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**Artifacts for making sense in the laboratory:
Some perspectives inspired by philosophy of technology and theories of
mediated action**

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Humans, intentionality, experience and tools for learning: Some contributions from post-cognitive theories to the use of technology in physics education.

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Abstract. Human cognition cannot be properly understood if we do not take the use of tools into account. The English word cognition stems from the Latin “cognoscere,” meaning “to become acquainted with” or “to come to know.” Following the original Latin meaning we should not only study “what happens in the head” if we want to study cognition. Experientially based perspectives, such as pragmatism, phenomenology, phenomenography, and activity theory, stress that we should study person-world relationships. Technologies actively shape the character of human-world relationships. An emergent understanding in modern cognitive research is the co-evolution of the human brain and human use of tools and the active character of perception. Thus, I argue that we must analyze the role of technologies in physics education in order to realize their full potential as tools for learning, and I will provide selected examples from physics learning environments to support this assertion.

Keywords: Labwork, experience, mediation, pragmatism, phenomenology, philosophy of technology, MBL.

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INTRODUCTION

In 1940 Müller [1] stated that:

“There is little evidence to show that the mind of modern man is superior to that of the ancients. His tools are incomparably better.”

I argue here that to study cognition properly we must take an experiential perspective [2, 3] and study person-world relationships. To do this we must study the tools, i.e. technologies, used by humans since, as implied by Müller above and succinctly expressed by Mitcham [4], we “*think through technology*.”

COGNITION AND MIND

The English word “cognition” stems from the Latin “cognoscere,” meaning “to become acquainted with,” “know” or “to come to know.” Thus, the meanings of the word’s roots indicate that we should not merely consider “what happens in the head” when studying cognition. It is important to understand that “cognitive science” is not synonymous with “cognitivism” or “mentalism.” What he calls the “myth of Descartes” and concepts of mind are more thoroughly discussed by Ryle [5]. Still and Costal [6] have summarized the dogma of cognitivism as

“the presumption that all psychological explanation must be framed in terms of internal mental representation, and processes (or rules) by which these representations are manipulated and transformed.” (p. 2)

Instead I argue, following Dewey [7, 8], Peirce [9] and James [10] that cognition is related to capabilities for action [11, 12] and is itself a specific kind of action of the human body. This is stated by Rorty [13] as: “[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.” Similarly, Noë [14] argues that “perception is not something that happens to us, or in us, [but] something we do” and Wartofsky [15] argues that “[separating] *logos* from *praxis* is impossible” (p. 173).

Central to Dewey’s theory of cognition is his principle of continuity, he states [3] that:

“there is no breach of continuity between operations of inquiry and biological operations and physical operations. ‘Continuity’ ... means that rational operations *grow out of* organic activities, without being identical with that from which they emerge” (p. 26).

Pragmatism provides us with a non-dualistic, non-representational model of an embodied mind. Lakoff and Johnson [16] (cf. [17]) purport the importance of Dewey and Merleau-Ponty [18] for the idea of the embodied mind. Related to this is the importance

Dewey saw in seeing acts as *dynamic* and *holistic* units. In his classic paper about the reflex arc concept [19] he criticized theories that turned the dynamic process of acting into a sequence of static and disjointed stimuli and responses.

In recent findings of cognitive science there is mounting evidence that the human brain co-evolved with the development of human culture and human use of tools [11, 20]. The neuroscientists Quartz and Sejnowski [21] summarize this as follows,

“culture plays a central role in the development [together] with genes to build the brain that underlies who you are” (p. 58). They argue that “the central role of culture in our mental life reveals that intelligence isn’t just inside the head” (p. 233). They further claim that “Our brains evolved to engage the world ... not to sit around passively. ... Brain functions ... are highly integrated and crosscut ... ‘multiple’ intelligences.” (p. 249)

In line with the concept of “intentionality” stemming from Brentano [22] the theories of for example pragmatism, phenomenology [23] and phenomenography [2] emphasize that there is no detached thinking, seeing, learning etc. We always think of something, learning is always related to something etc. The term “Intentionality” implies that we must treat the human-world correlate as a single unity, like it is in the “experiential perspective.”

Nardi and Kaptelinin [24] have attributed the term “postcognitivist” to theories of activity theory, distributed cognition, actor-network theory, and phenomenology, that are critical of the assumptions of “cognitivism.” According to them a “major point of agreement among postcognitivist theories is the vital role of technology in human life [and that these] theories are highly critical of mind-body dualism.” I here claim that pragmatism in the tradition of Dewey is missing in the list of “postcognitive” theories. Also, the term can give the mistaken impression that these theories post-dated “cognitivism.” Instead, the term post should be seen as an expression of the currently increased interest in some “classic” cognitive theories.

MEDIATED ACTION AND PHILOSOPHY OF TECHNOLOGY

Human experience of our world is, as briefly mentioned in the introduction, shaped by physical and symbolic tools (mediating tools). The concept of mediation and mediating tools could be represented diagrammatically as:

Human \Leftrightarrow Mediating tools \Leftrightarrow World

Questions about the role of technology (artifacts) in everyday human experience include: How do technological artifacts affect the existence of humans and their relationship with the world? How do artifacts produce and transform human knowledge? How is

human knowledge incorporated into artifacts? What are the actions of artifacts?

Tools play important roles in Dewey's philosophies of both education and technology [25]. In the socio-cultural theory and in activity-theory, which is rooted in the thinking of Vygotsky, “tool” and “mediation” are key concepts [12, 20, 26]. Miettinen [27] has pointed out the similarities between the thinking of Dewey and Vygotsky regarding tools and mediation.

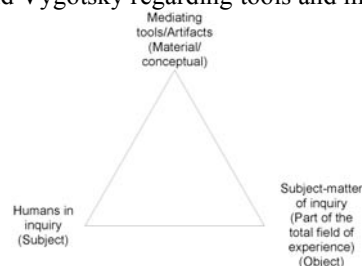


FIGURE 1. A model showing the concept of mediation adapted and modified from Vygotsky [26] and Cole [20]: the triadic relationship between *subject – mediating tools – object* illustrating that the relationship is transformed by mediation.

The philosopher of technology Don Ihde synthesized non-foundational phenomenology and pragmatism in an approach dubbed postphenomenology [28]. According to him perception is co-determined by technology. In science instruments do not merely “mirror reality,” but mutually constitute the reality investigated. 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 [29]. Neglecting the role of technology in science leads to naïve realism or to naïve idealism [29, 30]. Ihde developed the following schematic distinctions regarding mediated intentional relationships between humans and their world:

Embodiment: (Human \Leftrightarrow Technology) \Leftrightarrow World

Hermeneutic: Human \Leftrightarrow (Technology \Leftrightarrow World)

Alterity: Human \Leftrightarrow Technology (\Leftrightarrow World)

In embodiment relationships we are normally unaware of the technology. In hermeneutic relationships some kind of interpretation is involved, hence the term hermeneutic. In both embodiment and hermeneutic relationships experience is transformed by the mediating technology. In alterity relationships humans are not related to the world through a technology, or to a world-technology complex, but to a technology.

TECHNOLOGY IN LABS

‘Microcomputer Based Laboratory’ (MBL) activities are examples of the use of “interactive technology” as a tool for learning in physics education [31]. In MBL activities students do experiments using various sensors (e.g., force, motion, temperature, light

or sound sensors) connected to a computer via an interface. The arrangement provides a powerful system for *simultaneous* collection, analysis and display of experimental data, sometimes referred to as *real-time* graphing. The PER and lab-based curricula “Tools for scientific thinking” and “Real-Time Physics” have proven effective in fostering a functional understanding of physics [32], and in the “experientially based physics” project MBL has proven to be effective in a Swedish context [33], achieving normalized gains in the FMCE-test of 61%.

However, I have shown that the same sensor-computer-technology (“probeware”) used in MBL can also be implemented in ways that lead to low achievements in conceptual tests, thus refuting technological determinism. My findings indicate that the form of the educational implementation is crucial [33], i.e. we must look at how the intentional *Human-Technology-World* relationship is established.

Nevertheless, as noted by Ihde [29] and Kroes [34], for example, observation is not generally regarded as problematic in positivist approaches and from the anti-positivist perspective, the praxis-ladenness of observations tends to be overlooked. Kroes expresses this as follows:

“[i]n [the traditional] view, the physicist is essentially a passive observer in experiments: once the stage is set he just observes (discovers) what is going to happen.”

Figure 2 illustrates two common views of technology in education. In these views the *Human – World* relationship is not seen as being affected.

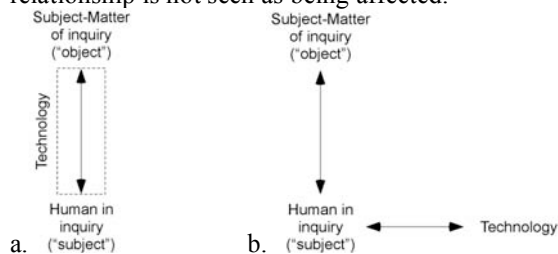


FIGURE 2. a) A ‘Transmissive’ view of technology where technology is seen merely as a vehicle for information b) An ‘Auxiliary’ view where technology is seen merely as a provider of information or support.

According to “Variation theory,” developed by Marton and co-workers [35], we learn through the experience of difference, rather than the recognition of similarity. In this theory the experience of discernment, simultaneity (synchronic and asynchronous) and variation are necessary conditions for learning.

It is not possible in this short paper to present a full phenomenological analysis [23, 36] of the role of technology and the *Human-Technology-World* relationships that the learning environment affords [37]. However, I will briefly discuss an example from one of the earlier tasks in a typical MBL-lab. In this task students are asked to walk a trajectory that matches a

given velocity-time graph. While moving the student, and his/her peers, can see the experimental graph produced in *real-time* (see figure 3). Prior to this, students have solved tasks involving position-time graphs.

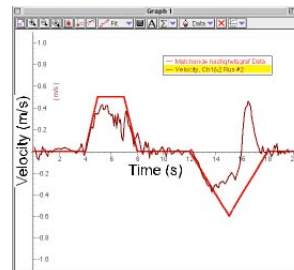


FIGURE 3. Example of a task that students attempt in a MBL-lab. Displayed is a $v(t)$ -graph with a curve that the students are asked to recreate together with an experimental graph produced by a student.

As mentioned above, the way technologies are implemented shapes figure-background relationships, and the variations that can be discerned. Wartofsky [15] expressed this as follows (p. 204):

“I take the artifacts (tools and languages) to be objectifications of human needs and intentions ... already invested with cognitive and affective content.”

What the technology does in this task is to bring velocity to the fore, i.e. it enters in the focal awareness [38] of students. Other features of the situation, physical as well as non-physical, are not highlighted, i.e. some discernment has already occurred. It is also important that velocity is established as a relationship to objects and events in the world (cf. [39]). In order to complete the assignment, students have to understand this and also make important conceptual distinctions.

I have examined labs that use “probeware” and have lead to either low or high achievements. In high-achieving labs the technology is used to bring important concepts and relationships into students’ focal awareness, i.e. it is used as a “cognitive tool.” A preliminary analysis of the critical aspects of “probeware” use have been presented previously [33] and a paper containing an in depth analysis based on variation theory and the philosophy of technology is forthcoming (cf. [40]).

CONCLUDING REMARKS

In this short essay it has only been possible to give a brief account of *some* theories that could be applied in analyzing the role of technologies in physics education. Important theories, such as those for tool-use by Heidegger and actor-network theory by Latour, have not been discussed due to space limitations.

In conclusion I contend that to use technologies as learning tools we must understand their cognitive role(s), identifying which aspects of the world are

brought into focus, thus making learning possible. By understanding this, and the active nature of perception, we can use technologies to their full potential.

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Thinking and learning through technology - Mediating tools and insights from philosophy of technology applied to science and engineering education*

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It is argued that all learning and thinking is about establishing experiential human – world relationships. Thinking and learning cannot be studied in isolation. Human experiences of our lifeworld are shaped by physical and symbolic tools (mediating tools). A common denominator in the design of many “innovative” learning environments is the insightful and careful application of computer based measurement technology as a mediating tool. Our research has shown that the way these tools are designed and implemented is critical for learning outcomes. Philosophy of technology deals with such questions as what role does technology (artifacts) play in everyday human experience: How do technological artifacts affect the existence of humans and their relations with the world and within our world? How do artifacts produce and transform human knowledge and how are human knowledge included in artifacts? What are the actions of artifacts? In this paper insights from philosophy of technology and theories of mediated action will be presented and related to the design of learning environments and analysis of learning. It is concluded that the role of technology can not be overlooked.

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1. INTRODUCTION

“*Learning is learning to think*” according to Dewey (Dewey, 1933/1986, p. 176) and similarly Vygotsky (1978, p. 90) argued that “*properly organized learning results in mental development*”.

Following Dewey (e.g. 1933/1986; 1938/1986; cf. Holder, 1995) and James (1890) I regard thinking as a kind of highly structured experience that emerges from less structured experiences. Knowledge and thinking are modes of experience; they are special kinds of mental operations thoroughly embedded in experiential situations. In his book *How We Think* Dewey (1933/1986, pp. 125-127) describes this as

“[Thinking] makes possible action with a conscious aim ... [Thinking] converts action ... into intelligent action. ... It makes possible systematic preparations and inventions. ... It enriches things with meanings”.

“Learning” and “thinking” are, thus closely and, I contend, dialectically related. In line with the thoughts of Dewey, Vygotsky and others I suggest that learning is about developing capabilities for thinking: during learning a human being is an active thinker, and not a passive recipient, and, in the same vein, it could be argued that developing thinking is about developing capabilities for learning.

Experience has its foundation in the *two-way* transaction between a human being and their environment. This experiential view means that learning and thinking are about human–world relationships. A common view of the mind is that of an isolated individual with thoughts in his/her head. In line with this metaphor for thinking is the view of learning as *acquisition* of knowledge. Another view is of learning and thinking as completely social activities. Learning is thought of as a process of *participation*. In the first model learning is seen as an individual enterprise and in the second as a social one. The experiential view refutes these dualistic views.

The dualistic discussion of “where is the mind?” (Cobb, 1994) otherwise referred to as “two metaphors for learning” (Sfard, 1998) can be traced back to Descartes' views about the mind–body antimony. In our (western) culture, dualistic ways of thinking are strongly supported by our language; some of the resulting antinomies, other than mind–body, include individual–social, inner–outer, cognition–emotion, reason–imagination, real–ideal, facts–values, subject–object and theory–practice. What he calls the “myth of Descartes” and concepts of mind are more thoroughly discussed by Ryle (1949). See also Roth, Hwang, Mafra Goulart, and Lee (2005) for a discussion how non-dualistic theories can be (mis–)interpreted.

I align myself with the experiential view: I see learning and thinking as developing a persons' (and a groups') ability to handle familiar and novel situations in powerful ways. As Rorty (1991) states:

“[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”.

I think that much of the debate surrounding the distinction between the individual and the social mind neglects the fact that we use tools (artifacts) to support and enhance our thinking – we “*think through technology*” (Mitcham, 1994) or in the words of Norman (1993) “*things make us smart*”. In this paper I will present a discussion and study about enhancing learning in engineering education through properly implemented technology. I will also relate this to theories of mediated learning.

2. THEORIES OF MEDIATED ACTION

Human experience of our world is, as briefly mentioned in the introduction, shaped by physical and symbolic tools (mediating tools). The concept of mediation and mediating tools could be represented diagrammatically as:

Human \Leftrightarrow Mediating tools \Leftrightarrow World

The role of mediating tools is discussed within theories of education and psychological science and also within philosophy of technology. Questions about the role of technology (artifacts) in everyday human experience include:

How do technological artifacts affect the existence of humans and their relationship with the world?

How do artifacts produce and transform human knowledge?

How is human knowledge incorporated into artifacts?

What are the actions of artifacts?

The use of tools is a dual process: humans both shape the world (including human culture) and are shaped through the use of tools. This means that humans are part of their world (and can not step outside and view the world from the “outside”). As Cole (1996) points out:

“traditional dichotomies of subject and object, person and environment, and so on, cannot be analytically separated and temporally ordered into independent and dependent variables.” (p. 103)

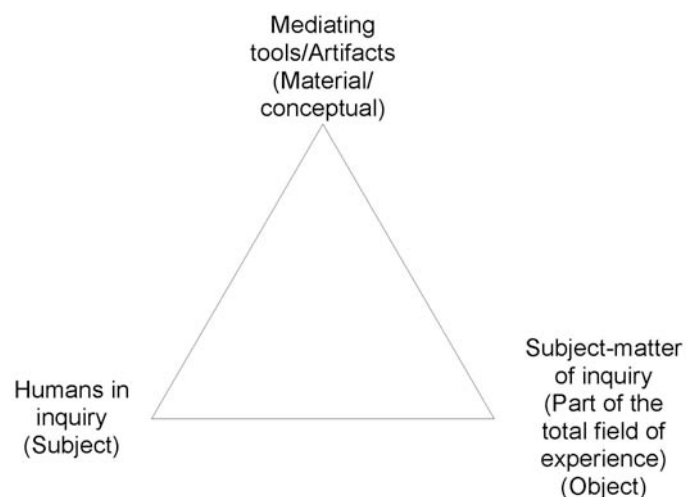


Figure 1. The basic mediational triangle in which humans in inquiry and the subject-matter of inquiry are thought of not only as directly related but also indirectly related via an artifact/tool. The objective (“intentionality”) of inquiry is at the same time regulating the inquiry (Drawing modified and adapted from Cole (1996) and Vygotsky (1978)).

In the socio-cultural theory of learning developed by Vygotsky and his co-workers and students (e.g. Cole, 1996; Kozulin, 1998; Kozulin, Gindis, Ageyev, & Miller, 2003; Leont'ev, 1978; Leontyev, 1981; Vygotsky, 1978; Wertsch, 1991, 1998, 1979, 1985) the concepts of “tool” and “mediation” are key. The central thesis is that the structure and development of

human psychological processes are co-constituted by the interaction with tools. These are historically developed and could be of different types such as “psychological tools”, “material tools”, language is also a tool. Using tools makes it possible to act in more powerful and functional ways and enhances and alter human development.

These tools (artifacts) are *simultaneously material and ideal/conceptual*. In the view of Vygotsky we can see the learner as an individual-in-society learning and thinking through artifacts. Vygotsky thus transcend dualistic thinking.

Vygotsky's ideas of artifacts as having a ”dual” material-conceptual nature are similar to the ideas of John Dewey and can be traced back to Engels (1925/1951), Marx (Marx & Engels, 1845/1957) and Hegel (1807/2006). See for example Cole (1996), Valsiner & van der Veer (2000), Ihde (Ihde & Selinger, 2003) and works within activity-theory extending and applying the ideas of Leontiev (e.g. Engeström, Miettinen, & Punamäki, 1999; Nardi, 1996; Nardi & Kaptelinin, 2006; Wertsch, 1991, 1979, 1985) for a further discussion.

Ihde (2003) have pointed out the similarities between the traditions mentioned above:

“One of the features of philosophy of technology that differentiates it from other styles of philosophy is its necessary sensitivity to the concrete, to materiality. The traditions of philosophy that are predisposed to precisely this concreteness are the praxis philosophies that include pragmatism, some strands of Marxism and neo-Marxism, and the phenomenology and hermeneutic traditions. It is not accidental that there is very little "analytic" philosophy of technology, and neither is it accidental that philosophy of technology associates with the praxis directions”. (cf. for example Davydov & Kerr, 1995; Engeström & Miettinen, 1999; Miettinen, 2001)

Tools play an important role in Dewey's philosophy of education and in his philosophy of technology (see for example Hickman, 1990) he proposed that “*language [is] the tool of tools*” (Dewey, 1925/1981, p. 134). According to Dewey “[*tools play*] a large part in consolidating meanings [*and they are*] means to consequences, instead of being taken directly and physically.” (ibid., p. 146) Tools are “*intrinsically relational, anticipatory, predictive*” (ibid., p. 146).

Common to the thinking of both Dewey and Vygotsky was the importance of seeing acts as *dynamic* and *holistic* units. For example Dewey (1896) criticised turning the dynamic process of acting into a sequence of static and disjointed stimuli and responses, thus eliminating the dynamic interdependence in the coordination of movement and sensation in the act.

According to the philosopher of technology Don Ihde perception is co-determined by technology. In science instruments do not merely “mirror reality” but mutually constitute the reality investigated. The technology actively shapes the relationship between humans and their world by placing certain aspects in the foreground (and others in the background) and also by making certain aspects of reality visible that otherwise would be invisible. According to Ihde (e.g. 1991) neglecting the role of instruments (i.e. technological artifacts) in science leads to naïve realism. However in the philosophy of science the emphasis is often placed only on concepts and ideas.

Ihde (e.g. 1979; 1991; see also Mitcham, 1994; and Verbeek, 2000/2005) have developed the following schematic distinctions regarding the intentional relationship between humans and their world:

Unmediated perception:
Human ↔ World

Mediated perception:
Human \Leftrightarrow Technology \Leftrightarrow World

By unmediated perception Ihde meant perception unmediated by technological artifacts. In some sense all perception is mediated through psychological tools such as language, theories and concepts. Within mediated perception Ihde make the distinction between embodiment and hermeneutic relations.

Embodiment relations:
(Human \Leftrightarrow Technology) \Leftrightarrow World

Hermeneutic relations:
Human \Leftrightarrow (Technology \Leftrightarrow World)

Alterity relations:
Human \Leftrightarrow Technology (\Leftrightarrow 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. In ideal embodiment relations the technology is “transparent”. In hermeneutic relations the technology is not transparent. Some kind of interpretation is involved, hence the term hermeneutic. 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. It should be stressed that in the views of Ihde these are not distinct categories but parts of a continuum.

In his book *What Things Do* Verbeek (2000/2005) claims

“the concept of mediation helps to show that technologies actively shape the character of human-world relations. Human contact with reality is always mediated, and technologies offer one possible form of mediation. On the other hand, it means that any particular mediation can only arise within specific contexts of use and interpretation.”

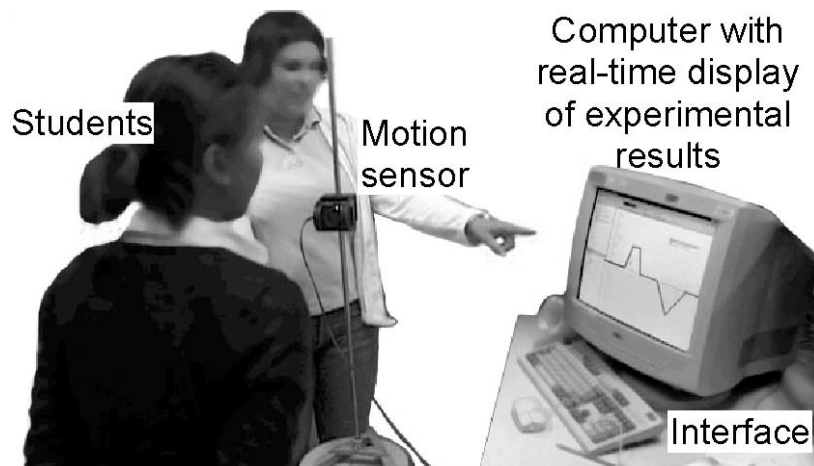


Figure 2. Picture of the setup in one of the labs concerning laws of motion. The motion sensor is connected to the computer via an interface. On the computer screen the result from the experiment is presented in real-time.

Thus we have to “give artifacts a voice” and “[bring] into account technology in educational analysis” (Waltz, 2004).

Selinger (2003) argues that if we

“[fail] to recognize the significance of non-humans [we will generate] idealistic and overly reductive analyses that [ignore] how material entities and forces influence how subjectivity is expressed.”

3. LEARNING THROUGH TECHNOLOGY IN LABS

More than ten years ago I started reforming physics and engineering education by starting a design based research project developing novel learning environments using computer based measurement technology (Microcomputer Based Labs, MBL) in labs or laborative learning environments (Bernhard, 1999, 2001, 2003, 2006; Bernhard, Carstensen, & Lindwall, 2005; Carstensen & Bernhard, in press; Lindwall, Engkvist, Bernhard, Lindström, & Lymer, 2005).

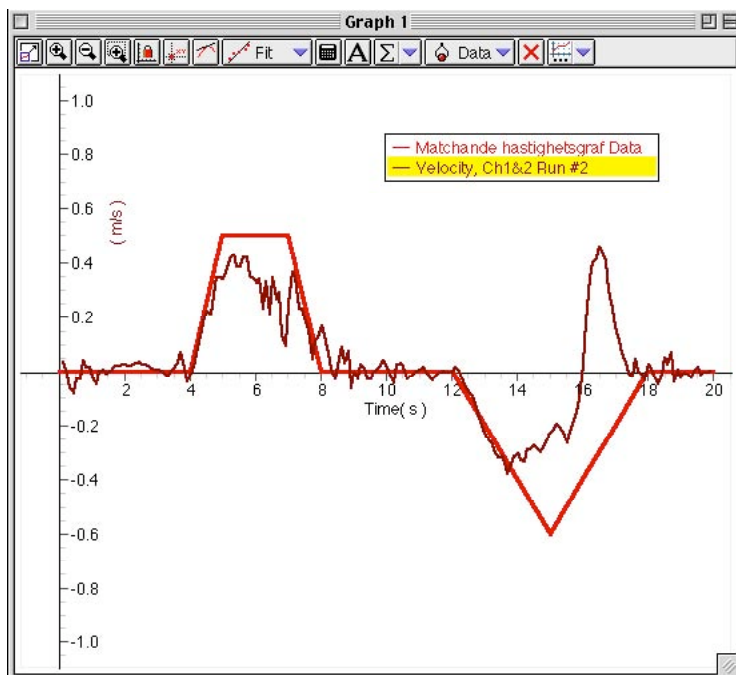


Figure 3. Example of a task that students attempt to solve in the motion labs. Displayed is a $v(t)$ -graph with a curve which the students are asked to match to an experimental graph produced by a student. The students will see their graph in real-time while trying to reproduce the prescribed graph. To successfully solve the task students have to realise the difference between position- and velocity-time graphs and several other important conceptual features.

The measurement and re-presentation technology in these labs serves as a mediating tool. The initial project was given the name “experientially based physics instruction” and the original design took Dewey's (e.g. 1938; 1925/1981; 1938/1986) theories of experience, Vygotsky's (1978) theory of mediation and the ideas of Thornton (1990; 1996) and Thornton and Sokoloff (1998) as points of departure. Later the design was further improved by applying Marton's theory of variation (Marton & Tsui, 2004). Central to this theory is that *we learn through the experience of difference*, rather than the recognition of similarity.

As is shown in table 1, the introduction of mediating tools in the form of MBL has dramatically changed the learning outcome as measured by the FMCE-test (Thornton & Sokoloff, 1998).

In the physics course for engineering students in the academic year 02/03 the difference made by the use of technology is clear. In the mechanics part of this course all students participated in the same lectures (20 h) and problem-solving sessions (12 h). However 25 students of a total of 125 participated in labs (16 h) using MBL-technology instead of labs using more traditional equipment. This means that, on the basis of hours taught, one third of the course was changed but the rest remained the same. The students participating in MBL-labs achieved a 48% normalised gain versus the 18% gain by the students participating in more traditional labs.

Teaching Method / Course	Norm. Gain (FMCE)	Reference
Workshop physics	65%	Saul and Redish (1998)
MBL 1997/98	61%	This study
Physics 02/03 MBL-labs	48%	This study
Physics 02/03 Richardson-labs	18%	This study
ILD 05/06	37%	This study
Traditional (USA)	16%	Saul and Redish (1998)

Table 1. Learning gains for different courses as measured by the FMCE-test (Saul & Redish, 1998).

We have followed students' activities in the MBL-labs by recording them on video and investigating how students orient to, interpret, and participate in these labs. We propose that students' course of action is framed by different experiences. A schematic model is presented in figure 4.

In this paper it is only possible to briefly describe the model (see also Bernhard et al., 2005; Lindwall et al., 2005, and forthcoming papers for a full discussion). The subject-matter of inquiry is placed at the top of the model. This is because the aim of the labs is that the students should improve their understanding of specific concepts in physics; in addition, it emphasises that learning is always learning *something*. From our empirical data we see that students' courses of action are framed (Goffman, 1974) by encounters with the instructions, the technology, the teacher and other students.

When using the technology, students receive immediate feedback. In the process of constructing graphs they can see when they make mistakes. Students intertwine different interpretative resources as well as different experiential domains such as graphical shapes with narrative accounts of past actions. The central aspect of the graph must be focused on and in order to complete the assignments the students have to make certain conceptual distinctions.

The instructions for the task specify the process and specify variance and invariance in the learning space. In order to solve the task the students have to deal with certain concepts in certain ways.

Teachers not only design the learning environment, chose technology and write instructions, but also scaffold students' activities, including encouraging students to shift their attention to central parts of the graph while downgrading less important aspects.

Students have a common perspective on the graph – they perceive the computer as an extra lab partner. Different interpretations of graphical representation, the experiment and subject-matter are negotiated by the students. Arguments are made an important component of the process of solving the task.

It should be noted that the technology is present in all encounters. For example, much of the student–student or student–teacher communication is via the graphical representation of experimental results on the computer screen. This demonstrates the importance of seeing relations and representations as triadic and not dyadic as shown in figures 1 and 4. Our analysis of students' courses of action in MBL-labs reveals that the student spends very little time in “pure” interaction with the technology. However, if we only consider the time spent on different interactions, we miss important features of and differences between learning environments.

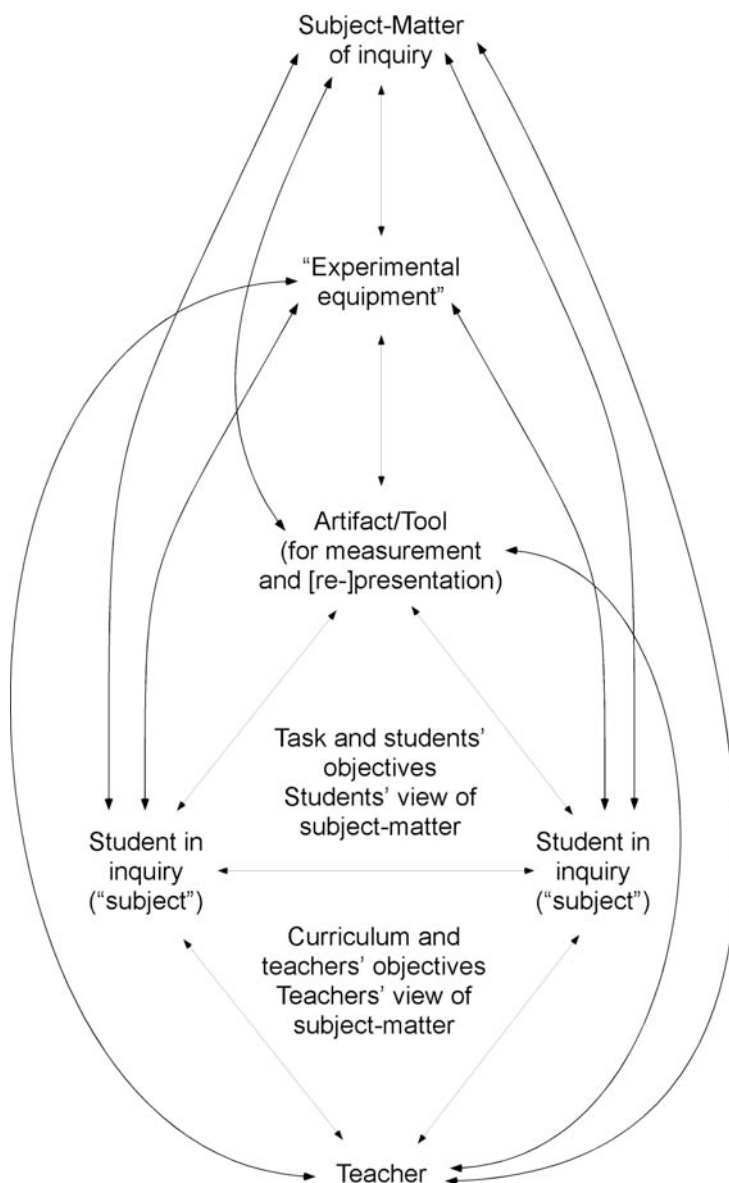


Figure 4. A schematic model of encounters and framing of activities in MBL-labs. The model shows several triadic relations and is an extension of the model presented in Figure 1.

This study is part of a larger project. In an ongoing project we have applied the ideas behind the MBL-labs to a lecture setting: We call these “interactive lecture demonstrations”; one

result of this project is presented as ILD 05/06 in Table 1. We have also implemented similar ideas in a course on electric circuit theory for engineering students (e.g. Carstensen & Bernhard, in press).

A preliminary analysis indicates that experts (for example teachers) tend to perceive relations in the form of embodiment relations to a greater extent than novices.

4. DISCUSSION AND CONCLUSIONS

Our results give examples of learning environments where the use of technology to create tools for mediation is essential for the design of the learning environment and the resultant educational achievements.

Different applications of technologies shape the character of the human–world relationship in education and hence the learning outcomes. Cuban (2001, p. 138), however, noted that “[i]n most cases, teachers used the new technology to maintain existing practices”. Similarly (Bernhard, 2003), noting the importance of educational design, argues

“this study shows that MBL doesn’t automatically give good learning results. ... [C]omputer aided learning, can not be implemented as only a technology. The educational implementation is of crucial importance and hence there is no definite answer to the common question if computers help to achieve ‘better’ learning” (cf. Tinker, 1996, p. 3).

The problems reported with some applications of computers in education are probably because theories of mediation and the available tools are not properly understood. However, in much theoretical and empirical work the role of technologies and of mediation is neglected. For example in Jay's (2005) otherwise excellent historical overview of theories of experience, the role of technology is never mentioned.

Ihde, in his post-phenomenology (e.g. Ihde, 1993, 2005; Selinger, 2006), tried to produce a synthesis of his phenomenology-based philosophy of technology with Dewey's pragmatism. We argue that there is a need to continue with this approach and also to try to incorporate theories of mediation derived from the ideas of Vygotsky (Engeström & Miettinen, 1999; Miettinen, 2001). Further there is a need to discuss epistemological and ontological issues (Sundlöf, Carstensen, Tibell, & Bernhard, 2003) in relational to technological mediation and to focus on the old concept of *techne*. *Techne* was used by the ancient Greeks to designate a productive skill (see for example Heidegger, 1926/2006; Hickman, 1990; Mitcham, 1994; Parry, 2003; Verbeek, 2000/2005). It involved both knowledge and ability directed towards the fulfilment of some aim. It involved a rational professional skill beyond simple experience.

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**Artifacts for making sense in the laboratory:
Some perspectives inspired by philosophy of technology and
theories of mediated action**

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It is argued that all learning and thinking is about establishing experiential human – world relationships. Thinking and learning cannot be studied in isolation. Human experiences of our lifeworld are shaped by physical and symbolic tools (mediating tools). A common denominator in the design of many “innovative” learning environments is the insightful and careful application of computer based measurement technology as a mediating tool. Our research has shown that the way these tools are designed and implemented is critical for learning outcomes. Philosophy of technology deals with such questions as what role does technology (artifacts) play in everyday human experience: How do technological artifacts affect the existence of humans and their relations with the world and within our world? How do artifacts produce and transform human knowledge and how are human knowledge included in artifacts? What are the acts of artifacts? In this paper insights from philosophy of technology and theories of mediated action will be presented and related to the design of learning environments and analysis of learning. It is concluded that the role of technology cannot be overlooked.

1. INTRODUCTION

According to White (1988, p. 186) the “laboratory sets science apart from most ... subjects”. In a similar vein Hofstein and Lunetta (1982) claimed that “[t]he laboratory has been given a central and distinctive role in science education, and science educators have suggested that there are rich benefits in learning from using laboratory activities”.

In the works of Marton and his co-workers it is pointed out that “[o]ne necessary condition for bringing about learning is that students are able to focus on the object of learning and *discern its critical features*” (Marton & Tsui, 2004, p. 230, my italics). In their work it is also pointed out that “people act ... in relation to situations as they perceive, experience, and understand them. ... If we want learners to develop certain capabilities, we must make it possible for them to develop a certain way of seeing or experiencing. Consequently, arranging for learning implies arranging for developing learners’ ways of seeing or experiencing, i.e., developing the eyes through which the world is perceived” (Marton, Runesson, & Tsui, 2004). For Marton perception is an active process in which person – world relationships are established (For a short discussion and review regarding the activeness of perception see for example, Bernhard, in press, and references therein).

A common question is if teaching in the laboratory in general or if a special approach is ‘effective’. For this discussion we must first discuss what we, explicitly or tacitly, implies in the term ‘effectiveness’ – what is the ‘intended object of learning’ of the lab, e.g. which capabilities and values is it expected that the students to develop (See for example Millar, Tiberghien, & Le Maréchal, 2002; Psillos & Niedderer, 2002a). The next question is if the design of the lab, or the sequence of labs, brings the critical features into the focal awareness (Marton & Booth, 1997) of the students, e.g. do the lab provide the possibilities for experiences critical for learning a *certain* ‘object of learning’.

Reflecting the importance seen in the laboratory there is nowadays a rich literature concerning teaching and learning in the science laboratory (i.e. Domin, 1999; Hodson, 1996; Hofstein & Lunetta, 1982; Jenkins, 1998; Lazarowitz & Tamir, 1994; Leach & Paulsen, 1999; Lunetta, 1998; Lunetta, Hofstein, & Clough, 2007; Psillos & Niedderer, 2002b; Tobin, Tippins, & Gallard, 1994; Trumper, 2003). It is often claimed, for example by Trumper (2003, p. 655), that it is critical to provide the learner with “[d]irect experience with physical phenomena”. However, what is striking, from reading the literature is the absence of a, or at best a surface,

discussion of the content of these experiences, how they are established, and which experiences are critical for learning a special ‘object of learning’. A fine-grained analysis is lacking.

Rather the discussion in the literature is often about of the organisation of the laboratory and a search for generic principles. The paper by Domin (1999) is a typical representative:

“Through a review of the literature, this paper asserts that four distinct styles of laboratory instruction have been utilized [in] education: expository, inquiry, discovery, and problem-based. [Each style] is unique and can be distinguished from the others by a set of three descriptors: outcome, approach, and procedure. *It is assumed that these differences will lead to different learning outcomes.* The establishment of a taxonomy of laboratory instruction styles [is hoped] to initiate ... research ... that *evaluates each style of instruction against the desired learning outcomes*”. (My italics, Domin, 1999, p. 547)

In a previous paper (Bernhard, Carstensen, & Lindwall, 2005) I have questioned the dichotomies such as ‘highly structured’ versus ‘open inquiry’ and these behind other taxonomies as the one above. It was argued that some of the lab-curricula that have proven to give good results are on conceptual tests should be understood as ‘highly structured open inquiry’. It was also shown the importance of some specific implementations of technology for shaping an activity that focus on meaning.

An essential part of the laboratory is the experiment, its object of study, for example some apparatus, and the instruments used for measurements on the object of study and the tools used for collecting, processing and (re-)presenting experimental data. In 1940 it was for example noted by Müller (1940, p. 571) that:

“history of physical science is largely the history of instruments and their intelligent use ... There is little evidence to show that the mind of modern man is superior to that of the ancients. His tools are incomparably better”.

In a similar vein Heidegger (1954, p. 18) claimed that

“modern physics, as experimental, is dependent upon technical apparatus and upon progress in the building of apparatus”.

Before continuing the discussion it is important to reflect what is involved in collecting experimental data in an experiment in a laboratory. In figure 1 a schematic illustration of relationships is presented. The experiment can be seen as consisting of an object studied, this could be a man made ‘apparatus’ such as a low-friction cart on an inclined plane or a more ‘natural’ one such as a lake or a star. The tools for measurement and collection of experimental data are sensors for measuring some physical or chemical property such as a

temperature or motion sensor. The collection of data could for example be through a computerized system, through a chart recorder or by notes in the students' or researchers' notebook. The tools for processing and (re-)presentation could be a computer utilizing specialized utilities such as the 'Fast Fourier Transform' (FFT) and advanced graphing facilities or a pocket calculator and a hand-made graph. The blocks representing 'Subject-Matter' and 'World' are included that there is no simple relationship between our 'World' and the experiment. 'Subject-Matter' provides disciplinary eyes that frames what kinds of questions could be asked, what kind of objects of study are possible to study and with what kind of tools.

It is important to remember that many objects of study are not designed to reflect features in the 'real world'; rather they are designed to reflect features ('ideal conditions') in a theory. Examples of this are the air-track with very low friction or the study of pure substances. It should be noted that the categorizations made are for analytic purposes only and that in a real case there are no sharp 'boundaries' (Harré, 2003, uses the term 'apparatus – world complexes'). For example in an oscilloscope the processing, presentation and measurement is integrated in a single unit. In other cases it makes no sense to make the distinction between 'tools for measurement' of experimental data and the 'apparatus'. It is also not meant to endorse a 'linear model' of the actual process in the laboratory (See for example Gooding, 1990, for an insightful discussion of the 'one pass fallacy'). Although it is often neglected, human agency is involved in all steps in the chain (See for a more complete, and complicated model of encounters in a lab Bernhard, 2007).

Rather the model in figure 1 is made to stress that we, when analyzing learning and meaning making in a lab, must attend to all elements in the chain since 'a chain is not stronger than the weakest link'. It is also clear that the link between a human and her world is not a simple one – experiments do not provide a simple mirror of reality. In all steps in the chain there is some kind of discernment and 'data' are not simply transferred. As will be discussed in more detail below in the section regarding philosophy of technology this will lead to that some features will be enhanced and made visible, but it is equally important that other features will be reduced and made less visible or invisible.

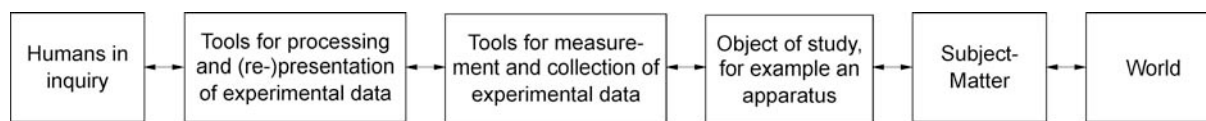


Figure 1. A simplified model for the elements involved in a lab.

From the discussion above I hope it has become apparent that it is important to study the whole chain of an experiment. However, Radder (2003, pp. 1-8) notes that this often not the case:

”[T]he fact that many scientists ... spend most of their time doing experiments of various kinds is not reflected in the basic literature in the philosophy of science. ... Thus, the philosophy of experimentation is still underdeveloped ... [T]here has been a strong tendency to take the production of empirical knowledge for granted. ... In sum, if philosophers keep neglecting the technological dimension of science, experimentation will continue to be seen as a mere data provider for the evaluation of theories”. (cf. Baird, 2004; Gooding, 1990; Harré, 2003; Kroes, 2003)

This means that a discussion of experimentation is lacking in the literature in philosophy of science as well as in the literature of science education. A consequence of this 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 artifacts) in science leads to naïve realism or to naïve idealism (Ihde, 1991; Ihde & Selinger). It leads also lead to that science educators will be ‘blindfolded’ in regard to critical features of the role of experimentation in a curriculum. This could reify existing practices. The neglect of the role of technologies or the taken-for-grantedness of the role technologies have profound implications for education and over a decennium ago Sabelli (1995) argued:

“what and how we learn have always depended on the *tools available* to students and teachers and should change with significant changes in the tools available. ... [E]ducators [are] responsible for exploring the profound *pedagogical implications of the changes brought about by technology on the practice of science.*” (p. 7, our emphasis)

(Linn, 1998, p. 266)

“As new technologies have become available to education, experts in science teaching, natural science and pedagogy have struggled to find ways to make them effective for all learners. ... Many call for active learning but fail to distinguish activities that help students to develop powerful ideas and activities that entertain”.

However if we are not aware of the role of tools and technologies we will instead, as Cuban (2001, p. 138) notes “[use] the new technology to maintain existing practices”.

As mentioned above I claim that a “serious study of artifacts as integral and inseparable components of human functioning” (Engeström & Miettinen, 1999, p. 29) is needed. With some exceptions I claim that this is missing in the literature of science education. In some literature there seem to be an awareness of technology (i.e. Nemirovsky, Tierney, & Wright, 1998; Roth, Hwang, Mafra Goulart, & Lee, 2005; Roth, McRobbie, Lucas, & Boutonne, 1997; Vince & Tiberghien, 2002). However, as is described by McDonald, Le, Higgins and Podmore (2005, p. 113) “tools and artifacts are generally referred to, rather than described, or seriously studied”.

The unawareness of technologies and instrumentation in the literature in philosophy of science can be contrasted the similar awareness in naturalistic studies of scientists in action making science. For example in the paper ‘seeing in depth’ by Goodwin (1995) there are ample discussion of the instruments the different scientists used and for what purpose. The paper displays an awareness of amplification/reduction issues involved in using different instruments that will be discussed below (See also, for example, Galison, 1987, 1997; Gooding, 1990; Hacking, 1983; Latour, 1987, 1994, 1999; Latour & Woolgar, 1979/1986; Lynch, 1993; Lynch, Livingston, & Garfinkel, 1983; Lynch & Woolgar, 1990).

We must recognise as Heelan (i.e. Heelan, 1983; Heelan & Schulkin, 1998) put forward that natural science is a ‘hermeneutic of instrumentation’. If we “[fail] to recognize the significance of non-humans” Selinger (2003) argues “[we will generate] idealistic and overly reductive analyses that [ignore] how material entities and forces influence how subjectivity is expressed”. Thus, I argue, we have to listen to the words of Waltz (Waltz, 2004) and “*give artifacts a voice*” and “*[bring] into account technology in educational analysis*”.

In this paper I will present a discussion and study about enhancing learning in engineering education through properly implemented technology, i.e. a discussion about the pedagogical implications on thinking and learning due to the use of different technologies. I will also relate this to theories of mediated learning. Finally I argue that if we do not do in-depth analysis of the role of technologies in science and engineering education we will miss to use technologies as tools for learning and thinking to its full potential.

2. THEORIES OF MEDIATED ACTION AND PHILOSOPHY OF TECHNOLOGY

Human experience of our world is, as briefly mentioned in the introduction, shaped by physical and symbolic tools (mediating tools). The concept of mediation and mediating tools could be represented diagrammatically as:

Human \Leftrightarrow Mediating tools \Leftrightarrow World

In his book *What Things Do* Verbeek (2000/2005) claims

“the concept of mediation helps to show that technologies actively shape the character of human-world relations. Human contact with reality is always mediated, and technologies offer one possible form of mediation. On the other hand, it means that any particular mediation can only arise within specific contexts of use and interpretation”.

The role of mediating tools is discussed within theories of education and psychological science and also within philosophy of technology. Questions about the role of technology (artifacts) in everyday human experience include:

- How do technological artifacts affect the existence of humans and their relationship with the world?
- How do artifacts produce and transform human knowledge?
- How is human knowledge incorporated into artifacts?
- What are the actions of artifacts?

The use of tools is a dual process: humans both shape the world (including human culture) and are shaped through the use of tools. This means that humans are part of their world (and can not step outside and view the world from the ‘outside’). As Cole (1996) points out:

“traditional dichotomies of subject and object, person and environment, and so on, cannot be analytically separated and temporally ordered into independent and dependent variables”. (p. 103)

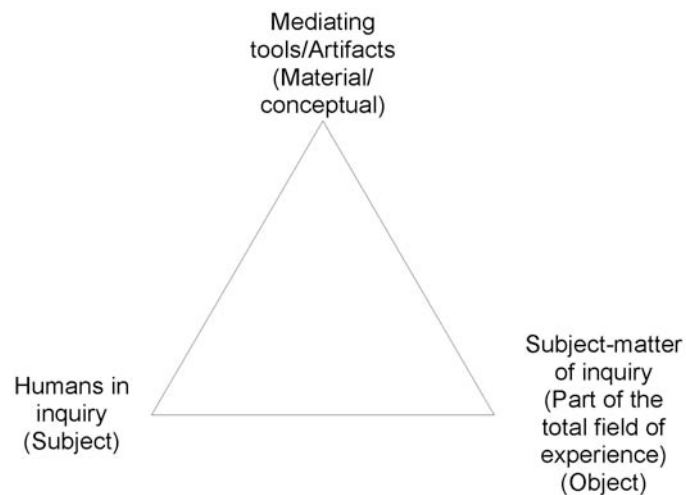


Figure 2. The basic mediation triangle in which humans in inquiry and the subject-matter of inquiry are thought of not only as directly related but also indirectly related via an artifact/tool. The objective ("intentionality") of inquiry is at the same time regulating the inquiry (Drawing modified and adapted from Cole (1996) and Vygotsky (1978)). The triadic relationship between *subject* – *mediating tools* – *object* illustrating that the relationship is transformed by mediation.

In the socio-cultural theory of learning developed by Vygotsky and his co-workers and students (e.g. Cole, 1996; Kozulin, 1998; Kozulin, Gindis, Ageyev, & Miller, 2003; Leont'ev, 1978; Leontyev, 1981; Vygotsky, 1978; Wertsch, 1991, 1998, 1979, 1985) the concepts of 'tool' and 'mediation' are key. The central thesis is that the structure and development of human psychological processes are co-constituted by the interaction with tools. These are historically developed and could be of different types such as 'psychological tools', 'material tools', language is also a tool. Using tools makes it possible to act in more powerful and functional ways and enhances and alter human development.

These tools (artifacts) are *simultaneously material* and *ideal/conceptual*. In the view of Vygotsky we can see the learner as an individual-in-society learning and thinking through artifacts. Vygotsky thus transcend dualistic thinking.

Vygotsky's ideas of artifacts as having a 'dual' material-conceptual nature are similar to the ideas of John Dewey and can be traced back to Engels (1925/1951), Marx (Marx & Engels, 1845/1957) and Hegel (1807/2006). See for example Cole (1996), Valsiner & van der Veer (2000), Ihde (Ihde & Selinger, 2003) and works within activity-theory extending and applying the ideas of Leontiev (e.g. Engeström, Miettinen, & Punamäki, 1999; Nardi, 1996; Nardi & Kaptelinin, 2006; Wertsch, 1991, 1979, 1985) for a further discussion.

Tools play an important role in Dewey's philosophy of education and in his philosophy of technology (see for example Hickman, 1990; Miettinen, 2001) he proposed that “*language [is] the tool of tools*” (Dewey, 1925/1981, p. 134). According to Dewey “[*tools play*] a large part in consolidating meanings [*and they are*] means to consequences, instead of being taken directly and physically” (ibid., p. 146). Tools are “*intrinsically relational, anticipatory, predictive*” (ibid., p. 146).

Common to the thinking of both Dewey and Vygotsky was the importance of seeing acts as *dynamic* and *holistic* units. For example Dewey (1896) criticised turning the dynamic process of acting into a sequence of static and disjointed stimuli and responses, thus eliminating the dynamic interdependence in the coordination of movement and sensation in the act.

According to the philosopher of technology Don Ihde perception is co-determined by technology. In science instruments do not merely ‘mirror reality’ but mutually constitute the reality investigated. The technology actively shapes the relationship between humans and their world by placing certain aspects in the foreground (and others in the background) and also by making certain aspects of reality visible that otherwise would be invisible.

This was also noted by Heidegger (1954, p. 29) that technology both reveals aspects of the world, we will be able to see things that we previously could not perceive or were difficult to perceive, *and* frames our experience, i.e. shapes figure-background relations:

“The essence of modern technology lies in enframing. Enframing belongs within the destining of revealing. ... But when we consider the essence of technology we experience enframing as a destining of revealing. ... The essence of technology lies in enframing”.

Ihde (e.g. 1979; 1991; see also Mitcham, 1994; and Verbeek, 2000/2005) have developed the following schematic distinctions regarding the intentional relationship between humans and their world:

Unmediated perception:

Human \Leftrightarrow World

Mediated perception:

Human \Leftrightarrow Technology \Leftrightarrow World

By unmediated perception Ihde meant perception unmediated by technological artifacts. In some sense all perception is mediated through psychological tools such as language, theories

and concepts. Within mediated perception Ihde make the distinction between embodiment and hermeneutic relations.

Embodiment relations:

(Human \Leftrightarrow Technology) \Leftrightarrow World

Hermeneutic relations:

Human \Leftrightarrow (Technology \Leftrightarrow World)

Alterity relations:

Human \Leftrightarrow Technology (\Leftrightarrow 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. In ideal embodiment relations the technology is 'transparent'. In hermeneutic relations the technology is not transparent. Some kind of interpretation is involved, hence the term hermeneutic. 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. It should be stressed that in the views of Ihde these are not distinct categories but parts of a continuum.

According to Ihde (e.g. 1991) neglecting the role of instruments (i.e. technological artifacts) in science leads to naïve realism. However in the philosophy of science the emphasis is often placed only on concepts and ideas. For example in Jay's (2005) otherwise excellent historical overview of theories of experience, the role of technology is never mentioned. Also, for example, in a recent paper, regarding the "contributions from the philosophy of science" (Mellado, Ruiz, Bermejo, & Jiménez, 2006) to education, the role of technology and instrumentation is virtually absent. However, in a paper by Gil-Pérez et al. (2005) it is argued, using an argumentation slightly different when the one in this paper, that we should not neglect technology. In line with this Pickering (1995, p. xi) notes "material agency has always been suspect in the sociology of scientific knowledge [except] in the actor-network approach" and other have noted this primacy is questioned or not considered (cf. Latour, 1994). As is obvious if one study many texts in philosophy of science, positivist as well as anti-positivist, the technologies, i.e. the instrumentation, used in the production of experimental evidence is invisible, i.e. seen as something unproblematic. See for example Hempel (1952; 1966). Experimental data are seen as pure unproblematic 'observables' in positivist stances and in

anti-positivist (e.g. Hanson, 1958) the praxis-ladenness of observations are overlooked (See also Heelan & Schulkin, 1998). Kroes (2003) notes that “[i]n [the traditional] view, the physicist is essentially a passive observer in experiments: once the stage is set he just observes (discovers) what is going to happen”.

It should be noted that one of the earlier critics of this ‘traditional’ point of view is Ian Hacking (1983) in his book *Representing and Intervening*. In a similar vein Wartofsky (1971/1979, p. 173) argues that “the separation of *logos* from *praxis* is impossible”. In his work Wartofsky (1973/1979, p. 194) points out that “perceptual artifacts [are] *means* [by] *which* we perceive real objects (or processes)”. I.e. in his theory of historical epistemology technology in form of perceptual artifacts is important. Further he claims “that ... modes of perception ... are historically variant ... related to *historical* changes in ... modes of human action (or *praxis*)”, he means when perceptual artifacts evolves human perception also evolves. That is the meaning of the term *historical epistemology* and he also claim (ibid., p 205) that “*artifact* is to cultural evolution what the *gene* is to biological evolution”.

Ihde (2003) have pointed some of the traditions who do not fail to recognize the significance of technology:

“One of the features of philosophy of technology that differentiates it from other styles of philosophy is its necessary sensitivity to the concrete, to materiality. The traditions of philosophy that are predisposed to precisely this concreteness are the praxis philosophies that include pragmatism, some strands of Marxism and neo-Marxism, and the phenomenology and hermeneutic traditions. It is not accidental that there is very little "analytic" philosophy of technology, and neither is it accidental that philosophy of technology associates with the praxis directions”. (cf. for example Davydov & Kerr, 1995; Engeström & Miettinen, 1999; Miettinen, 2001)

It is interesting to note that Nardi & Kaptelinin (2006, pp. 195-197) in their coining of the term ‘postcognitivist’ identified almost the same theories as Ihde above:

“We call the theories [of activity theory, distributed cognition, actor-network theory, and phenomenology] 'postcognitivist' because [they] remedy perceived shortcomings of cognitivist theory. ...A major point of agreement among postcognitivist theories is the vital role of technology in human life. ... Postcognitivist theories are highly critical of mind-body dualism. ... Postcognitivist theories provide an important alternative ... to authoritative theories ... in which technology is nearly invisible. ...Technology ... is not foregrounded in these theories, if it is mentioned at all”.

Postcognitivist theories take different experiential stances, i.e. are focusing on the man – world relationship in which the role of technology can not be neglected. In Nardi and Kaptelinin's mentioning of postcognitive theories I will claim that pragmatism in the tradition

of Dewey is missing. A pragmatist position following Dewey is put forward by McCarthy and Wright (2004, p. 30):

“[S]uggests a move away from understanding technology as ... augmenting knowledge and supporting decision making, and toward *technology as participating in the kinds of actions that make up our lives*. Moreover, when action is given primacy ... knowing is always engaged activity. There can be no detached understanding. Rather, understanding depends on pre-understanding which is the result of an individual’s experience within a tradition”. (Our emphasis)

The point McCarthy and Wright makes is not only that we have to understand the role of technology in knowledge and thinking, but that technology can not be seen as something ‘neutral’.

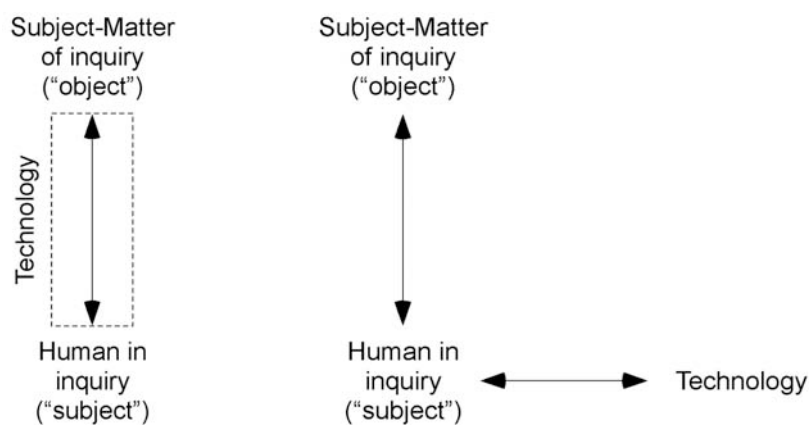


Figure 3. a. A ‘Transmissive’ view of technology where technology is seen merely as a vehicle for information **b.** An ‘Auxiliary’ view where technology is seen merely as a provider of information or support.

As will be further discussed below Ihde has recently further developing his philosophy of technology based on a synthesis between Dewey's pragmatism and a non-foundational phenomenology mainly inspired by Ricoeur and Merleau-Ponty.

3. LEARNING THROUGH TECHNOLOGY IN LABS

More than ten years ago I started reforming physics and engineering education by starting a design based research project developing novel learning environments using computer based measurement technology (Microcomputer Based Labs, MBL) in labs or laborative learning environments (Bernhard, 1999, 2001, 2003, 2008a).

The measurement and re-presentation technology in these labs serves as a mediating tool. The initial project was given the name ‘experientially based physics instruction’ and the original design took Dewey's (e.g. 1938; 1925/1981; 1938/1986) theories of experience, Vygotsky's (1978) theory of mediation and the ideas of Thornton (1990; 1996) and Thornton and Sokoloff (1998) as points of departure. Later the design was further improved by applying Marton's theory of variation (Marton & Tsui, 2004). Central to this theory is that *we learn through the experience of difference*, rather than the recognition of similarity.

As is shown in table 1, the introduction of mediating tools in the form of MBL has dramatically changed the learning outcome as measured by the FMCE-test (Thornton & Sokoloff, 1998).

Teaching Method / Course	Norm. Gain (FMCE)	Reference
Workshop physics	65%	Saul and Redish (1998)
MBL 1997/98	61%	This study
Physics 02/03 MBL-labs	48%	This study
Physics 02/03 Richardson-labs	18%	This study
ILD 05/06	37%	This study
Traditional (USA)	16%	Saul and Redish (1998)

Table 1. Learning gains for different courses (Saul & Redish, 1998) as measured by the FMCE-test and related to some of our results.

We have followed students' activities in the MBL-labs by recording them on video and investigating how students orient to, interpret, and participate in these labs. From our empirical data we see that students' courses of action are framed (Goffman, 1974) by encounters with the instructions, the technology, the teacher and other students.

When using the technology, students receive immediate feedback. In the process of constructing graphs they can see when they make mistakes. Students intertwine different interpretative resources as well as different experiential domains such as graphical shapes with narrative accounts of past actions. The central aspect of the graph must be focused on and in order to complete the assignments the students have to make certain conceptual distinctions.

The instructions for the task specify the process and specify variance and invariance in the learning space. In order to solve the task the students have to deal with certain concepts in certain ways.

Teachers not only design the learning environment, chose technology and write instructions, but also scaffold students' activities, including encouraging students to shift their attention to central parts of the graph while downgrading less important aspects.

Students have a common perspective on the graph – they perceive the computer as an extra lab partner. Different interpretations of graphical representation, the experiment and subject-matter are negotiated by the students. Arguments are made an important component of the process of solving the task.

It should be noted that the technology is present in all encounters. For example, much of the student–student or student–teacher communication is via the graphical representation of experimental results on the computer screen. This demonstrates the importance of seeing relations and representations as triadic and not dyadic as shown in figure 2. Our analysis of students' courses of action in MBL-labs reveals that the student spends very little time in "pure" interaction with the technology. However, if we only consider the time spent on different interactions, as is often done in many categorization schemas, we will miss important features of and differences between learning environments.

This study is part of a larger project. In an ongoing project we have applied the ideas behind the MBL-labs to a lecture setting (Bernhard, Lindwall, Engkvist, Zhu, & Stadig Degerman, 2007): We call these 'interactive lecture demonstrations'; one result of this project is presented as ILD 05/06 in table 1. We have also implemented similar ideas in a course on electric circuit theory for engineering students (Bernhard & Carstensen, 2002; Carstensen & Bernhard, 2007, in press)

Since the focus in this paper is on the role of technologies in experimentation and the affordances (Gibson, 1979) of different instruments I think it would be illuminating to discuss a case from 'real research' in solid state physics. Before turning my whole attention to research into physics and engineering education I spent 15 years as a researcher in solid state physics and solid state chemistry.

Magnetic structures studied by neutron diffraction

During my earlier research in solid state physics I was, among other studies, involved in researching the magnetic properties of the hexagonal and cubic polymorphs of ironmonogermanide, FeGe. We had first studied the hexagonal polymorph (B35-type, P6/mmm) doing macroscopic magnetization measurements as well as studying the more microscopic magnetic structures by means of neutron diffraction (Bernhard, Lebech, & Beckman, 1984, 1988). Later we continued to study the cubic polymorph (B20-type, P2₁3) (Lebech, Bernhard, & Freltoft, 1989). Both polymorphs display unusual magnetic properties indicating complicated magnetic structure. Although neutrons are uncharged, they have a magnetic moment, and they can therefore interact with magnetic moments, including those arising from the electron cloud around an atom. Neutron diffraction can therefore reveal the microscopic magnetic structure of a material.

The low-temperature magnetic structure of hexagonal FeGe proposed by us is displayed in figure 4a. The arrows in the figure are showing the direction of the magnetic moments on the Fe-atoms. If this structure, instead, had been ferromagnetic all magnetic moments had been collinear, i.e. the arrows would have been pointing in the same direction. And if the magnetic structure had been antiferromagnetic the arrows would have been parallel, but each alternate plane of arrows would have been pointing in opposite directions. In the case of hexagonal FeGe it does not have a simple antiferromagnetic structure, but it also have a helical component that is depicted as the magnetic moments lying on a cone. Without going into details this structure is revealed in the neutron diffraction data by the two smaller peaks (also called satellites) on each side of the main peaks (See figure 4b). For this structure to repeat itself (repeat distance) a distance of $\sim 100 \text{ \AA}$ is needed, corresponding to ~ 25 unit cells.

In all diffraction, regardless of it is electron, X-ray or neutron diffraction there is a reciprocal relationship between distances in the real crystal and the distances between corresponding peaks observed when detecting the intensity of scattered rays, i.e. if the repeat distance of

hexagonal FeGe had been longer the satellite peaks would come closer to the position of the main peaks.

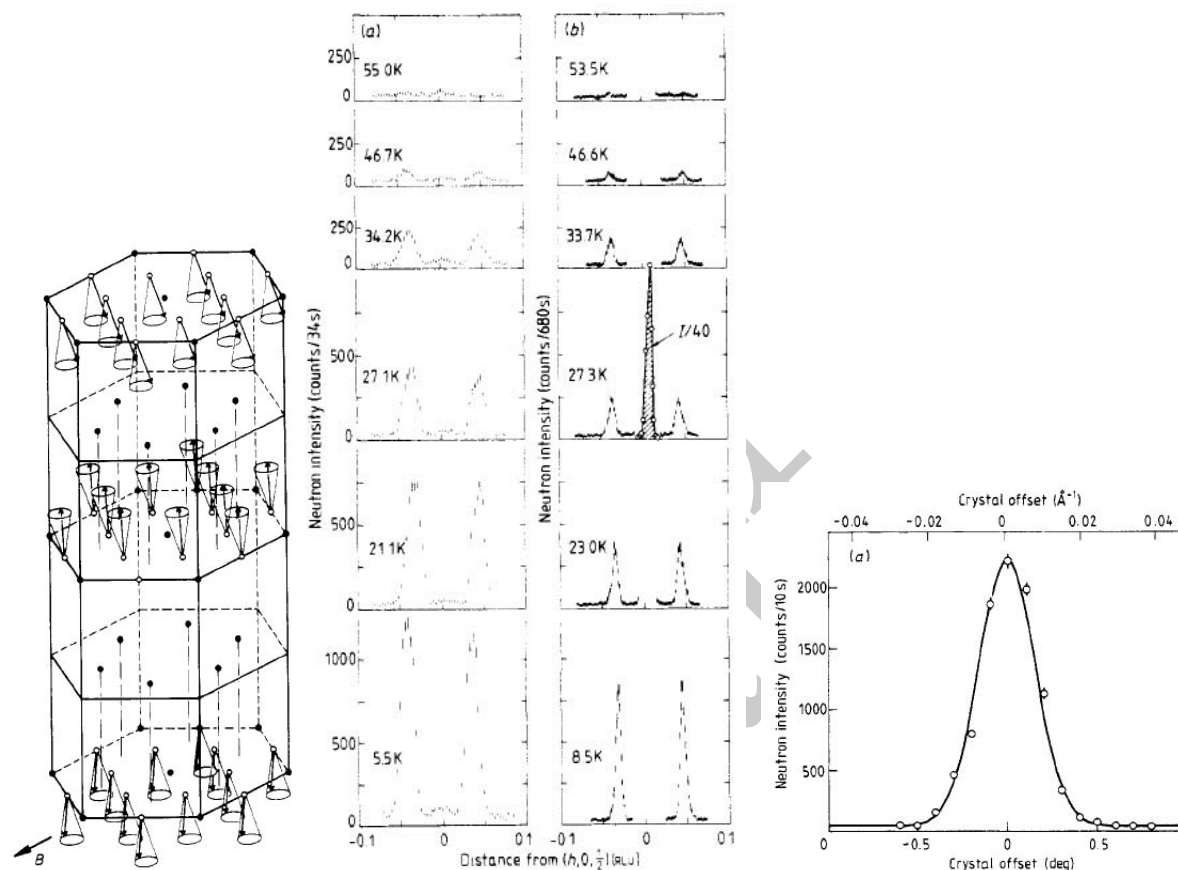


Figure 4. a. Crystal structure (P6/mmm) of hexagonal FeGe. The arrows on the cones indicate the directions of the Fe-atom spins of the proposed double-cone structure below -55 K (see text). The turn angle per layer has been increased for illustrative reasons. **b.** Neutron diffraction scans for hexagonal FeGe around $(0, 0, \frac{1}{2})$ and $(1, 0, \frac{1}{2})$ showing the temperature dependence of the magnetic satellites appearing below 55 K. **c.** Crystal rocking curve for the $(2, 0, 0)$ Bragg peak of cubic FeGe, measured with a conventional neutron spectrometer using incident neutrons of wavelength 2.54 Å.

When we continued our studies by turning our attention to cubic FeGe we had the hypothesis that it should have a plane helical magnetic structure. However we could not first resolve any satellites using high-resolution triple-axis neutron spectrometer. We then decided to try the so-called small-angle neutron spectrometer (SANS). The SANS-instrument used cold neutrons that have longer wave lengths (in most of our experiment with SANS we used $\lambda = 15.8$ Å) than thermal neutrons ($\lambda = 1.7 - 4$ Å in our experiments). This allows studies of samples with long repeat distances, for example bio-molecules or polymers. However at that time, this technique had not been used for studying magnetic structures of *single* crystals.

After some trials we finally got patterns similar to those displayed in figure 5b on our monitor. The satellite peaks could be well resolved. We found intensity patterns corresponding to different spiral magnetic structures. These had the very long range repeat distance of $\sim 700 \text{ \AA}$, corresponding to ~ 149 unit cells.

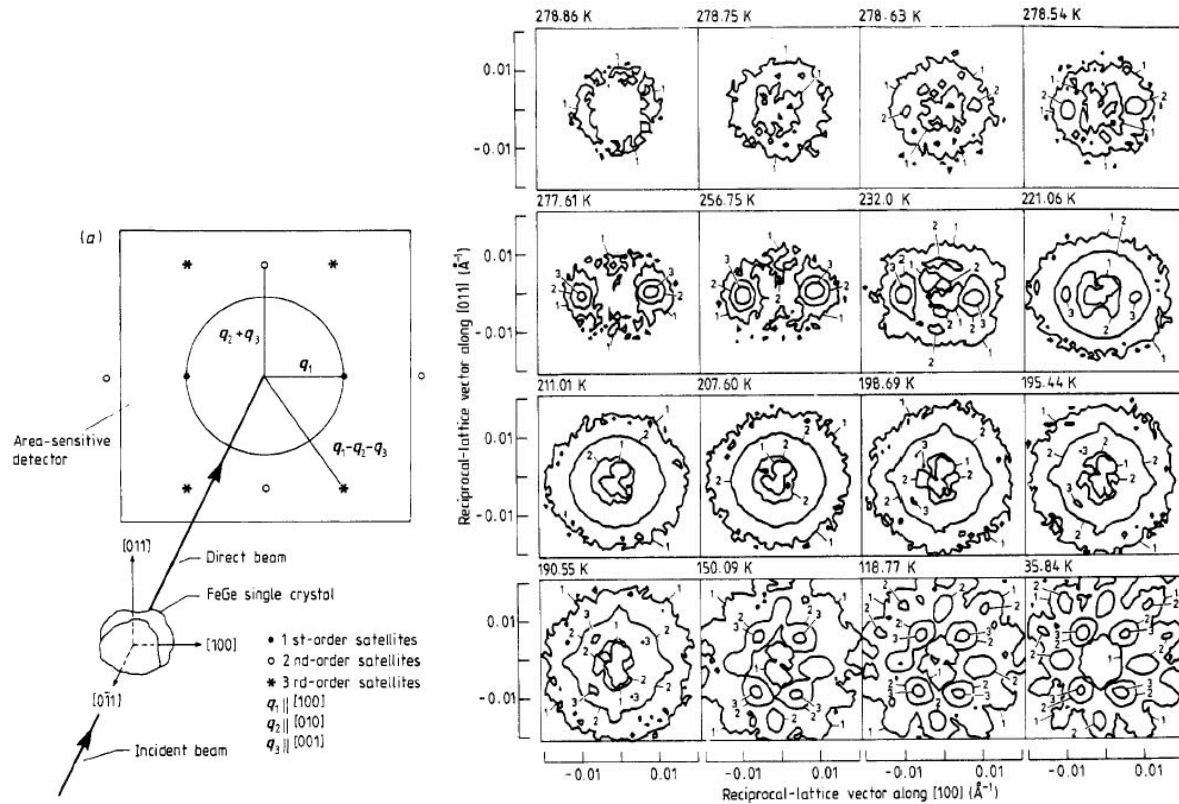


Figure 5. a. Illustration of the scattering geometry used in the small-angle neutron scattering measurements on cubic FeGe. b. Equal intensity contours (logarithmic scale) observed in the $(0\bar{1}1)$ plane of cubic FeGe at various temperatures below $T_N = 278.7 \text{ K}$ after background subtraction and normalisation. There are factors of 10 between the contour lines marked 1, 2 and 3.

This example shows two experimental procedures with different affordances, e.g. different physical phenomena could be ‘seen’ in the different experiment. It should be noted the SANS-technique also had disadvantages, for example we could not get an absolute scaling of the intensity against a nuclear Bragg peak and we were therefore not able to make an absolute calculation of the magnitude of the magnetic moment distribution in the case of cubic FeGe. Since the experiment using the SANS-technique was among the very first in the world to use this technique for studying magnetic properties of single crystals the advantages and the disadvantages were discussed in our paper (Lebech, Bernhard, & Freltoft, 1989).

In a later study on a complete other system, ErRh_3B_2 (Bernhard et al., 1993; Harris et al., 1993), we had to use isotope enriched Boron (93% B-11) since B-12 absorbs neutrons making neutron diffraction impossible if Boron with a natural isotope composition were used. In this case it is interesting to note two things: 1. We changed ‘nature’, e.g. our object of study, to suite or experimental needs. 2. Although it were mentioned in the papers that we had grown crystals using isotope enriched Boron it were not discussed why – This was taken for granted that the reader should know. If one were only reading the published papers one would miss many important considerations made by researchers (cf. Gooding, 1990).

In the standard textbook about neutron diffraction at that time (Bacon, 1975) much attention were paid to compare neutron diffraction against other methods and what you could ‘see’ with different methods, e.g. the affordances of different were discussed in detail. This was also discussed in the textbooks I had as an undergraduate student in engineering. In for example *Microscopy of Materials* (Bowen & Hall, 1975, p. viii-ix) one can read “what can this instrument be used for, and, which ... is best for this particular problem? ... [It] contains ... [a] review of ... techniques and their advantages and limitations ... [I]nstruments ... must be used intelligently, and ... the best and most *meaningful results are obtained ... only when the experimenter thoroughly understands ... his instrument ...*”. (My italics)

This, I argue, stands in sharp contrast to the unawareness in much of the literature in philosophy of science and in science education.

In the literature one can often find the view that an experiment is about testing theories. However in our research we discovered several phenomena not predicted by theory. Rather than giving theory precedence one could find a dialectical interplay between theory development and experimental phenomena in our case. In Bernhard (Bernhard, 1987) p. 7 it was also pointed out how difficult it were in practice to do theoretical predictions for the systems studied: “This possible mixture, in an actual substance [of a transition metal or transition metal compound], between localized and itinerant electrons is difficult to treat, and theoretical approaches to ordered magnetism are usually of a phenomenological character and tend usually to overemphasize either the localized or the itinerant nature of the electrons”.

Mechanics studied by different lab setups

I will now discuss three different cases where students studied mechanics in labs. On the surface it is the same mechanics content studied with similar physical setup, an object moving

on an inclined plane. My focus in this study is on the affordances of the instrument used and I will investigate what is possible to do and not. I will therefore not include transcripts from students' actions in these labs. However, transcripts and a discussion of students course of action will be presented elsewhere (Bernhard, 2008b).

It is well known from the literature (provide references in the final paper) that many students believe that acceleration is in the direction of motion when an object is tossed upwards and that the acceleration is zero at the top when velocity is zero. As will be shown some setups could address so address these issues, while other cannot.

1. Glider on an air track

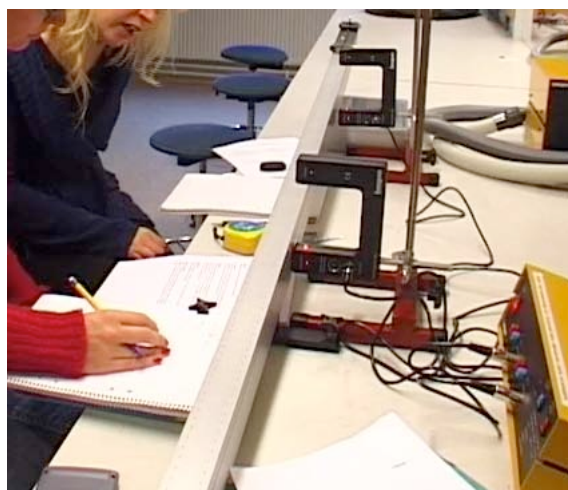


Figure 6. Glider on an inclined air track. Speed measured using photo gates.

In figure 6 is a setup with a glider on an air track displayed. The track is inclined and the air track system is made to provide a setup with low friction. A 'flag' is attached to the glider. This flag blocks the light beam of the two photo gates when the glider passes the gates. If Δx is the width of the flag and t_1 and t_2 are the times the light beams are blocked the instantaneous velocities can be calculated as $v_1 = \Delta x/t_1$ and $v_2 = \Delta x/t_2$. The mean acceleration can be calculated through $a = (v_2 - v_1)/t_3$, there t_3 is the time from gate 1 to gate 2.

The velocity and the acceleration when the glider slides down the inclined as well as for a motion upwards (after an initial push) could be calculated. Thus the view that the acceleration is in the direction of motion could be addressed (In the actual lab studied the students were not asked to do this, but the equipment affords this task). However it is not possible to show by experimental data that a glider given a push upward will have a non-zero acceleration at

the point there the glider turns (and have zero velocity) and it is not possible to follow a complete motion there the glider first moves upwards and when moves downwards in a continuous sequence.

By this technique it is not an easy task to draw position-time, velocity-time and acceleration-time graphs.

2. Tape timer



Figure 7. Motion of a cart down an inclined plane. Position as function of time measured using a tape timer.

In this method a paper tape is attached to a cart moving down an inclined plane. The ‘tape timer’ prints dots on the tape at equal time intervals (in this case the net alternating current frequency was used for driving and dots were made every 0.01 s (from 2·50 Hz)). The dots thus provided a time reference. By measuring the position on the tape by the dots it were quite straightforward to make a position-time graph. Velocity-time and acceleration-time graphs could be made by numerical derivation ($v = \Delta x / \Delta t$ and $a = \Delta v / \Delta t$).

Since the tape is pulled by the cart through the ‘tape timer’ only motion downward could be studied. Thus it is not possible to address the direction of the acceleration if the cart were given a push upward along the inclined plane or the magnitude of the acceleration at the turning point.

3. Probeware (MBL)

In the third case we still have an inclined plane with an object moving up or down (or both). In this case a motion sensor attached via an interface to a computer measures the position. The motion sensor is measuring the position of the cart in real-time and the computer can display on its screen, in real-time, the position as well as the velocity and the acceleration as function of time. Velocity and acceleration is obtained by numerical derivation by the computer.



Figure 8. A carts' motion on an inclined plane measured by means of a motion sensor connected to a computer via an interface.

Contrary to the previous cases the graphs are presented simultaneously with the actual motion. However, most important for my point in this paper is that a wider range of phenomena can be studied experimentally. In this case it is as convenient to study motion down the incline as one up the incline. Also the acceleration at the carts highest point, for a cart given an initial push upwards, can be measured and the view that acceleration is zero at this point can be addressed. The other methods mentioned above can not do this.

Also it is rather easy to address varying friction and investigate how this will affect the motion as is shown in figure 9. In this case the acceleration is different in the different directions due to the fact that the direction of the friction force is opposite to the actual motion. Experimental results are shown in figure 9b.

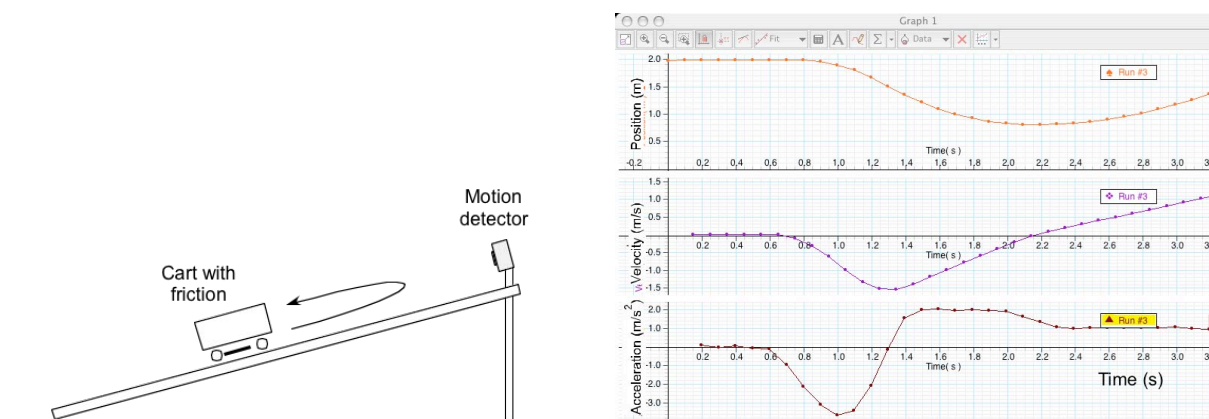


Figure 9. a) Demonstration involving a cart with friction given an initial velocity upwards along an inclined plane and b) the resulting experimental results.

	Motion down	Motion up	Whole motion (up and down)	Measurement type	Graphing
Photogates	+	+	-	Point	Difficult
Tape timer	+	-	-	'continuous', manual	Manual
Probeware	+	+	+	'continuous', 'automatic'	Real-time

Table 2. A summary of the affordances and some other characteristics of the different techniques used to study motion discussed above.

A summary of the different affordances is presented in table 2. This comparison may be interpreted, as it is possible to address a larger repertoire of conceptual issues regarding motion and bring these into focal awareness that might be one key to the success of well-designed curricula using probeware.

4. DISCUSSION AND CONCLUSIONS

Should be extended in the final version

Our results give examples of learning environments where the use of technology to create tools for mediation is essential for the design of the learning environment and the resultant educational achievements.

Ihde, in his post-phenomenology (e.g. Ihde, 1993, 2005; Selinger, 2006), tried to produce a synthesis of his phenomenology-based philosophy of technology with Dewey's pragmatism. We argue that there is a need to continue with this approach and also to try to incorporate theories of mediation derived from the ideas of Vygotsky (Engeström & Miettinen, 1999; Miettinen, 2001).

The idea that is put forward in this paper that technologies are important, and neither neutral nor deterministic, tools for learning and thinking have implications for our view about the 'nature of science'. The 'instrumental realism' put forward by Ihde (1991) also have implications for this. Ihde (1979, p. xxvi) points out that a "different ontology results in a different understanding of technology, science, and the results of both within the world of human experience". Problematic epistemic stances, for example regarding the role of theory and experimentation, are from my point of view put forward by the literature in science education. If we are not aware of the different stances Sundlöf, Carstensen, Tibell, & Bernhard (2003) argue that "confusion might ensue [if teachers' and students'] conceptions of representations' ontological and epistemic status [were in conflict]". Therefore there is a need to discuss epistemological and ontological issues in relational to technological mediation and to focus on the old concept of *techne*. *Techne* was used by the ancient Greeks to designate a productive skill (see for example Heidegger, 1926/2006; Hickman, 1990; Mitcham, 1994; Parry, 2003; Verbeek, 2000/2005). It involved both knowledge and ability directed towards the fulfilment of some aim. It involved a rational professional skill beyond simple experience.

Different applications of technologies shape the character of the human–world relationship in education and hence the learning outcomes. Similarly Bernhard (2003), noting the importance of educational design, argues

“this study shows that MBL doesn't automatically give good learning results. ... [C]omputer aided learning, can not be implemented as only a technology. The educational

implementation is of crucial importance and hence there is no definite answer to the common question if computers help to achieve ‘better’ learning” (cf. Tinker, 1996, p. 3).

Bernhard (2003) argues for the importance for the teacher *in* the learning environment as well as a designer *of* the learning environment. This is also argued by for example Säljö (1998, p. 158):

“Simultaneously, one can also see that what technologies provide are experiences, but they do not guarantee a specific interpretation of these experiences that would amount to learning what was intended. To facilitate understanding, the expertise of a teacher or a knowledgeable conversation partner would still be required”.

In conclusion, as stressed by Sabelli (1995, see introduction above), Dewey, Vygotsky and several others, we can not neglect the role of tools for learning and thinking. This is the main point of postcognitivist theories

But this does not implies that we forget that we as human beings are part of nature, or as beautifully stated by Larry Hickman (2001, p. 39) following Dewey:

“Viewed in this perspective, to say that human beings are uniquely *technological animals* is not to place them outside and above nature, *but within nature and a part of it*. Our activities differ from those of our non-human relatives and ancestors not in kind, but *only in level of complexity*”. (Our emphasis)

However the discussions regarding appropriateness of technologies are often transformed into a discussion into ‘high technology’ as in this citation of Lunetta (1998, p. 257-258).

“Yet, with the increasing availability of *high technology* resources ... it is increasingly important that teachers consider the appropriateness of specific technologies introduced in students’ laboratory experiences”.

However, I would argue that it is important to realize that technologies are part of our lifeworlds, and are shaping our experience, regardless of they are so called ‘high’ or ‘low’ tech. Some successful lab curricula uses ‘simple’ material and technologies. The important thing is how the technologies used constitutes or experience, e.g. does the critical features for learning a specific object enter into the focal awareness of students and are the necessary discernments made?

I would claim that the inconclusive and contradictory results regarding the ‘effectiveness’ of labs for teaching science and engineering and regarding the ‘effectiveness’ of computers in education are due to that the role of technologies as mediation tools are not fully analysed or understood. I fully agree with Ihde’s statement there is a need for a practice informed by philosophy of technology:

“Indeed, late modern science without instruments would have to shrink to the limits of a now ancient past. Here, again, is a role for philosophy of technology, a philosophy sensitive to the material culture, conditions and capacities of human-technology relations” (2007, p. 114).

Lunetta (1998, p. 250) claims that “To many students, a ‘lab’ means manipulating equipment but not manipulating ideas”. However, the main point of this paper is that by manipulating equipment we are more or less manipulating ideas and reciprocally in dialectical way our perceptions and conceptions are ‘manipulated’ by the equipment we are using. Artifacts are both mind and matter. My final claim is that ‘effectiveness’ of some of the technology rich learning environments discussed above is due to the fact that the designers have (at least partially) been aware of the mediating role of technologies. There is room for more research investigating the intentional correlate human-technology-world in relation to educational issues.

Galison (1987, p. 19) argues that we must focus on the activities in the laboratory and reminds us that “[f]or years the history and philosophy of science has relied on an image of experimentation viewed through theory. Experiments, when they were discussed at all were reduced to observations, the psychology of observations, and theorists' use of observations. ... *Only there, in the laboratory itself, can one see how the miner sifts gold from pyrite*” (My italics). Only by carefully studying the interplay between students, instructions, teachers and technologies can we see how meaning is constituted.

Some of the points, and the examples provided, may seem to be trivial. However, since the role of technologies in labs has been neglected in most studies they can not be treated as something trivial. Maybe we do not see the technology because it is right before our eyes as Wittgenstein points out “The aspects of things that are most important for us are hidden because their simplicity and familiarity. (One is unable to notice something – because it is always before one’s eyes.) ...” (Wittgenstein, 1953/2003, §129).

In an earlier paper Hofstein and Lunetta (1982) talked about ‘neglected aspects of research’ – I hope that this paper has shown that the role of technologies in labs is a clearly neglected aspect of research.

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