Furthermore, it is a *place of inquiry*, where students’ “ways of seeing or experiencing … the world [are developed]”; i.e. the lab is an arena for further learning and not simply for the confirmation of theories and formulas that have already been taught in lectures. A common feature in these learning environments is the use of technology in form of probe-ware as a tool to aid students’ inquiry. In addition, systematic variation, based on the theory of variation [20], has been introduced into the design of the assigned tasks. Results from conceptual inventories have demonstrated the success of conceptual labs [25].

Probe-ware systems were introduced into physics teaching almost three decades ago and are good examples of the use of interactive technology in physics education [27]. They consist of a sensor or probe connected to a computer, which analyses data collected by the probe, and transforms experimental data directly into a graph displayed on the computer screen. When using probe-ware, students can perform experiments using a range of sensors to gather data on variables such as force, motion, temperature, light or sound. The *simultaneous* collection, analysis and display of *experimental* data is sometimes referred to as *real-time* graphing. The immediacy of this technology allows the design of labs that foster a functional understanding most effectively [27-30].

2.2 Video-analysis and settings

To help answer the question which aspects of the learning environment direct the students towards the intended object of learning we have since 2001 recorded students' courses of action in labs using digital camcorders. The data have been used to detect typical interaction patterns and find evidence of, or to reject hypotheses on, the generality of these patterns [31]. In the analysis, we have been inspired by an emerging research practice that focuses on students' interactions in science and mathematics education. The approach analysing students interaction [32] using video data is inspired by *ethnomethodology* [33, 34] and *conversation analysis* [35], i.e. I will focus on students practical, contingent and embodied inquiry in the setting of the lab. Selected parts of the videos have been transcribed verbatim [36].

In this study the focus in analysis is on the role of instrumental technologies as agencies of observation [37] in labs. Videos and transcripts from conceptual labs have been analysed. To complement and contrast these studies data has also been collected from "conventional" labs in physics and in electrical engineering. The setting in each case is described together with the results. Due to the limited space in this conference paper excerpts from transcripts is only presented in one of the cases.

3 RESULTS

3.1 Kinematics using probe-ware

Data were collected from labs used probe-ware in a physics course for teacher students and a physics course for engineering students. These labs contained several tasks and one of the tasks the students were asked to do were first to match a position-time-graph (fig. 3a) with their own motion by walking in front of a motion sensor connected to a computer through an interface. Later they were asked to match a velocity-time-graph (fig. 3b). During motion the students' could see the graph of their own motion in real-time on the computer screen.

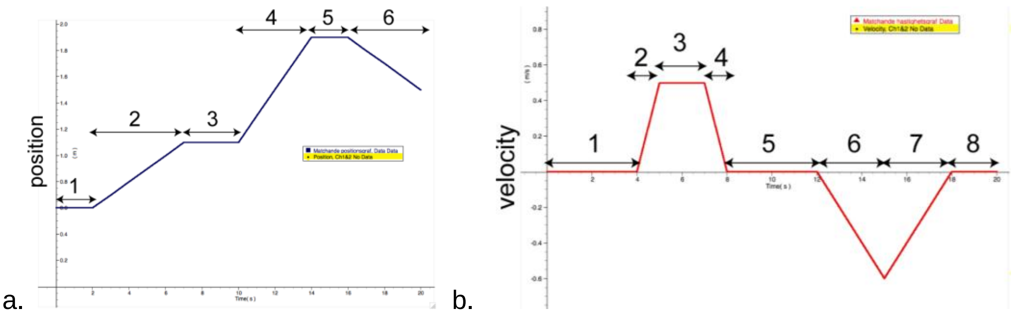


Fig. 3. Examples of a *position-time* (*a*) and *velocity-time*-graph (*b*), that students are asked to recreate in the motion (kinematics)-lab, by their own motion in front of a motion sensor. The different parts of the graphs are not numbered in the task, but numbered in this paper to facilitate an analysis.

For students to be successful in performing these tasks they have to make several conceptual distinctions. For example they have to realise that moving at constant velocity as in section 3 in fig. 3b is not the same as constant position, i.e. standing still. In the transcribed excerpt 1 below Emily is trying to match the graph in figure 3b. When she reaches part 3 she stops and she and Felicia instantly recognise that the velocity graph drops to zero (It should be noted that positive direction is away from the motion sensor and to be able to see the graph the students walk backwards facing the computer screen when moving in the positive direction).

Excerpt 1

```
1.  Emily:    [backwards (0.3) a::nd
              [((takes a step backwards and stops, the graph rises and drops))
2.  Felicia: *oops*
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3.  Emily:   *but what's it doing* (0.7) yeah but it [is
4.  Felicia:                                         [yea:h
5.  Emily:   ='cause you stand still here
6.  Felicia: no::
7.  Emily:   then it [goes down to zero
8.  Felicia:         [yes you shouldn't stand still
9.  Gina:    =no
10. Felicia: =no it's the velocity that should be [constant
11. Gina:                                         [cons - yea:h
```

In this excerpt we can see that the task in combination with the technology bring velocity to the fore. Other aspects are put in the background.

Another part of the kinematics lab-structure using probe-ware is the study of motion of accelerated motion of a cart on an inclined plane. Motion is studied using a motion sensor and the experimental results are displayed in form of position-time, velocity-time and acceleration-time graphs in real-time. It can be seen in the collected data that student focus on making sense of different cases of motion and for example talk about velocity and acceleration.

Using the categories of Ihde [17] students' experiences in these kinematics labs can be interpreted as examples of hermeneutic relationships, Human ⇔ (Technology ⇔ World), with traces of embodiment.

3.2 Kinematics using photo-gates

In this case data were collected in a physics lab in a college preparatory course. Similarly to the case presented earlier a carts motion on an inclined plane were studied. However the velocity of the cart was measured by two photo-gates. A "flag" was mounted on the cart and by knowing the width of the flag and measuring the time the flag interrupted the light-ray in the photo-gates the velocity could be calculated (The setup was similar to the one in fig. 4a. except that only one cart was used and the air-track was inclined). Acceleration could be calculated in a second step using the time it took for the cart to move from one photo-gate to another and the differences in velocity.

In contrast to the previous case were motion were studied using probe-ware motion concepts such as position, velocity and acceleration were rarely discussed. Instead focus was on reading numbers from the electronic control box for the photo-gates and manipulating these as can be seen in excerpt 2 below.

Excerpt 2

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1.  Birgit:  it only seems to read once
2.  Ann:     °yeah°
3.  Birgit:  then it stops
4.  Birgit:  okey (.) result one is here
5.           (1 s)
6.  Birgit:  e::h fifty three point eight fifty three
7.  Birgit:  fifyfour (.) lets see
8.  Ann:     [°yeah°
9.  Birgit:  [point nine
10. Ann:     when we do
11.          (2 s)
12. Ann:     second
13. Birgit:  =second
14.          (3 s)
15. Birgit:  e::h thirtytwo point three
16.          (5 s)
17. Ann:     four well
18.          (2 s)
19. Birgit:  m::
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The relation could be seen as an alterity relation [17], Human ⇔ Technology (⇔ World), were the technology serves as a terminus of perception with little connection to the world.

3.3 Studying collisions using probe-ware

In this case two colliding carts are studied with the aim of understanding conversation of momentum and Newton's third law. The velocities and forces exerted during the collision are measured by two motion sensors (one at each end of the track) and by a force sensor on each cart. As in previous labs using probe-ware experimental results were presented as graphs in real-time. The weight of carts and the character of the collision (elastic versus inelastic) can be varied using different bumpers. The setup is portrayed in figure 4b. This lab was part of a physics course for teacher students and of a course for engineering students.

In the analysed courses students' discourse was centred on the forces involved in the collisions. The relationship can be seen as a hermeneutic one [17].

a.  b. 

Fig. 4. Illustration of two different physics labs both studying collisions. In *a)* the speed of two carts colliding are measured using photo-gates and in *b)* two carts are also colliding but velocity and forces during the collision are measured using sensors and the result is presented as graphs in real-time.

3.4 Studying collisions using photo-gates

This case is similar to the previous one using probe-ware. The setup is portrayed in fig. 4a and the lab were part of a college preparatory course. The main difference between this case and the case described in section 3.3 is that velocity measurement is not continuous, but is measured before and after the collision using two photo-gates (similar procedure to the one described in section 3.2 previously). Force, in contrast to the case in section 3.3, were not possible to measure and results are *not* displayed in graphic form in real-time, but as numbers on a electronic control box.

In parallel to the case in section 3.2 an analysis of students' discourse in this lab revealed that it also centred on the reading of numbers from the control box and manipulating these numbers. The relationship can be seen as an alterity one [17], but with some strains of hermeneutics could be seen.

3.5 Oscilloscope

The final case is an analysis of students learning to use an oscilloscope (as is displayed in fig. 1) in an electric circuit course for engineering students. In this case the oscilloscope itself was focus of attention and little connection were made to the actual circuit and its physical behaviour and the concepts involved. Also in this case the relationship was an alterity one [17]. However, the students in this lab were novices. In my experience more advanced students and experts tend, indeed, to use the oscilloscope as a cognitive tool. Investigations into more advanced labs are planned.

4 DISCUSSION AND CONCLUSION

In some of the cases presented above the technologies were used as tools to see the world with and some aspects of the world were put in the foreground. In other cases the technology in itself become the focus of attention and no, or inadequate, connection to the world was made.

The cases presented in section 3.1 and 3.3 have rather consistently, when combined with appropriate pedagogical design, resulted in excellent results on conceptual tests [25, 38-40]. However, our analysis based on the video data from the labs suggests a slightly different explanation for the success of these lab curricula. Our proposal is that the technologies used as agencies of observation in these labs serves as a tool for students inquiry there the important aspects, i.e. the critical aspects in the terminology of variation theory [41], some aspects of reality in the foreground, others in the background, and makes certain aspects visible that would otherwise be invisible. Some technologies are better in doing this (for a deeper discussion see reference [42]) and if they are combined with a proper pedagogical design insightful learning is made possible.

Although some technologies seem to better afford insightful learning and a focus on the critical aspects it is important to understand that the use of a technology is not deterministic. I have earlier [26, 43] reported from a case there the same probe-ware technology were used to study collisions as the one used in section 3.3 but with another pedagogical design. In that case the difference in pedagogical design resulted in significantly lower gains on conceptual tests. I.e., the same technology can be used only as a technical tool (in a narrow sense) or as a cognitive tool {Bernhard, 2003}.

In much educational research [e.g. 4, 5] experimental technologies are described as something just being "manipulated". Indeed, in my data in the cases described in sections 3.2, 3.4 and 3.5 it can be seen that this is true for these cases. My results, however, put forward that this does not need to be the case and that technologies can be used as cognitive tools, i.e. as tools for making sense. We can not continue to neglect the active role of technologies for student learning and discourse can not be seen as language only – a material-discursive analysis of learning is needed.

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