

Thinking and Learning through Technology - Mediating Tools in Science and Engineering Education

Jonte Bernhard
Engineering education research group, ITN,
Linköping University, Campus Norrköping,
SE-601 74 Norrköping, Sweden.
E-mail: jonbe@itn.liu.se

Abstract

It is argued that all learning and thinking is about establishing experiential human – world relationships. Thinking and learning cannot be studied in isolation. Human contact with reality is always mediated. Technology offers one form of mediation and projects in engineering education are presented here where learning through technology is central to the design of the learning environment.

Keywords: Artifact mediation, technology supported learning, philosophy of technology

1 Introduction

“*Learning is learning to think*” according to 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 ↔ Mediating tools ↔ 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)

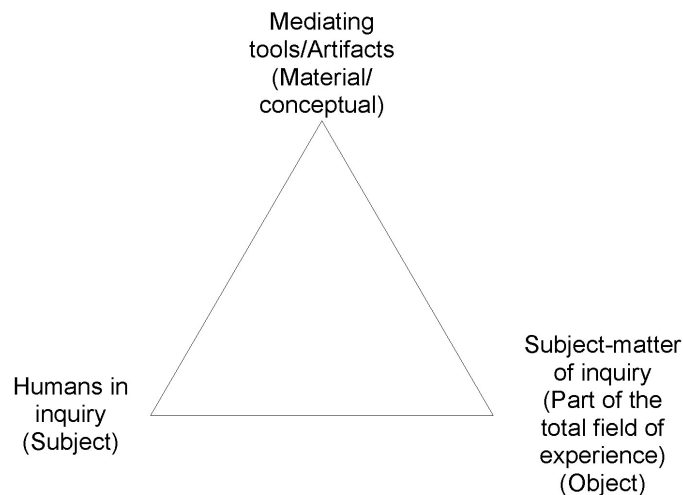


Figure 1. The basic mediational triangle in which humans in inquiry and the subject-matter of inquiry are thought of not only as directly related but also indirectly related via an artifact/tool. The objective ("intentionality") of inquiry is at the same time regulating the inquiry (Drawing modified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

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.”

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.”

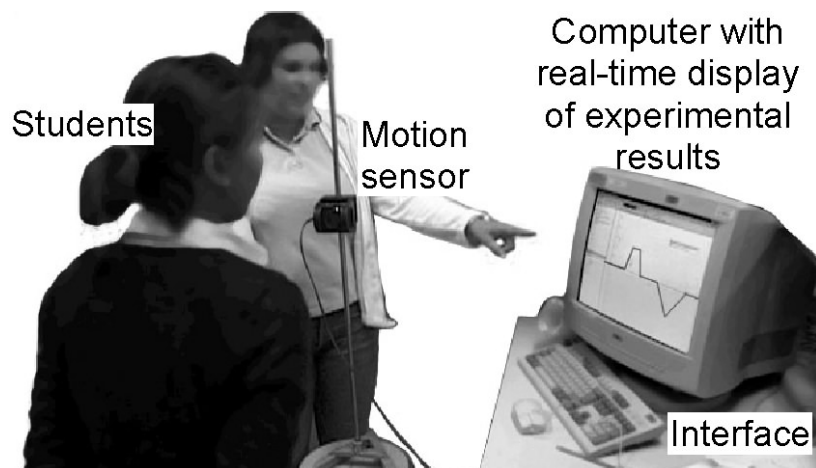


Figure 2. Picture of the setup in one of the labs concerning laws of motion. The motion sensor is connected to the computer via an interface. On the computer screen the result from the experiment is presented in real-time.

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).

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 below, 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).

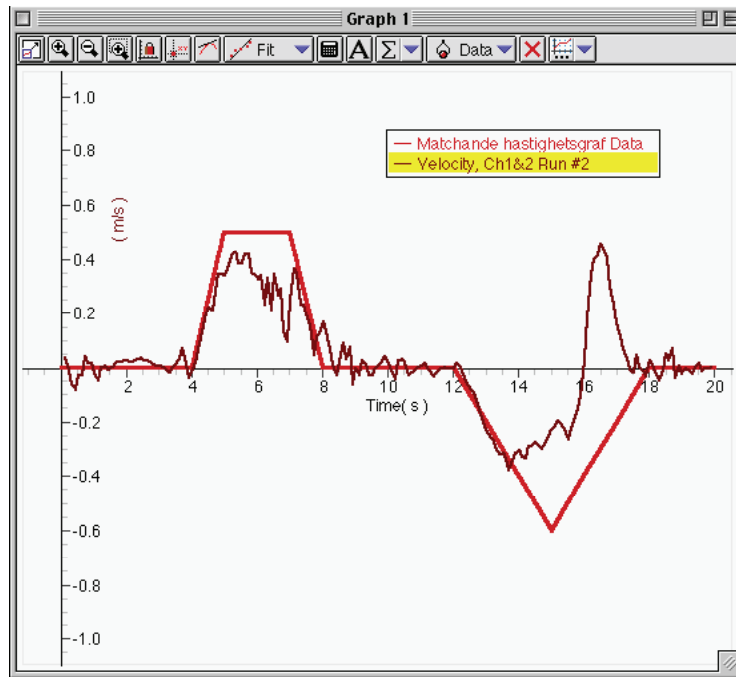


Figure 3. Example of a task that students attempt to solve in the motion labs. Displayed is a $v(t)$ -graph with a curve which the students are asked to match to an experimental graph produced by a student. The students will see their graph in real-time while trying to reproduce the prescribed graph.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

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.

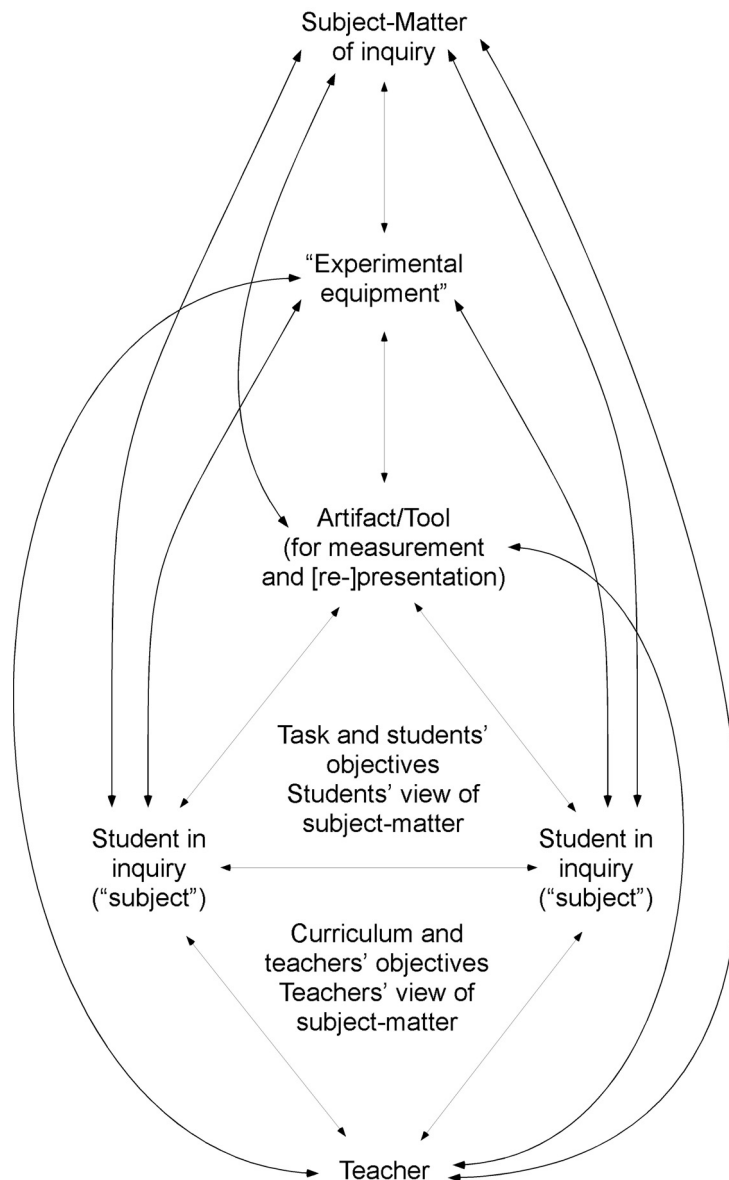


Figure 4. A schematic model of encounters and framing of activities in MBL-labs. The model shows several triadic relations and is an extension of the model presented in figure 1.

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 (Cuban 2001), 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.

Acknowledgements

The Swedish Research Council and the Council for renewal of higher education funded part of the research and development presented in this paper. It is also part of a larger ongoing project and I am grateful to colleagues and friends in Sweden and abroad for valuable discussions, suggestions and assistance.

References

- Bernhard J. (1999) "Hands-on experiments in advanced mechanics courses", Born G. & Harreis H. & Litschke H. & Treitz N. (Eds.), *Hands on-Experiments in Physics Education*, Didaktik der Physik, University of Duisburg, Duisburg, pp. 175-177
- Bernhard J. (2001) "Does active engagement curricula give long-lived conceptual understanding?" Pinto R. & Surinach S. (Eds.), *Physics Teacher Education Beyond 2000*, Elsevier, Paris, pp. 749-752
- Bernhard J. (2003) "Physics learning and microcomputer based laboratory (MBL): Learning effects of using MBL as a technological and as a cognitive tool", Psillos D. & P. K. & Tselfes V. & Hatzikraniotis E. & Fassouloupoulos G. & Kallery M. (Eds.), *Science Education Research in the Knowledge Based Society*, Kluwer, Dordrecht, pp. 313-321
- Bernhard J. (2006) "Conceptual labs - experiences from a decennium of design and implementation", Paper presented at the *EARLI CCSIG, Bridging the gap between mental models and situated cognition?*, Saltsjöbaden.
- Bernhard J., Carstensen A.-K., & Lindwall O. (2005) "Highly structured open inquiry labs", Paper presented at the *EARLI 2005*, Nicosia, Cyprus.
- Carstensen A.-K., & Bernhard J. (in press) "Threshold Concepts and Key Concepts - Some examples from Electrical Engineering", Land R. & Meyer E. & Smith J. (Eds.), *Threshold Concepts within the Disciplines*, Routledge, London,
- Cobb P. (1994) "Where is the mind? Constructivist and sociocultural perspectives on mathematical development." *Educational Researcher*, Vol 23, No 7. pp. 13-20
- Cole M. (1996) *Cultural psychology: A once and future discipline*, Harvard University Press, Cambridge
- Cuban L. (2001) *Oversold & Underused: Computers in the Classroom*, Harvard University Press, Cambridge
- Davydov V. V., & Kerr S. T. (1995) "The Influence of L. S. Vygotsky on Education Theory, Research, and Practice", *Educational Researcher*, Vol 24, No 3. pp. 12-21
- Dewey J. (1896) "The Reflex Arc Concept in Psychology", *Psychological Review*, Vol 3. pp. 357-370
- Dewey J. (1938) *Experience & Education*, Touchstone, New York
- Dewey J. (1981) "Experience and Nature", Boydston J. A. (Ed.), *John Dewey: The Later Works* (Vol 1), Southern Illinois University Press, Carbondale,
- Dewey J. (1986) "How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process", Boydston J. A. (Ed.), *John Dewey: The Later Works* (Vol 8), Southern Illinois University Press, Carbondale,
- Dewey J. (1986) "Logic: The Theory of Inquiry", Boydston J. A. (Ed.), *John Dewey: The Later Works* (Vol 12), Southern Illinois University Press, Carbondale,
- Engels F. (1925/1951) *Dialektik der Natur*, Dietz Verlag, Berlin
- Engeström Y., & Miettinen R. (1999) "Introduction", Engeström Y. & Miettinen R. & Punamäki R.-L. (Eds.), *Perspectives on activity theory*, Cambridge University Press, Cambridge, pp. 1-16
- Engeström Y., MIETTINEN R., & PUNAMÄKI R.-L. (Eds.). (1999) *Perspectives on activity theory*, Cambridge University Press, Cambridge
- Goffman E. (1974) *Frame Analysis: An Essay on the Organization of Experience*, Harper & Row, New York
- Hegel G. W. F. (1807/2006) *Phänomenologie des Geistes*, Felix Meiner Verlag, Hamburg
- Heidegger M. (2006) *Sein und Zeit* (Neunzehnte ed.), Max Niemeyer Verlag, Tübingen
- Hickman L. A. (1990) *John Dewey's Pragmatic Technology*, Indiana University Press, Bloomington
- Holder J. J. (1995) "An Epistemological Foundation for Thinking: A Deweyan Approach", *Studies in Philosophy and Education*, Vol 13. pp. 175-192
- Ihde D. (1979) *Technics and Praxis*, D. Reidel Publishing Company, Dordrecht

- Ihde D. (1991) *Instrumental Realism: The Interface between Philosophy of Science and Philosophy of Technology*, Indiana University Press, Bloomington
- Ihde D. (1993) *Postphenomenology: Essays in the Postmodern Context*, Northwestern University Press, Evanston
- Ihde D. (2003) "Introduction: Part One", Ihde D. & Selinger E. (Eds.), *Chasing Technoscience: Matrix for Materiality*, Indiana University Press, Bloomington, pp. 1-7
- Ihde D. (2005) "Phenomenology+Pragmatism=Postphenomenology", Paper presented at the *Husserl Circle*, Dublin.
- Ihde D., & Selinger E. (Eds.). (2003) *Chasing Technoscience: Matrix for Materiality*, Indiana University Press, Bloomington
- James W. (1890) *The Principles of Psychology*, Henry Holt, New York
- Jay M. (2005) *Songs of Experience: Modern American and European Variations on a Universal Theme*, University of California Press, Berkeley
- Kouzulin A. (1998) *Psychological Tools: A Sociocultural Approach to Education*, Harvard University Press, Cambridge
- Kozulin A., Gindis B., Ageyev V. S., & Miller S. M. (Eds.) (2003) *Vygotsky's Educational Theory in Cultural Context*, Cambridge University Press, Cambridge
- Leont'ev A. N. (1978) *Activity, Consciousness, and Personality*, Prentice-Hall, Englewood Cliffs
- Leontyev A. N. (1981) *Problems of the development of the mind*, Progress Publishers, Moscow
- Lindwall O., Engkvist J., Bernhard J., Lindström B., & Lymer G. (2005) "The use of technology in physics education: Making mechanics visible and learnable", Paper presented at the *EARLI CSCL SIG meeting*, Gothenburg.
- Marton F., & Tsui A. B. M. (Eds.). (2004) *Classroom Discourse and the Space of Learning*, Lawrence Erlbaum, Mahwah
- Marx K., & Engels F. (1845/1957) *Die deutsche Ideologie: Kritik der neuesten deutschen Philosophie in ihren Repräsentanten Feuerbach, B. Bauer und Stirner, und des deutschen Sozialismus in seinen verschiedenen Propheten*, Dietz, Berlin
- Miettinen R. (2001) "Artifact Mediation in Dewey and in Cultural-Historical Activity Theory", *Mind, Culture & Activity*, Vol 8, No 4. pp. 297-308
- Mitcham C. (1994) *Thinking through Technology: The Path between Engineering and Philosophy*, The University of Chicago Press, Chicago
- Nardi B. A. (Ed.). (1996) *Context and Consciousness: Activity Theory and Human-Computer Interaction*, The MIT Press, Cambridge
- Nardi B. A., & KAPTELININ V. (2006) *Acting with Technology: Activity Theory and Interaction Design*, MIT Press, Cambridge
- Normand D. A. (1993) *Things that make us smart: Defending human attributes in the age of the machine*, Basic Books, New York
- Parry R. (2003) "Epistêmê and Technê", Zalta E. (Ed.), *The Stanford Encyclopedia of Philosophy (Summer 2003 Edition)*,
- Rorty R. (1991) *Objectivity, Relativism, and Truth: Philosophical Papers Volume I*, Cambridge University Press, Cambridge
- Roth W.-M., Hwang S., Mafra Goulart M. I., & Lee Y. J. (2005) *Participation, Learning, and Identity: Dialectical perspectives* (Vol. 14), Lehmann Media, Berlin
- Ryle G. (1949) *The Concept of Mind*, The University of Chicago Press, Chicago
- Saul J. M., & Redish E. F. (1998). An Evaluation of the Workshop Physics Dissemination Project. College Park: Dep. of Physics, University of Maryland.
- Selinger E. (2003) "Introduction: Part Two", Ihde D. & Selinger E. (Eds.), *Chasing Technoscience: Matrix for Materiality*, Indiana University Press, Bloomington, pp. 7-12

- Selinger. (Ed.). (2006) *Postphenomenology: A Critical Companion to Ihde*, State University of New York Press, Albany
- Sfard A. (1998) "On Two Metaphors for Learning and the Dangers of Choosing Just One", *Educational Researcher*, Vol 27, No 2. pp. 4-13
- Sundlöf A., CARSTENSEN A.-K., TIBELL L., & BERNHARD J. (2003) "Real Models in Modelled Reality: epistemic confusion when communicating science?" Paper presented at the *ESERA 2003*, Noordwijkerhout, Netherlands.
- Thornton R. K. (1990) "Tools for Scientific Thinking: Learning Physical Concepts with Real-Time Laboratory Measurement Tools", Redish E. F. & Risley J. S. (Eds.), *The Conference on Computers in Physics Instruction: Proceedings*, Addison-Wesley, Redwood City, CA, pp. 177-189
- Thornton R. K. (1996) "Using Large-Scale Classroom Research to Study Student Conceptual Learning in Mechanics and to Develop New Approaches to Learning", Tinker R. F. (Ed.), *Microcomputer-Based Labs: Educational Research and Standards*, Springer, Berlin, pp. 89-114
- Thornton R. K., & SOKOLOFF D. R. (1998) "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula", *American Journal of Physics*, Vol 66, No 4. pp. 338-352
- Tinker R. F. (1996) "Introduction", Tinker R. F. (Ed.), *Microcomputer-Based Labs: Educational Research and Standards*, Springer, Berlin, pp. 1-10
- Valsiner J., & VAN DER VEER R. (2000) *The Social Mind: Construction of the Idea*, Cambridge University Press, Cambridge
- Verbeek P.-P. (2005) *What Things Do: Philosophical reflections on technology, agency, and design* (Crease R. P., Trans.), The Pennsylvania State University Press, University Park
- Vygotsky Y. L. S. (1978) *Mind in society: The development of higher psychological processes*, Harvard University Press, Cambridge
- Waltz S. B. (2004) "Giving artifacts a voice? Bringing into account technology in educational analysis", *Educational Theory*, Vol 54, No 2. pp. 157-172
- Wertsch J. V. (1991) *Voices of the Mind: A Sociocultural Approach to Mediated Action*, Harvard University Press, Cambridge
- Wertsch J. V. (1998) *Mind as Action*, Oxford University Press, Oxford
- WERTSCH J. V. (Ed.). (1979) *The Concept of activity in Soviet psychology*, Sharpe, Armonk
- WERTSCH J. V. (Ed.). (1985) *Culture, communication, and cognition: Vygotskian perspectives*, Cambridge University Press, Cambridge