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Logic of Sherlock Holmes in Technology Enhanced Learning

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ABSTRACT

Abduction is a method of reasoning that people use under uncertainty in a context in order to come up with new ideas. The use of abduction in this exploratory study is twofold: (i) abduction is a cross-disciplinary analytic tool that can be used to explain certain key aspects of human-computer interaction in advanced Information Society Technology (IST) environments; (ii) abduction is probably the central inferential mechanism at work when learners learn or in general make sense of things in an IST or mobile context. Consequently, abduction illuminates the special epistemological circumstances of IST enhanced learning, in particular when the learning materials and the learning environment have been arranged in accordance with constructivist pedagogical guidelines. A study of abductive reasoning will help us better understand IST enhanced learning and IST user behaviour as well as give us some valuable hints to the design of human-computer interaction in general.

Keywords

Information society technology (IST), Information and communication technology (ICT) enhanced learning, Abductive reasoning, Human-computer interaction (HCI), Constructivism

Introduction

Sherlock Holmes, the hero of Arthur Conan Doyle's novels, often amazed his loyal friend Dr. Watson by drawing a correct conclusion from an array of seemingly disparate and unconnected facts and observations. The method of reasoning used by Sherlock Holmes is abduction. As will be argued in this paper, an advanced Information Society Technology (IST) environment – a mobile computing environment in particular – calls for, or even compels to, the use of abductive reasoning. Abduction is not yet fully understood but it is a better conceptual tool than descriptive adjectives like "interactivity," "mobility" and "ubiquity" that are presently used in IST research. It is better because: First, abduction is a single, rigorous and well-defined unit of analysis, allowing one to analyze and compare diverse phenomena with good scientific accuracy. In the words of Uwe Wirth, research on abduction provides the unique opportunity of approaching interdisciplinarity under a single aspect (1995, p. 405). Second, abduction catches the gist of how we humans reason under uncertainty in a context. Consequently, abduction illuminates the special epistemological circumstances of IST enhanced learning, especially when the learning materials and the environment have been arranged in concord with constructivist educational principles (Patokorpi, 2006a). If it is true that abduction is a central element of everyday thought, and especially significant and ubiquitous in advanced IST environments, it follows that a study of abductive reasoning will help us better understand IST enhanced learning and IST user behaviour as well as provide some insights into Human-Computer Interaction (HCI) design.

The paper at hand will focus on abduction as a central process of everyday human reasoning and its role in HCI, especially its role in IST enhanced learning. Thanks to portable and ubiquitous technology, education increasingly takes place in authentic real-life contexts instead of in the confines of a classroom (Nyíri, 2002; Patokorpi et al., 2006). As a result, the learner is most likely to resort to abductive reasoning more than before. Abduction is of course a central element in traditional education, too, but the new IST lends it a heightened importance. Constructivist pedagogy enters the picture as the currently predominant theory of learning. Constructivist pedagogues have embraced the new IST because it in their opinion naturally supports, or can be made to support, the fundamental constructivist instructional strategies and learning objectives (Tétard and Patokorpi, 2005). Abduction clarifies how learning takes place especially on the level of individuals in and out of cyberspace.

Abduction as an inferential process

The canonical example of abductive reasoning comes from Charles Sanders Peirce:

Rule: All the beans from this bag are white.

Result: These beans are white.
Case: Therefore, these beans are from this bag (CP 2.623).

The inference is not deductively or analytically valid – because the beans could come from somewhere else – but this form of reasoning conveys the manner in which people reason when making discoveries in the sense of coming up with new ideas. Abduction is the only inferential process that gives birth to new ideas, thus expanding our knowledge (CP 2.777; CP 5.171; Wirth, 1995; von Pückler, n.d.). Abduction is a backwards-tracking process of finding or forming hypotheses or theories that might explain a (surprising) fact or an (unexpected) observation. Contrary to a widespread misconception, the fact or facts observed do not necessarily have to be surprising. Abductive reasoning may be used for opening up a new perspective into things even when there is nothing out of the ordinary in them (e.g. humour) (Hoffmann, u/d). Abduction comes to its own in the face of incomplete evidence and high uncertainty that are usually related to very rare or nonrepeatable events and to the realm of the unique in general (Flach, 1996; Yu, 2004; Leake, 1995; Shanahan, 1989).

Abduction has both a psychological (synthetic) and a logical (analytic) dimension closely intertwined (Pückler, u/d; Hoffman, u/d). To borrow Roesler's (n.d.) illuminative example: (P1) a surprising object (fact) is observed which is round, orange coloured and porous. (P2) Oranges are round, orange coloured and porous. If this object were an orange, the object would make sense to us and thus cease being surprising. (C) Ergo: it is plausible that this object is an orange. The premises, containing perceptual judgments, and the conclusion, containing an abductive inference, cannot be sharply separated from one another. However, abductive judgments are more conscious and more controllable than perceptual judgments (CP 5.184; Merrell, n.d.). By producing hypotheses abduction simplifies the complexity of reality, making it intelligible to us. When abduction, as a form of synthetic and qualitative thought, is given a central place in knowing, the hypothetical and provisional nature of human knowledge is underlined (Wirth, 1995; Bertilsson and Christiansen in Peirce, 2001).

Some forms of abductive inference

For the purposes of this study abduction is divided into four basic forms: selective, creative, non-sentential and manipulative (see Magnani, 1998; Magnani et al., 2002). Selective and creative abduction may be further divided in two distinct types (see Figure 1 below). The non-sentential form, in turn, may be divided into five and the manipulative into three subcategories. Finally, the quasi-automatic abduction is here further divided into species-specific and doxatic modes, and all of the five non-sentential modes as well as the man-made manipulative mode may be further divided into two subcategories: creative and selective.

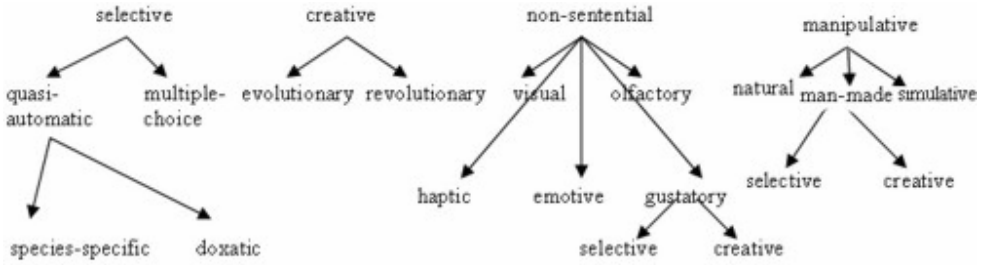

Figure 1. Some forms of abductive inference

Selective abduction, as the name indicates, selects among existing bags (alternative rules, antecedents) the bag that these particular beans (result, clues, consequent) come from. There are two forms of selective abduction: quasi-automatic (Eco's overcoded abduction) and multiple-choice (Eco's undercoded abduction). Abduction may happen almost automatically (quasi-automatically) when there is just one bag (i.e. a singular cause or a general rule or law) to choose from.

Figure 2. Quasi-automatic abduction

Umberto Eco (1983) gives the example that upon seeing a portion of tuna fish on a plate on the table and next to it an opened tin of tuna, one without any conscious effort concludes that the tuna on the plate comes from the tin. In quasi-automatic abduction there is no need to search for a rule as one already exists in the mind. The inference thus proceeds from the result to the case. The principles of proximity, similarity, an objective set, closure, completion and pregnancy could be seen to number among the quasi-automatic abductive processes of human perception (see Wertheimer, 1923). The last-mentioned abductive processes could be said to be common to the human species, whereas some abductions are rather based on culture. Stopping at red lights in traffic is an example of a culturally or conventionally embedded abductive inference. In this case the power of the sign is more due to convention (i.e. to the social institution of the sign) instead of to shared psychological principles or propensities of human perception. The 'traffic light' abduction could be called doxatic and the other one (the gestalt-psychological) could be called species-specific abduction (Bertilsson, 2004).

In a multiple-choice abduction there are two or more rules to choose from. Thus the mind proceeds from the result to the rule (Wirth, 1995).

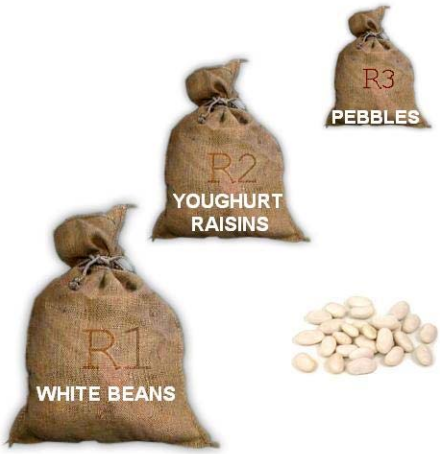

Figure 3. Multiple-choice abduction

An example of a multiple-choice abduction is to be found in Peirce (CP 2.707; quoted in Eco, 1983). The data that Kepler had about the longitudes and latitudes of Mars' revolutions around the sun suggested a finite number of geometrical curves from which to choose. Kepler's hypothesis was that the orbit is elliptical, which he then corroborated against the available evidence.

Creative abduction creates a new bag of beans (i.e. rule) from which the particular beans come from. In other words, the immediately existing (present to the reasoner's mind) bag or bags (contexts) do not fit the result (these beans are white) or there does not exist any general rule, so the reasoner needs to find or create a new one. Generally speaking, by abduction we come up with rules, reasons or laws that explain the case. Insofar as we stick to our prior experience as a ready repertoire of hypotheses, we are not properly engaged in a creative abduction. To infer by abduction that a patient has hepatitis because he or she has jaundice (Josephson and Josephson, 1994, p. 13) is a multiple-choice abduction. If one explains some (in this case the same above-mentioned plus some) symptoms by inferring a new disease (e.g. AIDS when there was no such disease in medical records), it is a case of an evolutionary creative abduction (Reid, 2003; see also Hoffman, 1997).

Figure 4. Evolutionary abduction

The creative revolutionary abduction (Eco's meta-abduction) is a further abduction based on earlier ones. It assesses whether the potential universe created by earlier abductions corresponds to our experiences (Roesler, u/d).

Figure 5. Revolutionary abduction

Galileo's hypothesis of the earth circling the sun, leading to a heliocentric worldview, is an example of revolutionary creative abduction. A revolutionary abduction replaces existing sets of rules by new sets of rules, thus challenging our beliefs in a wholesale manner.

All or any of the five senses may provide the required clues for abductive reasoning (Pierpaolo, n.d.). Especially medicine is known for exploiting all the five senses in the finding of clues (symptoms) when diagnosing an illness. Consequently, there is reason to think that there are many forms of non-sentential abduction, involving vision, touch, smell, taste and feelings. For instance, instead of verbal representations of things and events, we can form pictorial representations. These pictorial representations can be used as vehicles of inferences and explanations, that is, as tools of thought (Thagard and Shelley, 1997). Visual abduction is a form of inference that is based on signs which resemble the thing they represent (i.e. the signs used are icons). This pictorial form of thinking is usually instantaneous, uncontrolled and automatic, thus verging on perception. Visual abduction retrieves from the mind a previously stored piece of (pictorial) knowledge by which a result (these white beans) is referred to a familiar rule (a bag of white beans) (Magnani, 1998). Visual abduction can be either selective or creative. Here is an example of creative visual abduction from Thagard and Shelley (1997). An archaeologist finds two notches on the skullcap of a hominid that probably have led to its death. Is this a case of cannibalism? By picturing the hominid in the jaws of a leopard, the archaeologist can infer (by creative visual abduction) to an alternative explanation. The first explanation that comes to the archaeologist's mind, namely that the hominid has fallen a victim to cannibalism, is a selective visual abduction because the rule is part of the furniture of the reasoner's mind. Creative visual abduction involves the introduction of a new or additional element (diagram or icon; of a leopard in this case) into the reasoning process.

The manipulative abduction could be said to be based on action rather than perception. The reasoner acts non-verbally upon reality, changing the object of observation and then uses the resultant tacit knowledge (which may be embodied in an external or externalised object) as an auxiliary element of the reasoning process. An example of manipulative abduction is the use of auxiliary figures by hand in geometry (Magnani et al., 2002).

Semiotic paradigm of knowledge

In the late 20th century, epistemology has taken an abductive turn. It means among other things that the earlier division into hermeneutic understanding and natural-scientific explanation gives way to abductive educated guessing, that is, to the semiotic paradigm of knowledge (Wirth, 2000). It means also that it is increasingly difficult to keep up strict borders between fields of knowledge as phenomena spill over from one discipline into another (e.g. biophysics). Presumably, the bulk of human knowledge in everyday life is based on hypothetical (abductive) thinking.

Abduction is essentially a matter of finding and following clues (CP 5.262; CP 8.238; Wirth, 1993; Schulz, n.d.; Radford, 2004). However, as Matti Peltonen (1999, pp. 36-37) points out, a clue merely leads the reasoner to something that he or she already knows. Abduction, in contrast to the mere following of clues, aims at eliciting new knowledge. Therefore clues need to be connected to (more or less rough) models or theories, which in turn lays the ground for contrafactual reasoning. The semiotic paradigm (i.e. the science dealing with signs, symbols and clues) of knowledge does not deal with a disciplined regulation of coded knowledge, yet the clues are there for all to see. As Matti Peltonen says (1999, p. 61; with a reference to Clifford Geertz), rather than rediscovering knowledge or things that were forgotten or covered from sight, we constantly create things or knowledge anew by interpretation. By actively interpreting, that is, by giving meanings to things, the observer produces new knowledge. Culture is public and the meanings are recognized by other members of the same culture although they do not always share them. Consequently, the knowledge based on abduction is not esoteric but something that can be communicated to others.

Abduction is first of all a reasoning pattern with strong claims to being democratic. All the relevant knowledge (clues) is in principle "out there," that is, laid out in the open for all to see. Historians (Ginzburgh, 1989; Peltonen, 1999) sometimes talk of this sort of semiotic interpretation and knowledge as low or shallow knowledge, the knowledge of the poor, the oppressed or otherwise marginalized groups in society. Low knowledge should not be understood as sheer, unadulterated observation. Abduction, rather than observation alone, is for instance required to tear down theoretical constructions or social agreements: the Emperor has no clothes. In Hans Christian Andersen's story of the Emperor's new clothes, it is not enough to see (observe) that the Emperor has no clothes because we still believe that he has. A process of abductive reasoning is required: the hypothesis that the Emperor does not have any clothes is a better explanation of the facts of the case. In this way abduction opens up a new perspective. It is material to notice how easy it is to communicate knowledge by abduction; the clues are not hidden but public and the reasoning process is easily repeatable by others.

The clues that are there for all to see are qualitative and unique. They cannot be measured and regulated. This sets the stage for knowledge that is essentially personal. It is personal in the sense that individuals differ in their ability to detect clues, due to individual differences in their prior knowledge and experience as well as logical acumen (Ginzburg, 1989, pp. 8-39; Peltonen, 1999, p. 61). Despite the apparent paradox, knowledge by abduction is simultaneously both personal and democratic.

Art of abductive reasoning

Abduction is best understood as a pattern of temporal reasoning (CP 1.444; CP 2.229; Spina, n.d.; Uslucan, 2004; Bergman, 2002; 2000). The process of abductive reasoning may not come to a conclusion for a very long time but may be suspended until all the relevant or adequate information is in (Josephson and Josephson, 1994; Paavola, 2004b). Abductions stretching over a long period of time are typically complex. An example of a prolonged complex abduction is Darwin's theory of evolution by natural selection. As Thagard and Shelley (1997; see also Roesler, u/d) have pointed out, complex abductions are layered. Layeredness means that each abductive conclusion may become the premise of the next abduction. Thus the higher level hypothesis "John hated Paul" can be used to explain a lower level hypothesis "John killed Paul" (Thagard and Shelley, 1997, p. 417).

In complex abductions the steps of the reasoning process may break out from the confines of a single mind. Reasoning and argumentation may thus be seen not only as internal dialogue or suspended reasoning over time but also as a process involving two or more participants (Wirth, 2000; Pape, n.d.). The following example derives from Richard Whately's Elements of Logic (1st edn. 1826):

> Let us suppose that a group of labourers has dug up a fossil animal with horns on the skull. In other words, the labourers know the minor premiss: "This animal has horns on the skull." Let us further suppose that there is a distant naturalist who knows that all horned animals are ruminants. The naturalist knows the major premiss: "All horned animals are ruminants." As the labourers are ignorant of that all horned animals are ruminants and as the distant naturalist to whom the fossil is described is ignorant of that it has horns, they are both unable to draw the conclusion that it was a ruminant. This is clearly a case in which to reach the conclusion both premisses are required (Whately, 1882, pp. 156-165; elaborated in Patokorpi, 1996, pp. 107-109).

The above example nicely brings out the dialogical nature of thought.

It is possible to trump up hypotheses that meet the formal requirements of abduction but are too far-fetched to be taken seriously. Achinstein's (1970, p. 92; quoted in Paavola, 2004a; CP 2.662; Wirth, 1999) example is that he is happy because he has won the Nobel Prize. There are certainly other reasons for a person to be happy, although winning the Nobel Prize would explain why one is happy. Something else is clearly needed for making abduction a useful mode of inference. What is needed are strategic rules or principles whose job is to guide the reasoner in fitting the hypothesis with the background information and other relevant clues related to the subject matter, the situation and the reasoner's goal. From a strategic viewpoint, it may become necessary to resort to further explanations to show how the hypothesis fits the context in question, and that potential counter-arguments can be warded off (Paavola, 2004a; Paavola, 2004b; CP 5.181; Hoffman, 1997).

Constructivist learning principles

Constructivists maintain that because the learner builds on his or her prior knowledge and beliefs as well as on the knowledge and beliefs of others, learning should be seen in its social, cultural and historical context (Piaget, 1982; Piaget and Inhälder, 1975; Vygotsky, 1969; Leontjev, 1977; Järvinen, 2001; Poikela, 2002; Tynjälä, 1999; Jonassen, 1994). Tétard and Patokorpi (2005) have summarized constructivist instructional principles as follows:

- a larger goal that organizes smaller tasks into a sensible whole
- ownership of the problem so that the learner will be motivated to try to solve it
- the problem should be close to a real world problem
- many possible solutions to a problem
- the learner has the main responsibility for gathering knowledge

- the learning environment should be similar to a real-world environment
- building on the learner's prior knowledge and experience
- room for alternative individual learning strategies
- opportunities for social interaction and cooperation should be provided
- communication with peers and outsiders should be encouraged
- iterative learning process
- guidance should be provided

A quick look at what constructivist educationalists say about IST in education indicates that IST-enhanced learning seems to be in harmony with the constructivist instructional principles. Sotillo (2003) maintains that "New developments in wireless networking and computing will facilitate the implementation of pedagogical practices that are congruent with a constructivist educational philosophy. Such learning practices incorporate higher-order skills like problem-solving, reasoning, and reflection". The students are reckoned to cooperate more, work more intensively and be more motivated than in conventional classroom teaching. IST enhanced teaching is regarded as an efficient equalizer, levelling regional and social inequalities (Puurula, 2002; Hussain et al., 2003; Gruba and Sondergaard, 2001). Langseth (2002) stresses creativity and the fact that the pupils take responsibility for their own work, and, instead of using their logical and linguistic faculties, use a "broader range of intelligences according to their personal preferences" (pp. 124-125). Langseth continues: "The web offers individuality in the sense that you can choose your own pace, your own source of information, and your own method; in a group or alone" (p. 125; Hawkey, 2002; Kurzel et al., 2003). Finally, the students focus more on collaborative work than on the final product (Patokorpi et al., 2006; Tétard and Patokorpi, 2005).

Constructedness of human cognition

Constructivist pedagogues strongly stress the element of active construction in human thinking and perception. A central inferential process behind the constructedness of human experience is abduction. Abduction enables one to posit learning between the rationalist and the empiricist viewpoints, and *a fortiori*, to strike a balance between constructivist, pragmatist and behaviourist learning theories. The existence of several different forms of abductive reasoning may throw light on some disagreements between the constructivists and the proponents of other learning theories, the pragmatists and the behaviourists in particular. Accordingly, the purpose of this section is to illuminate the constructedness of human cognition with the help of the abductive mode of inference.

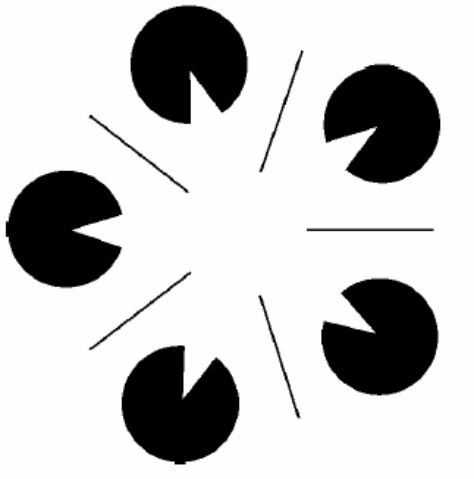

Figure 6. White star illusion

A central piece of criticism levelled at constructivist theories of learning is that they stress deliberation too much. In terms of abductive inferences it means that constructivists exaggerate the role of creative abduction. As learning in the sense of training familiar things and skills seems to belong to quasi-automatic abduction, learning as expansion

of knowledge seems to be based on creative abduction and multiple-choice abduction (Wirth, 1993). Fox (2001), who numbers among the recent critics of constructivist learning theories, presents the following figure that illustrates visual illusions:

Figures like this give support to the idea of constructedness of human perception. However, according to Fox (2001), virtually all humans "construct" the figure in the same way, and they do it without any conscious effort or deliberation, and they may at will resist the illusion: "Thus, as well as being impressive examples of the 'constructed' nature of our perceptions, such figures can also be read as examples of the objectivity of human perception, of its deep innate roots and of the way in which we can, up to a point, resist various features of our own initial view" (p. 31). Now, all these three observations made by Fox may be explained by applying different forms of abduction in a layered manner: a selective (quasi-automatic or multiple-choice) abduction followed by a creative evolutionary or revolutionary abduction. Insofar as the reasoner has only one figure present to his or her mind, it is a case of quasi-automatic abduction. Gestalt switches and Necker cubes are good examples of figures in which by training one learns to keep two figures (i.e. two general rules) present to the mind consecutively so that one jumps from one figure to the other more or less at will (Merrell, u/d). If there are two figures (two alternative bags of beans) to choose from, it is a case of multiple-choice abduction. The ability to resist the illusion takes us to the so-called metacognitive level of human mental processes. To make our perceptual and thought processes an object of thought (i.e. reflection in some form) comes to us as naturally as the initial illusionary vision of the figure. Revolutionary abduction is a way of, purposefully, to see things different from what they appear at first. As Wenyan Zhou says, "identifying the abductive object entails comparing one's existing beliefs and evidences revealed in the current situation, becoming aware of the incongruence between them, and discovering the anomalies" (2004, p. 132). Reasoning in its expansive and creative mode is by nature temporal and layered (Roesler, u/d), involving a varying degree of reflection (Leontjev, 1977).

Kivinen and Ristelä (2003, p. 370) criticize the idea of metacognition. They ascribe to constructivists a picture of metacognition as a higher level of consciousness that monitors and evaluates the lower levels. Nevertheless, if metacognition is not seen as two simultaneous levels of cognition but as a temporal process where knowledge-in-action and reflection take turns, the problem vanishes. Some pragmatists seem to have trouble in admitting reflection any clear place in human action. Kivinen and Ristelä's example of an experienced driver and a novice driver misses the point. It is clear that a novice driver makes a worse job of driving than an experienced driver but the main reason for it hardly is because the novice tries to be careful while driving. One of these drivers does not yet know how to drive whereas for the other driving is a routine task. Moreover, reflection and action take turns even when one does something in which one is experienced; reflection merely shows that one is still learning something. Cases of training in which no or very little reflection occur are relatively rare. Much of the conceptual muddle in the case at hand derives from a too elevated picture of reflection. As Bengt Molander (1996) has convincingly argued, reflection allows many forms and degrees. "Just do it!" is a good advice for a timid and ponderous learner learning some very practical skill. On the other hand, it does not validate the conclusion that taking, from time to time, back a step from what one is doing would be a bad thing even in more practical learning tasks. By verbalising, visualising, in a word, externalising learning, it can be made more easily accessible to others as well as to the individual learner himself or herself. Social or collaborative learning is a powerful reason for making learning explicit by reflection and externalisation (Kankkunen, 2004).

IST enhanced learning

As the section on semiotic knowledge above indicates, knowledge by abduction is, by nature, personal, democratic, creative and based on prior knowledge. This is almost exactly the way that many constructivist pedagogues describe learning, as the above section on constructivist learning principles indicates. It is not difficult to become convinced of the resemblances between knowledge by abduction and constructivist learning. Information Society Technology (IST) enhanced learning in general and mobile learning in particular seem to favour the abductive form of reasoning. Abduction could be called the mobile or "pedestrian" form of reasoning *par excellence* because it so well meets the requirements of a mobile learner envisioned by constructivist pedagogues (Nyíri, 2002; Patokorpi et al., 2006).

Abduction is a tool for low knowledge with a tendency to (over)simplification. Therefore, resorting to abductive reasoning has its pitfalls. The construction of a personal meaning goes at times against the objectives of more traditional educational principles, which include the dissemination of uniform knowledge and eradication of false

conceptions. Especially due to the immense increase in information, the eradication of erroneous conceptions has become one of the most important and most difficult tasks of today's teachers. In abductive reasoning there is a tendency to resort to guessing before all the facts are in, which leads to over-generalisation and error. Sticking to prior knowledge and experience when the guesswork ends in error may send the reasoner to prolonged attempts at second-guessing the cause of the error and thereby to lengthy error recovery (Carroll, 1990; 1997). A real-life example of this kind of behaviour is when one ignores the manual and proceeds guessing, and when it ends up in error, resorts to some more guessing. Umberto Eco (1983, p. 220) refers to a similar problem when saying that detectives tend uncritically to rely on their abductions whereas scientists meticulously put their hypotheses to test. By modelling learning after scientific discourse, the knowledge creation movement (Bereiter, 1994; Scardamalia and Bereiter, 1994) aims to get the best of both worlds. In epistemic terms, when the learners start with their own questions, the adoption of knowledge produced by others is, as a process, analogous to that of creating knowledge (Bereiter, 1994). The remedy they prescribe to the pitfalls of abductive reasoning is added reflexivity. Added reflexivity translates into increased layeredness of abduction, more attention to logical strategies, more thinking about thinking and intensified dialogue and collaboration between the members of a knowledge community.

According to Hussain et al. (2003), "Edutainment offers children a way to wander through stories, information or games at their own pace and in their own way. They can connect ideas in paths they choose or investigate one particular idea among many" (p. 1077). This is the hypertextual property of the content on the Web. Hypertext is a web of links that sends the reader onto a quest from one piece of text to another. In every act of reading, one piece of text can in principle be connected with any other piece of text. Thereby a text on the Internet loses its book quality (Wirth, 1999). In the words of Spiro et al. (1988):

> The computer is ideally suited, by virtue of the flexibility it can provide, for fostering cognitive flexibility. In particular, multidimensional and nonlinear hypertext systems … have the power to convey ill-structured aspects of knowledge domains and to promote features of cognitive flexibility in ways that traditional learning environments (textbooks, lectures, computer-based drill) could not … (pp. 2-3/20).

So, on the Web the materials (ideas, objects) may be arranged as one pleases. The endless semiosis thus seems to find full vent in the digital media. The user or reader on the Internet may either follow aimlessly the links that he or she comes across or seek clues (meaning) as a detective (Wirth, 1999). We no longer seem to need so much as before a memorized and often visual path to pieces of information or knowledge (e.g. be able to trace by hand a certain passage in Hegel's *oeuvre*). Admittedly, there are technological solutions to tracking paths in a computing environment – bookmarks, track changes and 'go back to the previous page' – but to date, owing to technological limitations, these memory traces are mostly our own personal creations. The point is that it is easier to avoid listening to other points of view (other universes of discourse, world-views) as one may pick up a passage and ignore the rest of the work. As a result, hypertextuality gives more room for our abductive competence and strengthens our personal knowledge structures – sometimes at the expense of not understanding other points of view.

A Sherlock Holmes type of learner calls for laying out the learning materials as in a detective story. In actual fact, often in the new learning media, at least so far, the learning materials have been arranged in a rather strict hermeneutical path of the master. The learner, just like the reader of Internet texts, is supposed to follow the links (clues) so that he or she eventually goes through the same path as the author of the text and links. On the Internet, texts may lose their book quality, but they still need to be read as books, or rather, as detective stories, in order to make sense. Texts, in general, need to be inherently coherent to enable us to interpret them instead of just utilizing them (Wirth, 1999). We still have to see the text as a contribution coming from another conscious mind because human thought is by nature dialogic. This comes close to the idea of a hermeneutic cycle. In the footsteps of Karl-Otto Apel (1973), abduction is here interpreted as an inherent part of the hermeneutic cycle. At the very least, knowledge building, hermeneutics and abductive reasoning could be seen as complimentary perspectives to the temporal and dialogical process of knowledge creation and renewal in a shared culture.

Along with the new media (TV, video, PC games, virtual reality etc.) images have become a more pivotal vehicle of meaning and communication in all walks of life. Pictorial knowledge has always had its defenders, although they seem to be in the minority. Peirce is a case in point: "For Peirce, the human mind is not a calculating engine, but it is a mind which draws figures," says Leila Haaparanta (2001; CP 3.363). Pictures often are more concrete and simpler than meanings mediated by verbal language but they are often also clearer and easier to understand. In the words of Kristóf Nyíri: "Due mainly to advances in cognitive science, philosophers today increasingly recognize that we do

indeed have the capacity of thinking *directly* with images, without verbal mediation. And, due mainly to advances in computer software, pictures are today becoming a convenient vehicle for communicating ideas" (Nyíri, 2002, p. 3/4). Especially moving images are important because they have the capacity to be self-interpreting. Pictorial knowledge is essentially interdisciplinary and less hierarchical than verbal knowledge. However, language and communication have their anthropological basis in all of the five senses, not just in vision. With this cognitive species-specific makeup in mind, Kristóf Nyíri (2002) argues for the natural suitability of modern ubiquitous and multimodal IST to human communication and learning. Today, learning takes increasingly place not in the school but out there in the world, and it is supported by the same tools with which most communication and work is done, namely the ISTs. If and when mobile learning gets under way within and outside the educational system, abduction seems like a good candidate for an interdisciplinary conceptual tool for both educational and technological research.

Conclusion

Abduction is a form of expansive and qualitative thought that makes reality intelligible to us. The paper has introduced well over ten forms of abductive inference, with examples showing how this type of reasoning works. Abduction is the cornerstone of the semiotic paradigm of knowledge. This type of knowledge is low knowledge: creative, personal, democratic, easy to understand and easily communicable to others (Patokorpi, 2006). The main argument put forward in this paper is that abduction illuminates the special epistemological circumstances of IST enhanced learning, especially when the learning materials and the environment have been arranged in concord with constructivist educational principles. If it is true that abduction is a central element of everyday thought, and especially significant and ubiquitous in advanced IST environments, it follows that a study of abductive reasoning will help us better understand IST enhanced learning and IST user behaviour as well as give us some valuable hints to the design of human-computer interaction in general.

Constructivist pedagogues strongly stress the element of active construction in human thinking and perception. A central inferential process behind the constructedness of human experience is abduction. By clarifying the role of abduction in learning should enable one to strike a balance between constructivist and pragmatist learning theories. Accordingly, some forms of abductive reasoning have been used in this paper to throw light on some central disagreements between the constructivists and the pragmatists.

Today, learning takes increasingly place not in the school but outside the classroom, and it is supported by the same tools with which most communication and work is done, namely the ISTs. If and when mobile learning gets under way within and outside the educational system, abduction seems like a good candidate for an interdisciplinary conceptual tool for both educational and technological research.

In this paper, an abductive learning or thinking style is connected to a pedagogical approach. The analysis of an abductive reasoning style utilized by users of IST could be used to develop new educational strategies. Constructivist pedagogy could give some directions for building educational programmes around IST and this particular form of reasoning. The developing of such educational programme and practical approach using the presented connections between computer-based information systems, human reasoning, and the learning process will be left to others or to future work. As has been argued in Patokorpi (2006b; Patokorpi et al., 2006), there are some mismatches between the available technology and the constructivist learning theory and practice. Especially the personalisation technologies are still too immature to provide good support for constructivistically oriented IST enhanced learning. Abduction also requires backing up by deduction (to trace the consequences of hypotheses) and induction (to test hypotheses) to make the hypotheses (guesses) not just plausible but accurate as well. The cyberspace can in principle be made to support also deductive and inductive reasoning. New research is needed to clarify how particular technologies and applications, applied by different pedagogical approaches to various learning environments support or fail to support an abductive learning style.

Finally, the recent systemically oriented research and design of IST enhanced learning, particularly under the label of computer supported collaborative learning, is all well and good as it often gives a sophisticated picture of the process of learning and of the dialogical unity of knowledge and action. However, there is need for research which analyses the learning process more from the concrete viewpoint of individuals – without covering from sight other minds, action and artefacts. Abduction could have an important role in this kind of research and instructional design.

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