GÖTEBORG STUDIES
IN EDUCATIONAL SCIENCES 207

JONAS IVARSSON

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Studying artifacts in human knowing

ACTA UNIVERSITATIS GOTHOBURGENSIS

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ABSTRACT

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Today, we are in the midst of a rapid development of digital technologies. Following this development in our communicative infrastructure, many far-reaching claims about the promises of multimedia learning have been, and are still, made. For instance, in research on multimedia and interactive learning environments one will typically find claims to the effect that modern technologies offer radically new and innovative forms of presenting and communicating information. These instructional technologies are sometimes claimed to be *interactive*, to have *real-time* features, to offer rich *animations* in a *multimodal* environment and so forth. Such descriptions, however, risk oversimplifying and concealing much of the variation that characterise the *use* of technologies.

Accordingly, one aim of this thesis is to go beyond the employment of general categories and abstract analytical concepts when discussing the relation between technologies and learning. Through four separate studies, practical actions and practical reasoning performed in technology-mediated learning environments are scrutinized. The outcomes of the empirical investigations are illustrations of some of the aspects that can go unnoticed if handling these matters in the abstract.

As a theoretical contribution in the longstanding debate on human knowing, the research further illustrates how human reasoning is dependent on tools. One general observation is that when people are familiar with a particular tool (e.g., maps), they can accomplish sophisticated modes of reasoning that they seem unable to perform without such support in external devices. At a methodological level, the results point to the gains of investigating the *interactions* between people, and between people and technologies. Some concrete aspects of the interaction with explicit pedagogical consequences are attended to. In one analysis, it is shown how the use of a visually driven learning environment can become an interactive puzzle that keeps the students in a local and non-conceptual world. The results suggest that the mastery of conceptual knowledge that the students develop is tied to local features of the situation that they operate in. A different analysis shows how two instructional technologies – which have been described in similar terms – afforded different courses of action. It is argued that this difference is of crucial importance for what experiences the students had and, hence, for what they learned.

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Göteborg, February 2004
Jonas Ivarsson

Part One

RENDERINGS & REASONING

ren·der·ing *n.*

1. A depiction or interpretation, as in painting or music.
2. A drawing in perspective of a proposed structure.
3. A translation: *a rendering of Cicero's treatises into English.*
4. A conversion from a computer file into visual form, as on a video display.

Under »rendering«, I include not just what a draftsman does but all the ways of making and presenting worlds – in scientific theories, works of art and versions of all sorts. (Goodman, 1978, p. 109)

INTRODUCTION

This thesis is about the ways we relate to the world through the use of a whole range of auxiliary means, and how such human-made *artifacts* inform our cognitive and communicative activities and contribute to our development as sociocultural beings. Or, to borrow the words of the philosopher Nelson Goodman (1978), this work has to do with our »ways of worldmaking« in an environment where various kinds of technologies play an increasingly important role. Through a series of interrelated empirical investigations of interactions between people, and between people and representational technologies, some aspects of a general, theoretical and philosophical discussion on human development and reasoning will be dealt with and analysed in the flesh. Thus, the main thrust of the book is an attempt to contribute to the scientific conceptualisation of representational technologies and their possible relations to learning.

The controversy that swirls around the origins and development of human knowing is vast, and extends far back in the history of philosophy. One important contributor to this longstanding debate was Immanuel Kant. In 1781, he published the *Kritik der reinen Vernuft,* in which he elaborates both earlier empiricist and rationalist ideas. Central to his *transcendental idealism*, is the idea that some concepts – e.g. space, time, causality and number – are universal and necessary; they are given *a priori*, i.e. before experience. Much later, the Swiss psychologist Jean Piaget (radically) reformulated Kant's transcendental epistemology into his own developmental, evolutionary theory of genetic epistemology (Piaget, 1972). This approach emphasised the genesis of structures that emerge from the interaction between the human subject and its environment. Still, as argued by Wartofsky (1983), Piaget's program sought to discover essential features, historically and culturally invariant, in human cognition and in human cognitive development. A critical voice, challenging this biologically oriented kind of species essentialism, is grounded in a sociocultural perspective (Vygotsky, 1986; Wertsch, 1998) – the theoretical position taken in this thesis. The main arguments from this tradition are that our understanding of human knowing has little to gain from treating the human subject as an isolated entity, and that communicative and cognitive development should be understood as intertwined with historically created artifacts. One central aspect of artifacts, then, is the fact that they emerge through history, and, in addition, they develop rapidly in comparison with the biological evolution of the species. In a few generations, technology can undergo tremendous transformations as is evident from the developments in recent centuries. What is more, as the intellectual achievements of developing societies become mapped into the artifacts, social structures, institutions and different forms of communication, new conditions for human development are continuously created. By regarding cognition as intimately coupled with technologies, which evidently undergo change, even cognitive development itself can be seen as historically contingent (Luria, 1976; Wartofsky, 1979, 1983).

AIM

Although some of the issues discussed above will be examined further in what follows, the general characterisation of the historical development of artifacts, and thus of the very forms of cognitive growth itself, make up the theoretical premises for the current work. Given this background, the more specific point of departure for this thesis has to do with the present-day situation in which we see a rapid development of new technologies and, in connection with this, a range of problematic claims on the promises of multimedia learning. To narrow down an overwhelmingly broad set of questions, my analytical foci will be set on a subcategory of artifacts used as *representational* tools in human practices, where they provide *renderings* of the world, suitable to these practices. The empirical context for this thesis is the use of representational technologies and, in particular, digital representations as parts of different *interactive learning environments*. However, most of these tools, and the modes in which they render the world, originally derive from other human practices. This could make it relevant to consider the historical dimension of the genesis of the artifacts in addition to their *in situ* use.

In the research literature on multimedia and interactive learning environments, one will typically find the view that modern technologies offer many new and innovative forms of presenting and communicating information. Electronic equipment is seen as both facilitating the construction of certain forms of representation and as allowing users to combine forms of representation that relate to different modalities (Stern, Aprea, & Ebner, 2003). The imaging possibilities are often pointed to as central, and some argue that it is now possible to operate with computer images in completely new ways (Healy & Hoyles, 1999). There are also expectations that multimedia environments may have a considerable role to play in facilitating knowledge acquisition and reasoning in a variety of content domains (cf. Ainsworth, Bibby, & Wood, 2002; Cairncross & Mannion, 2001; Mayer, 2003; Stern et al., 2003).

This is a dynamic and highly interesting area of research but, from my perspective, a major problem with this research is the widespread and somewhat unreflected use of general descriptions of characteristics of technologies. Sometimes, the claims about the radical and innovative qualities of various multimedia applications seem to overshadow the fact that the qualities they are described as having could easily be ascribed to older technologies as well. Different instructional technologies have, for example, been described as being *interactive*, as having *real-time* features, as containing *animations*, as *multimodal* and so forth. At a descriptive, denotative, level I see no problems with this use; we have to be able to differentiate between objects in our communication. Within the context of a scientific practice though, there are methodological problems with taking these descriptions for granted and using them as variables when conducting research. When these descriptions are put to work as categories that are claimed to be characteristic of various technologies, they oversimplify and conceal much of the variation that can be found within each category. Hence, in any such use, caution must be exercised, and always at the risk of losing sight of occurrences with a larger explanatory value than the category itself. What is more, by employing categories like these, one can downplay the role of the actual *use* of the technologies, thereby emphasising technological determinism over, for example, rational and creative aspects of human action.

In this thesis, I suggest we postpone any grand judgements of technological characteristics, and instead reopen the case for further empirical analysis. To do this, I will investigate practical actions and practical reasoning performed in technology-mediated learning environments. Starting from detailed analyses of a few examples of human conduct, the aim is to examine and enrich the current discussion on representational technologies and their characteristics. However, this is a complex research area that cannot be addressed in its totality in any single investigation. Through four separate studies, this general issue will be approached from somewhat different angles.

OUTLINE OF THE THESIS

This book is a work of synthesis, and it consists of two separate parts. The remainder of Part One is divided into four chapters.

(1) A general overview of the research interest.
(2) A discussion of data and the methodological agenda.
(3) Summaries of the individual studies.
(4) A summarising discussion.

Part Two contains the following four studies:

I) IVARSSON, J., SCHOULTZ, J., & SÄLJÖ, R. (2002). Map reading versus mind reading: Revisiting children's understanding of the shape of the earth. In M. Limón & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 77–99). Amsterdam: Kluwer.

II) IVARSSON, J. (2003). Kids in Zen: Computer-supported learning environments and illusory intersubjectivity. *Education, Communication & Information, 3*(3), 383–402.

III) LINDWALL, O., & IVARSSON, J. (submitted). *What makes the subject matter matter? Contrasting probeware with Graphs & Tracks*. Manuscript.

IV) IVARSSON, J., & SÄLJÖ, R. (in press). Seeing through the screen: Human reasoning and the development of representational technologies. In P. Gärdenfors & P. Johansson (Eds.), *Cognition, education and communication technology.* Hillsdale, NJ: Lawrence Erlbaum Associates.

The Appendix contains a transcript legend, the original Swedish versions of the transcripts found in the studies, and their respective translation.

ARTIFACTS, COGNITION AND HUMAN KNOWING

One central concept in the sociocultural tradition is the notion of mediation. It was Friedrich Engels' notion of *instrumental mediation* that was extended to involve also psychological functioning, mainly through the works of Lev Vygotsky, Alexander Luria and Alexei Leont'ev (Wertsch, 1985). At the time when this historical approach to cultural psychology emerged, behaviourism (and reflexology) was the prevailing theory of learning, predominantly represented through the work of the eminent Russian physiologist and psychologist Ivan Pavlov. Against this backdrop, it is understandable that the early attempts to formulate the theory of mediation depicted such processes as an intermediate step between a stimulus and a response. Over time, the descriptions of mediation have been refined and extended (cf. Cole, 1996, p. 116; Wertsch, 1991, p. 28). Today, we have a more sophisticated view of how artifacts as mediational means are constitutive of human action in general, but also with respect to how they serve as tools in reasoning.

Although the concept of mediation gained considerable currency among psychologists and educational theorists during the latter part of the twentieth century, it still serves as a line of division between mainstream theories of learning and cognitive development and sociocultural approaches. Cognitivism succeeded behaviourism as the major psychological framework, and this perspective is to a large extent still dominant. To critically dialogue with the latter approach, some ideas from the Russian thinkers will be expounded and developed further – especially in relation to current technological developments. Before I undertake such an examination, though, I will briefly revisit some of my assumptions as regards perception and human reasoning, since the view on human perception adopted in research is fundamental to how one construes concepts such as cognition and learning.

PERCEPTION AS ACTION

The theory of perception in this work can be characterised as a practice theory, where perception is understood as a mode of human action. The analytical model advanced here, is to regard, and analyse, perception as an activity performed by the organism as a whole. Such a unified view has been advocated by several thinkers, for instance, Bateson (1972), Merleau-Ponty (1962), Gibson (1979), and Wartofsky (1979).

In his formulation of an *historical epistemology*, the philosopher Marx Wartofsky (1979) argues that we need a historical theory of perception – a theory that views the genesis of perception as linked to its function and its uses in the life-activities of organisms. When acknowledging that perception has a history, the notion of *mediation* becomes central to this theory, as it forms the organising principle that explains the relation between organism and environment.

> Even at the biological level, which we share in common with other animals, it is not the organ which perceives, but the whole organism *by way of* the organ. And as a whole organism, the animal embodies not its own, or individual modes of perception, but the species-modes of perception, as they have evolved. Ontologically, of course it is not a *species* which perceives, but an individual organism, *by means of* a species-evolved apparatus, and in a ›world‹ which is species-defined, in terms of the characteristic modes of activity in meeting life-needs. (Wartofsky, 1979, p. 196)

It is further argued that the human species has reached a point where our forms of perceptual activity are no longer limited by the biological apparatus, which has evolved in the course of evolution. What Wartofsky proposes to be the genesis of *human* perception is »the fundamental activity of producing and reproducing the conditions of species existence, or survival. What is distinctively *human* about this activity … is that human beings do this by means of the creation of artifacts« (Wartofsky, 1979, p. 200). At this point, the close parallels to the sociocultural tradition should be obvious. The focus on human-made objects as mediational means, guiding both perceiving and cognising, stand as a common denominator between the two perspectives. However, more will be said about these interconnections in the next section, where I turn to the development of the symbolic embodiments of human praxis.

FROM PRAXIS TO REPRESENTATION

One of the fundamental ideas in Wartofsky's historical epistemology is that the objectifications of our ways of acting *in* artifacts provide the very genesis of cognition and human consciousness. Although elaborated and extended, as will be discussed later, this idea was taken up from the writings of Karl Marx. In his analysis of labour, Marx (1844, 1845) presented a general theory of how productive human action, termed *social praxis*, constitutes human consciousness through the processes of externalisation and objectification. This radical move, which relocated the origin of consciousness from the heads of people to their interaction with the world, was also espoused by Vygotsky (1978) in his semiotic analysis. What Marx suggested was that consciousness followed language, which, in turn, developed as a result of human needs of interacting in social practices.

> Language is as old as consciousness, language is practical consciousness that exists for other men, and for that reason alone it really exists for me personally as well; language, like consciousness, only arises from the need, the necessity, of intercourse with other men. (Marx, 1845)

When commenting on this passage, Leont'ev (1978) is careful in pointing out that we should not understand this as if language were the causation of consciousness – it is, rather, seen as its form of existence. This idea can also be found among philosophers of language such as Voloshinov (1973) and Wittgenstein (1953, § 329). Voloshinov rephrases Marx and states that consciousness can arise only in the material embodiment of signs – that it »can harbor only in the image, the word, the meaningful gesture, and so forth« (1973, p. 13). To better understand how the genesis of consciousness is conceived in this line of thought, one must return to the idea of the *objectification* of human action.

Extending the analysis by Marx, Wartofsky (1979) suggests that human production proceeds by a transformation of part of the environment into what becomes an extension of the animal organs: what we commonly label as tools (cf. Cole, 1996; Säljö, 1998). But in this line of argument, the *tool* may be any artifact created for the purpose of »successful production and reproduction of the means of existence« (p. 201). Wartofsky continues by suggesting that the crucial character of the human artifact is that »its production, its use, and the attainment of skill in these, can be transmitted, and thus preserved in a social group, and through time, from one generation to the next« (1979, p. 201). This theme, of how artifacts create stability and continuity in societies, has been picked up by Latour and others in more recent work in the sociological study of artifacts (Latour, 1992a, 1992b). In his own phrase, »technology is society made durable« (Latour, 1992a), an observation that he regards as ignored by most sociologists (and other social scientists, I might add).

When Vygotsky extended Engels' notion of instrumental mediation, he introduced the distinction between *psychological tools* and *technical tools* of production (Vygotsky, 1978; Wertsch, 1985). This distinction has also been referred to as *mental and physical* artifacts (Säljö, 1996). However, if one seriously takes the position that artifacts arise out of the necessities of productive human action, this analytical separation needs some consideration when used for studying human practices. In my view, the very principle for making this distinction may be questioned. In fact, it could be seen as a residual form of Cartesian dualism that possibly creates more problems than it solves. Even if artifacts are described as *psychological* or *mental*, they must, at some point in time, be instantiated in physical reality apart from the individual (organism). Some authors have tried to resolve this problem, by portraying artifacts as simultaneously ideal (conceptual) and material (Cole, 1996), or, by pointing to *materiality* as »a property of *any* mediational means« (Wertsch, 1998, p. 31). Few however, have proposed the more radical position of abandoning the separation altogether.

Wartofsky (1979) offers an additional approach to this separation by suggesting a simple taxonomy of artifacts based on their relation to production rather than on traditional dualistic categories. He suggests that *primary* artifacts, such as axes, clubs or needles, are those directly used in production. *Secondary* artifacts are used in the preservation and transmission of the modes of action characteristic of the use of primary artifacts. It is the ability to represent an action through symbolic means that creates this distinctive class of secondary artifacts, a class which he also refers to as *representations*. And it is this particular definition of representation that will be used in what follows.

> Such representations, then, are *reflexive* embodiments of forms of action or praxis, in the sense that they are symbolic externalizations or objectifications of such modes of action – ›reflections‹ of them, according to some

> convention, and therefore understood as images of such forms of action – or, if you like, pictures or models of them. (Wartofsky, 1979, p. 201)

The classification made by Wartofsky also includes a third level of artifacts, abstracted from their direct representational function. Wartofsky refers to these as *tertiary* artifacts. In relation to the division between *psychological* and *technical* tools made by Vygotsky, *language* cuts across all three different levels. In this thesis, I take a primary interest in the role of the second class, the representations for learning and cognitive development.*

REPRESENTATIONS AND COGNITIVE DEVELOPMENT

As mentioned in the introduction, one aim of this thesis is to investigate practical actions and practical reasoning performed in technology-mediated learning environments. I will examine situations in which individuals use, and learn to use, historically developed modes of knowing. More specifically, I will look at situations connected to science education where graphical representations form a fundamental part of the interaction. In the research on science instruction, it is possible to find numerous reports of the difficulties students have in handling graphical representations (for an overview, see Leinhardt, Zaslavsky, & Stein, 1990). Difficulties in this domain are often related to what one refers to as students' *conceptions* of the scientific phenomena and the associated processes of conceptual change

* Throughout this work, I predominantly use the term *representation* instead of the term *rendering* found in the title. The reason is that I model much of my argumentation on the theories of Wartofsky (1979; 1983). As noted elsewhere, however (e.g., Roth & McGinn, 1998), the word representation has been used in the cognitivist tradition, in the double sense of *external* and *internal* (mental) means for information storage (for instance, by Mayer (2003), who regards learning as a matter of translating external representations into internal representations). To avoid such mentalistic connotations, the alternative word *inscription* (Latour, 1987) has been launched, and in recent years, there has been a growing acceptance of this term when "referring to graphical displays created and used for the sake of communication" (Sfard & McClain, 2002, p. 155). Even if I fully welcome this dissociation from the traditional use, the choice of word could be reconsidered. For me, *inscriptions* have always denoted the markings on tombstones, made to withstand the ravages of time, which is far from the dynamic flow of information on a computer screen. For the future, I would personally like to substitute the terms *representation* and *inscription* with the term *rendering.* The benefit of this would be to further emphasize the perspectivising, interpretative and mediational functions of representations and inscriptions.

(e.g., Duit & Treagust, 2003; Oliva, 2003; Russel, 1998). The use of ideas from research on conceptual change in science teaching are not new, but go far back in time, with several studies relating directly to the works by Piaget (Driver & Easley, 1978). Given that my own project entails a view of cognitive development that in some respects differs from ideas in mainstream developmental psychology (Sfard & McClain, 2002), I will take a closer look at how research has been conducted in this area. The purpose is partly to address some methodological issues, and partly to explicate my theoretical position as regards cognitive development.

In the cognitivist, and Piagetian, tradition, a series of empirical studies has examined the nature of the conceptual problems that children have in understanding, among other areas, the shape of the earth and gravity, and the conceptual change that takes place as they develop (e.g., Mali & Howe, 1979; Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). A major outcome of this line of research has been analytical descriptions of the difficulties children have in understanding, for instance, that the earth is a sphere, the nature of gravity and some related phenomena. The nature of these difficulties was clearly described in a pioneering study by Nussbaum and Novak (1976). In this study, the authors' aim was to assess children's concepts of the earth by using structured interviews, a method modelled on the Piagetian interview methodology. Fifty-two children from two second-grade classes were randomly assigned to two groups. One group was interviewed prior to six audio-tutorial lessons about the earth, while the children in the other group were interviewed after this treatment. The reported results of this study do not so much point to the effects of the instruction as dealing with »five different *notions* or concepts … inferred from the children's responses to the interview items« (Nussbaum & Novak, 1976, p. 542). In a subsequent study, Nussbaum (1979) further examined these »qualitatively different notions about the earth as a cosmic body« (p. 83). This time, 240 pupils from grades four to eight participated, and the open-ended interview questions from the previous study were modified to a multiple-choice format. For each question, four alternative answers were presented by a drawing. The results from the first study were supported, although with some adjustments to the characterisations and categorisations of the notions.

The findings have later been refined and elaborated but are still, by and large, confirmed in more recent studies. Since these early observations, considerable effort has been put into describing in detail the different constructs children allegedly hold, and the transitions in conceptual understanding that take place as individuals develop. The current version of the different notions obtained within this tradition of research on children's understanding of the earth can be summarised by means of the study reported in Vosniadou and Brewer (1992). In this study, they describe a number of misconceptions, in the form of various mental models of the earth, allegedly held by the children. These models range from regarding the earth as flat, to describing it in the form of hollow and flattened spheres, and at the end of the developmental continuum we find versions that are close to the scientifically correct one. Some children are also claimed to hold dual models, that is, they describe it as both flat and round.

One critical aspect of this body of research is the use of structured interviews; a method which, according to Nussbaum (1979), was found to be »a very valuable technique for the evaluation of the Earth concept« (p. 92). As I wish to show, this practice builds on several assumptions that differ from my own view of how to conceive human reasoning and the role of artifacts in cognitive development. The following quote from Nussbaum and Novak (1976) illustrates some of these differences:

> In the process of developing the interview, it was observed that visual props were apt to provide the child with some cues that would interfere with the spontaneity and authenticity of his natural thinking (thereby risking the validity of the interview interpretation). (Nussbaum & Novak, 1976, p. 537)

First, the notion of *natural thinking* is open to doubt, and there are at least two interpretations of this expression. One reading is that the child should present her ideas *unaffected by the interviewer* or the surrounding environment, which pinpoints one of the fundamental problems of the dominant tradition of interview research. The nature of interviewing as a *form of discourse* between people has been neglected, and the interview has been considered a reliable method for eliciting information, as long as one adheres to certain technical procedures (Mishler, 1986). Although the cognitive tradition would be far from admitting any intellectual dealings with behaviourism, this practice comes close to a stimulus-response model, with an added layer of *underlying conceptions*. This view is clearly at odds with a dialogical perspective on communication (Bachtin, 1986; Linell, 1998; Rommetveit, 1992), and, if used in research, it is crucial to regard and analyse interviews as concrete social encounters. A second interpretation of the quote is that the thinking should be *unaffected by instruction*. This reading is also problematic, especially as Nussbaum and Novak actually tried to study the effects of instruction on children's conceptions of the earth. In my view, such an idea of natural thinking has long been outdated, and we must acknowledge that children come across philosophical ideas and scientific principles outside school as well. Even long before formal schooling has begun, they will have encountered presentations of the world in books, TV programs, works of art and media of all sorts. Schools are no longer a privileged context for learning about these matters. Furthermore, it is interesting to note how representational technologies, the perhaps principal medium for preserving and transmitting scientific ideas such as the one at stake here, are dismissed as *interfering* with the, so-called, spontaneous and authentic thinking of the child. Although I agree that the *visual props* possibly co-determine the nature of reasoning that emerges in the interviews, I would take this in the positive sense. This is, in my opinion, what is »natural« about human reasoning.

This line of research, typified by Nussbaum and Novak, represents a strand of developmental psychology with a rationalist heritage (Case, 1999). In this tradition, cognitive development is typically portrayed as a number of consecutive steps. As exemplified above, children are seen as holding naïve theories, which later become re-worked as they progress through formal schooling. According to Case (1999), there is also a large group of developmental psychologists, epistemological heirs to the British empiricists, who regard cognitive development more in terms of *cumulative learning* and as less influenced by factors of a general maturational nature. Still, there is a general disregard for the impact of our objectified forms of knowing in the guise of historical artifacts. In accordance with a sociocultural framework, the concept of cognitive development should be reformulated and considered as denoting a multitude of processes, which all involve the interface between (the analytically separated) organism and technology. As we learn to coordinate our actions with different technologies, our capacities are transformed and often expanded beyond their former state. However, this is an abstract characterisation, which needs clarification, and there is reason to look at a few illustrations.

KNOWING AS SITUATED PRACTICE

During the last three decades, there has been a growing interest in the ways representations are used in human activities, and how they help to organize knowledge and shape perception. The sociologist Bruno Latour has made detailed sociological studies of scientists and their development of scientific knowledge (e.g., Latour & Woolgar, 1979). In his view, representations are not only regarded as adding and clarifying information, but as fundamentally transforming the scientific practice and simultaneously serving as an inseparable part of understanding. He argues that scientists, in order to make progress, and to start seeing something relevant, must »stop looking at nature and look exclusively and obsessively at prints and flat inscriptions« (Latour, 1990, p. 39). He continues by stressing the role of representations in the debates around perception: »what is always forgotten is this simple drift from watching confusing three-dimensional objects, to inspecting two-dimensional images which have been *made less confusing*« (p. 39).

A similar view on the mediated nature of perception is expressed by Säljö and Bergqvist (1997) in a study of, not scientists, but science education. They examined student-teacher interactions in the context of a physics laboratory in school. The curricular goal of this activity was to offer the students possibilities to discover and discuss some of the central properties of light. The students experimented with a so-called optical bench on which phenomena such as reflection and the behaviour of light rays in various contexts can be observed. Säljö and Bergqvist showed that observations of physical phenomena in this setting did not occur in any direct or unmediated fashion. The students had difficulties seeing what they were supposed to see. In fact, in order to understand the way the experiments were arranged, and the associated behaviours of light, the students needed »access to elements of a theory of light that make the phenomena produced appear as significant according to a particular perspective« (1997, p. 385). For instance, the students saw that when light rays could not pass through a solid object, a shadow appeared. However, they did not understand what was significant about this and what such an illustration implies for the understanding of the properties of light. In short, what the students needed in order to see what they were supposed to see is a specialist language developed within a specialised community of practitioners.

A third example, of this complex relationship between perception and historically developed modes of knowing, comes from Goodwin (1994), who followed the professional activity of archaeological field excavations. He shows that the archaeologists have specific routines through which they create what he refers to as a *professional vision*, which consists of socially organised ways of seeing and understanding events emerging from the distinctive interests of this particular social group. One way the archaeologists transformed the soil on which they were working into meaningful categories was through the deployment of *coding schemes*. These coding schemes include elaborate sets of categories for describing the colour, consistency and texture of the soil under scrutiny. However, a material artifact known as the Munsell colour chart also supports this work of categorizing.

> The Munsell book encapsulates in a material object the theory and solutions developed by earlier workers faced with this task of classification. The pages juxtapose color patches and viewing holes that allow the dirt to be seen next to the color sample, providing a historically constituted architecture for perception. (Goodwin, 1994, p. 608)

The archaeologists did not only use these historically constituted artifacts, they were also actively engaged in the *production* of graphical representations of the excavation site. And, according to Goodwin, »the practices clustered around the production, distribution and interpretation of such representations provide the material and cognitive infrastructure that make archaeological theory possible« (1994, p. 626).

In summary, these three studies from various fields illustrate how representations enter into human activities and organize knowledge, shape perception and structure future action. They also show how different social groups have specific ways of organising knowledge and how this organisation corresponds to particular needs and interests. In the next section, I will discuss the tendency of some innovations and forms of knowing to expand beyond their original social settings, and the consequences this has for new generations of learners.

THE NATURALISATION OF ARTIFACTS

As was the case with scientists and archaeologists, we generally associate the use of advanced technologies with specialist practices. In proportional terms, very few people know how to make use of anaesthesia machines, nonlinear regression analyses or nuclear magnetic resonance spectrometers. This is a consequence of the division of labour and a necessity in a complex society. In order to learn how to successfully operate, for instance, an anaesthesia machine during surgery, extensive training and experience are needed (Rystedt, 2002). In the industrialised world, the secondary socialisation associated with education is constantly being prolonged for an increasing part of the population (Levin & Kelley, 1997). Moreover, the technologies mentioned would normally be attended to late in this educational process.

In spite of this, there is an interesting side to this development. Some technologies, once state-of-the-art within their respective fields, start to migrate into other social spheres. A few of them even become so common that they can be found within practices in the context of primary socialisation. Examples of such technologies could be anything from measuring instruments (for time, weight, length, etc.), diagrams, blueprints and various atlases to name but a few. Compared to bulky and expensive machines, *representations* have an advantage in that they can be propagated through media such as books, magazines, television or computers. The development of inexpensive microcomputers has also led to a new market for hi-tech toys, aimed even at the very young.

So, what consequences does this have for the cognitive/communicative development of people? Through a historical example it can be illustrated how the conditions for human development are restructured as new technologies emerge. Law (1987) makes a historical analysis of the development of new methods and technologies for navigation during the fifteenth and sixteenth centuries. In the 1480s, the Portuguese developed a practical method for the astronomical determination on board ship. The idea was to determine the *altura*, or height above the horizon, of the sun or a determined star. The measured altura could then be compared to the known altura of the port of destination. From this comparison, one would know whether to sail north or south in order to reach the desired latitude. This method included the use of an *alidade*, which could be found on astronomical instruments like quadrants or astrolabes. It was also necessary to know the latitudes of a number of ports and important coastal features. Such lists were compiled by organizing a large number of competent observers and having them report their measurements back to Lisbon. These new methods for navigation proved difficult for most mariners to learn and master. Even if they were already skilled and experienced sailors, they were not prepared to meet the challenges posed by the new technology. To overcome this problem, a new social group had to be created, and only through the education of new pilots, did the Portuguese fleet eventually manage to produce a body of competent astronomical navigators.

To make a somewhat daring comparison, many children of today are frequent and competent users of technologies, which normally would be considered as far more complex than those mastered by the fifteenth-century mariner. An interesting issue here is what has changed. That many modern *practices* contain a complexity greater than celestial navigation is beyond dispute (the technology controlling a modern computer game is more powerful than all the computer power that was used to put the first man on the Moon), but is there a corresponding increase in complexity regarding what is demanded of the individual? Children grow up in a world of things, forged out of social labour to use Marxist jargon, and intended for use in specific activities. When relocated into other social practices, these artifacts will be implicated in the formation of new activities. Hence, the follow-up question would be whether the access to representational technologies could be seen as contributing to the creation of »new problems, new modes of behavior, new methods for taking in information, and new systems of reflecting reality«, as suggested by Luria (1976, p. 9). Even though theory can provide some general guidance on these issues, we still lack knowledge of the details of these processes. In the context of the alleged properties of digital representations, discussed in the next section, these questions are well worth exploring in empirical settings as well.

STUDYING REPRESENTATIONS AND LEARNING

As noted earlier, the empirical context for this thesis is the development and use of representational technologies as educational resources. In this section, I will look more closely at some studies in this area of research, although it is not possible to make a comprehensive review of this research in a few pages. The aim of this discussion is merely to be a bit more specific about how research has been conducted, and to point to some problems I see with some of the methods used (for comprehensive overviews of this research see Berger, Lu, Belzer, & Voss, 1994; de Jong & van Joolingen, 1998; Kozma, 1991; Roblyer, Castine, & King, 1988; for documented research of this kind see Bliss, Säljö, & Light, 1999; Koschmann, 1996; Säljö & Linderoth, 2002). This discussion will later be used as a point of departure for my own empirical investigations.

In the area of multimedia learning research, it is easy to find claims to the effect that multimedia promise new ways for improving learning. For example, Mayer argues that the »promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone« (2003, p. 125). Consequently, there is a huge interest in mapping out which characteristics of multimedia will improve learning (e.g., Ainsworth et al., 2002; Mikk & Luik, 2003; Vincent, 2001).

One typical study from this line of inquiry has been presented by Schnotz and Bannert (2003), where they examined learning from verbal and pictorial representations, respectively. The subject matter chosen for the study concerned time differences and time zones on the earth. Sixty university students were randomly assigned to one of three experimental conditions. One group (labelled *text-only*) worked with the subject matter by means of a hypertext. The two other groups worked with a hypermedium including this hypertext and different kinds of graphics. The effects of the different treatments were assessed by pre- and post-test measurements of the students' comprehension of the subject. Schnotz and Bannert assert that the structure of graphics does affect the mental models allegedly used by students. But they also indicate that graphics may not always be beneficial for the acquisition of knowledge. They conclude that »pictures facilitate learning only if individuals have low prior knowledge and the subject matter is visualized in a task-appropriate way« (2003, p. 154).

These ambivalent results concerning the effects of the treatment are in no way unique to this study. As will be illustrated further, a common theme of many experimental studies of instructional technologies, when viewed through meta analyses, is the lack of evidence about the effectiveness of the technologies in question (Berger et al., 1994). What is rarely discussed, however, are methodological issues, like whether the independent variables are reasonable constructs, or if the comparisons with the non-treatment groups are justifiable. In the study by Schnotz and Bannert (2003), it was the inclusion of pictures in an instructional design that was assessed. In my view, the category of *pictorial representations* is too wide and unspecific to work as an explanatory concept. It could mean almost anything. When the study was implemented, the pictorial representations must have taken on specific meanings for each participant, which, however, were not investigated by the researchers. Consequently, regardless of the outcome of the study, it is impossible to draw any general conclusions that hold substantial explanatory value vis-à-vis the general category of pictorial representations.

Tsui and Treagust (2003) draw on a similar approach, although this time, the independent variable was *multiple external representations*. They studied how students' genetics reasoning developed as they used a computer program that featured multiple representations of chromosomes, genes and their effects on a simulated offspring. A comparison between pre- and post-tests showed that the majority of the 24 students had improved their genetics reasoning, but only for easier reasoning types. Tsui and Treagust argue that the multiple representations appeared »intrinsically motivating« (2003, p. 124) to most students, which is an unusually bold claim to make. However, they also note that some students did not have »mindful interaction« (2003, p. 130) with the representations. Mindfulness is characterized by the authors as a process that links motivation, metacognition and cognition, and which helps students to transfer their learning to new situations. From their observations, the authors conclude that students must be engaged in *mindful learning* in order to benefit from the interaction with representations. The initially bold claim is thus hedged by an obscure theoretical construct, which takes the whole argumentation close to a contradiction in terms. If multiple representations really were intrinsically motivating, would not mindfulness (as conceptualised by the authors) be an unconditional consequence? Besides this display of rhetorical acrobatics, Tsui and Treagust handle their independent variable quite schematically. As in the case of the previous study, the relation between their general notion of multiple external representations and the specific representations used in the study is not clarified in any detail.

In another recent study, Lowe (2003) examined the potential benefits of using animated weather maps, as opposed to static representations, within the domain of meteorology education. Through an experimental design, 24 undergraduate students were randomly assigned to one of two groups. One group received training with a computer-based interactive animated weather map. The reported results are said to run counter to earlier ideas that animations should be intrinsically superior to static representations. Lowe argues that the students who were working with the animation tended to focus on the perceptually salient features, irrespective of whether these had conceptual significance or not. He concludes that if animations simply display processes without providing further instructional enrichment that is relevant to a particular mode of understanding, their educational potential may be compromised. Although these particular observations are interesting findings as such, the study is still based on the problematic assumption that the large collection of applications, which can be referred to as *animations*, can be conceptualised as a unified whole that is supposed to have specific effects on outcomes of learning.

In a series of experiments, Moreno and colleagues (2001) set out to explore the effects of *social agency* when students learn from educational technology. The authors wanted to investigate »the potentially more productive application of educational technology in which an individual learner has the opportunity to develop a social relation with a computer by interacting with an animated pedagogical agent« (p. 178). In this study, the general interest in social agency was approached by subdividing the concept into three attributes (participation, modality and visual presence). As a basis for the study, there was a micro-world program (Design-A-Plant), designed to teach students about the relation between the biological make-up of plants and environmental features. The program was manipulated in order to accommodate to the dimensions the authors aimed to measure. For instance, in the last condition of visual presence, the pedagogical agent was either a fictional character wearing dark sunglasses, or a »close-up of an expressive drama actor« (p. 205). According to Moreno et al., this design would measure the effects of eye contact, which, they argue, would entail greater attention from the students, and hence lead to increased retention. The results showed no statistically significant differences between the two groups for this experimental condition. The authors conclude that visual presence neither provided any advantages, nor presented a learning impediment. As a response to this experimentally designed study, one could question whether Moreno et al. managed to measure eye contact at all. Another critical question, more in line with the reasoning above, is if *eye contact* is a one-dimensional phenomenon, susceptible to easy measurement.

Perhaps the notion of *family resemblances*, introduced by the philosopher Ludwig Wittgenstein (1953), would help in clearing up this, and the other muddled constructs, as seen in the previous examples. Wittgenstein pointed to the fact that even if we use the same word, in order to label a number of different phenomena, this does not imply that there is something in common for all labelled instances.

> Consider for example the proceeding we call »games«. I mean board-games, card-games, ball-games, Olympic-games, and so on. What is common to them all? – Don't say: »There *must* be something common, or they would not be called ›games‹« – But *look and see* whether there is anything common to all. – For if you look at them you will not see something that is common to *all*, but similarities, relationships, and a whole series of them at that. To repeat: don't think, but look! (Wittgenstein, 1953, § 66)

This quote suggests *observation* as a possible way out of the semantic dilemma, a recommendation that will be favoured in what follows. In my view, we cannot take notions like *animations* or *pictorial representations* for granted. Therefore, we should suspend our judgments about their meanings and instead examine the details of their use. Such an examination, however, calls for a different set of methods than those used in the preceding review. In the subsequent chapter, I thus turn to a discussion of these issues.

RESEARCH: METHODS AND APPROACHES

So far, I have presented a general overview of my research interest in fairly philosophical and conceptual terms. It is now time to change tack, and attend to some of the finer details of communication and social interaction. In this section, I will discuss the analytical and methodological concerns that have guided the implementation of the studies.

DRAWING DATA TOGETHER

In order to address the issues outlined above, I have carried out a set of empirical studies with somewhat varying characteristics: Participants range in age from around six to between twenty and thirty. The tasks performed by the children/students differed, as did the technologies they had at their disposal. What draws these clusters of data together is the possibility of analysing *reasoning*, and, in particular, scientific reasoning, in relation to some form of *representational technology*.

All the studies in this work have an exploratory character: they are all empirical investigations of the interaction between human beings with each other and with representational technologies. To capture the nature of the interrelations between individuals and the social, cultural and technological environments within which they develop, it is important to choose a corresponding unit of analysis. In the research literature, several units of analysis have been suggested. The one most closely corresponding to my empirical and analytical undertakings has been proposed by Granott (1998), and, in line with a musical metaphor, it is called the *ensemble*.

> An ensemble is a collective variable, indicating the smallest group of people who directly interact with one another while co-constructing developmental processes within a specific activity context (Granott, 1993/1994). The ensemble's activity context includes the symbol systems that the ensemble uses; the objects (e.g., tools, artifacts, or materials) that are directly involved in the activity; and socioculturally based layers of interpretations, norms and conventions that are reflected in the activity. (p. 50)

How one should account for this unit, and what it implies for the analysis, will be articulated further in the next section, where I discuss some approaches to the study of how technology features in the practical accomplishment of social action.

METHODOLOGICAL CONCERNS

With a major interest in studying human reasoning within complex, technology-mediated learning environments, this thesis builds on a number of analytical concerns and assumptions that are primarily adopted from ethnomethodology and conversation analysis. This choice of methodological position is shared with a growing body of video-based studies of social interaction and the use of technologies (Heath & Luff, 2000). In the description that follows, it should be noted that ethnomethodology and conversation analysis are theoretical positions in themselves. My aim is not to take on additional theoretical frameworks, but only to use their analytical stance as a means to approach and analyse my data.

Ethnomethodology was developed by Garfinkel (1967) as a radically new approach to the understanding of human practical activity. When applied to the study of conversations, this approach led to the development of conversation analysis, mainly through the works of Sacks, Schegloff and Jefferson (Heath, 1997). Ethnomethodology takes a primary interest in the *methods*, or the *methodological resources*, in and through which social actions and activities are produced and recognised (Garfinkel, 1967; Sacks, 1984). This includes talk, bodily conduct, the uses of various tools or artifacts and other parts of the material environment. A second concern, of great importance for this approach, is with the sequential organisation of interaction. The emergent and sequential organisation of action and interaction is examined in order to address the issue of how participants themselves orient to each others' conduct and in order to identify the resources they rely on to accomplish social action (Heath, 1997; Heath & Luff, 2000).

In the late eighties, a debate concerning the *situated* character of human action and learning emerged (Brown, Collins, & Duguid, 1989; Lave, 1988; Suchman, 1987), and during the nineties, these ideas became integrated with much sociocultural theorising. An important part of this line of reasoning, though, can be traced back to Garfinkel (1967) and his treatment of *indexicality*. The notion of indexicality refers to the observation that the denotation of, for instance, utterances, is relative to the particular circumstances in which they occur. Garfinkel (1967) saw this feature as *fundamental* to all practical action and practical reasoning, and not something one should seek to overcome, as previous sociologists, linguists and philosophers of language had attempted to do. This was, and still is, a radical position that has far-reaching consequences for how to conceptualise the notion of *context*. In following this approach, »social actions and activities are treated as inseparable from, part and parcel of, the ›context at hand‹; not as framed or influenced by prespecified characteristics of a context« (Heath & Luff, 2000, p. 24). Garfinkel summarised ethnomethodology as »the investigation of the rational properties of indexical expressions and other practical actions as contingent ongoing accomplishments of organized artful practices of everyday life« (1967, p. 11).

Callon and Latour (1981) have criticised ethnomethodology for not taking into account the fact that some uncertainties in human interactions are eliminated by a range of artifacts. They argue that these artifacts must be included in the analysis of human action to a larger extent than they have been so far. One could view this analytical blind spot, pointed to by Callon and Latour, as a consequence not so much of the methods used, but of the technological resources available at the time. What has been studied in this research tradition has largely been influenced by what one could get hold of in terms of naturally occurring conversations and social action. The development of conversation analysis was actually a direct response to the increased availability of tape-recorders. Sacks (1984) has described his interest in recorded talk as conditioned by its accessibility.

> It was not from any large interest in language or from some theoretical formulation of what should be studied that I started with tape-recorded conversations, but simply because I could get my hands on it and I could study it again and again. (Sacks, 1984, p. 26)

The same thing that happened to audio technology has now happened to video technology, first analogue and later digital. Parallel with the increasing availability of affordable and reliable video equipment, there is an increasing interest in the »social organization of the actions and activities accomplished through the body and physical artefacts, as well as talk, in face to face interaction« (Heath, 1997, p. 183). Jordan and Henderson

(1995) describe this emerging field as *interaction analysis*. In their view, this is an interdisciplinary method for the empirical investigation of human activity, which is particularly effective in complex, multi-actor, technology-mediated work settings and learning environments. Apart from the above-mentioned influences from ethnomethodology and conversation analysis, the particular approach of interaction analysis also builds on ethnography, sociolinguistics, kinesics, proxemics and ethology. Mainly through the detailed analysis of videotaped interaction, interaction analysis tries to describe the »mechanisms through which participants assemble and employ the social and material resources inherent in their situations for getting their mutual dealings done« (Jordan & Henderson, 1995, p. 42). In comparison to these earlier traditions, Interaction Analysis also takes a more explicit interest in learning.

> Interaction-Analytic studies see learning as a distributed, ongoing social process, in which evidence that learning is occurring or has occurred must be found in understanding the ways in which people collaboratively do learning and do recognize learning as having occurred. (Jordan & Henderson, 1995, p. 42)

Especially Studies II and III in this thesis should be seen as contributions to this line of research. Although Studies I and IV make use of structured interviews and tape-recorded interaction, they too should be seen as sharing the same set of analytic concerns. How one should regard interviews, when following an analytic agenda such as the one described above, is discussed at length in the first study. In summary, it is argued that one must abandon the position where the interview situation is regarded as a privileged context in which the mind can be tapped of its conceptual content. Instead, interviews must be analysed as concrete social encounters, regulated and guided by norms of appropriateness and relevance that are part of the participants shared competence as members of a community (Mishler, 1986).

SUMMARY OF THE STUDIES

STUDY I – MAP READING VERSUS MIND READING: REVISITING CHILDREN'S UNDERSTANDING OF THE SHAPE OF THE EARTH

At one level, this study presents a contribution to the age-old debate about the nature of human thinking and learning. At another level – the empirical – it provides a discussion of the difficulties that children face when reasoning about the shape of the earth and gravity. This work is a contribution to present-day research on conceptual change and the aim is to scrutinize what happens to children's reasoning when they encounter the issues of the shape of the earth and gravity in the context of using a map.

This ongoing debate about how to conceive the nature of the conceptual problems that children have, and the conceptual change that takes place as they develop, has mainly been conducted by researchers from a cognitivist and Piagetian tradition (Mali & Howe, 1979; Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). In this research, the focus has been on the nature of misconceptions and an array of mental models supposedly held by children has been described, as I have already alluded to. For example, Vosniadou and Brewer (1992) report that children have mental models of the earth that range from various kinds of flat entities, to dual models and hollow and flattened spheres, and that they eventually end up with versions that are close to the scientifically correct one. The dominant method for generating data on children's beliefs has been the structured interview in the Piagetian tradition of the méthode-clinique (Piaget, 1929). From such interviews, the observed utterances are used in order to infer the underlying, unobserved level of conceptions or mental models.

In this study, we argue that this practice is susceptible to both epistemological and ontological problems. As an alternative, we suggest that a distinction can be made between *having* mental models on the one hand, and reasoning *in terms of* them, on the other. The latter assumption avoids making ontological claims and makes a clear distinction between the researcher's perspective and analytical tools on the one hand, and mental models that children allegedly have on the other.

While remaining critical to much earlier research, the present study builds closely on a study reported by Schoultz, Säljö and Wyndhamn (2001). This was a study of how children reasoned about elementary astronomical concepts when doing this in the context of an artifact, a globe. The results were dramatically different from the ones reported in the research tradition discussed above. None of the children considered it possible to fall off the earth or suggested that the earth might be flat, hollow, or take on any of the shapes that have been found in previous research. The authors conclude that the differences in outcome testify to the tool-mediated nature of reasoning.

The starting point for Study I, then, is the question of to what extent the considerable sophistication, which children seemed to show when reasoning with a globe present, can be seen as limited to the use of this particular tool only. The three-dimensional nature of a globe makes it a powerful model of the earth, and the interesting issue is what happens to children's reasoning when presented with a different artifact – in this case, a map of the world? A two-dimensional map can be conceived as a somewhat more abstract model of the earth. The empirical data were collected through interviews in schools. Eighteen children, aged seven to nine, participated. The interviews were conducted in a Piagetian fashion, and largely modelled on studies in the cognitive tradition. The analysis, however, was not made in an identical fashion; instead, the interviews were regarded as concrete social encounters.

The results of this study in many respects confirm the general observations made in the previous work where the globe was present in the interview situation. The conceptions about the earth as a flat object, as hollow, etc., do not appear in this material either, in spite of the fact that this study involves the use of a two-dimensional artifact. The claim that children hold such mental models seems questionable, and one would suspect that this is a product of the methods used in previous research. When children are interviewed without any support in the form of a meaningful artifact, they obviously express views that disappear completely when there is a map present. Furthermore, by using the map as a mediational tool, they can accomplish rather advanced modes of reasoning about the shape of the earth and gravity. In some fascinating sense, the distinctions made by these children would have been impossible for the most advanced scholars a few hundred years ago to make.

STUDY II – KIDS IN ZEN: COMPUTER SUPPORTED LEARNING ENVIRONMENTS AND ILLUSORY INTERSUBJECTIVITY

The ambition of Study II is to give a contribution to the extensive literature and general discussion of learning and technologies by taking observations of local and specific practices as the point of departure. For this work, a detailed description of a *single case* is used. The case is a short videotaped sequence in which three young pupils (12–13 years of age), together with two supervisors and supported by technology, reason about *recursion*, one of the fundamental principles of computer science.

The data derive from a previous study where thirty-two pupils in the sixth grade worked with a technology called LEGO-dacta during a period of two weeks (for further details see Ivarsson, 1999, 2002; Lilja, 1999; Lilja & Lindström, 2002). This interactive learning environment contained LEGO models augmented by different sensors and motors, all of which could be monitored and controlled by a visual programming language. The class was divided into groups, who worked with the technology on three separate occasions. The sessions lasted about 30 to 60 minutes and took place during regular school hours. To help them, the pupils had two researchers who functioned as teachers/supervisors.

In the case analysed here, one group of pupils was introduced to the problem of recursive programs. This case presents an interesting example as this problem is normally first introduced at university level. Nevertheless, it seems as if the pupils quickly grasped the nature of the problem and tried to contribute to its solution. The case is also interesting in relation to the view that interactive and visually driven learning environments challenge the traditional, linguistically dominated, mode of communication. The development of these tools has been guided by a constructivist position that states that students themselves should discover the underlying principles built into the technology (Jonassen, 2000; Papert, 1993). When empirically addressing the issues of learning and the use of computers, however, one must remain neutral to claims of this kind. What pupils actually do when they have access to these computer-based environments is an open question. The aim, thus, was to explore what the pupils did when they were working in this interactive learning environment, what the nature of the communication was and what resources the participants utilized in their interaction.

The results suggest, firstly, that the nature of the technical environment led to a specific way of working and talking. The participants used a large number of indexical terms (like here, there, that, etc.) along with pointing gestures. It is argued that this communicative style was facilitated by the visual and dynamic characteristics of the graphical representations.

The results also suggest that there is a possible conflict between this highly indexical language and more theoretical knowledge. The use of simple words made it easier for these young pupils to articulate their ideas and make active contributions with respect to the problem. On the other hand, the lack of a more general language, with connections to other contexts, could make this discussion an isolated event.

Finally, the analysis revolves round how this conflict is concealed from the participants by the wider scope of interpretations provided by the indexical expressions. The reasoning being performed by the students and the teachers, respectively, can be seen as two almost separate lines of reasoning. These lines converged in the local expressions and the actions that are connected to the activity of programming. What makes these lines of reasoning so different from each other is that the students and the teachers had access to differing resources for their interpretations. The participants, however, did not acknowledge this discrepancy – a condition termed *illusory intersubjectivity*.

STUDY III – WHAT MAKES THE SUBJECT MATTER MATTER? CONTRASTING PROBEWARE WITH GRAPHS & TRACKS

The general interest of this study is the reported difficulties students have with handling graphical representations in science and mathematics teaching. Of particular interest are the technological innovations that have been developed to solve these difficulties. In this study, we focus on two interactive environments, which were designed for the learning of kinematics: probeware and a simulation program (called Graphs & Tracks).

The background of this study is a number of conceptual tests that have shown that students perform significantly better after working with probeware compared to other similar activities (Barclay, 1985; Mokros, 1985; Mokros & Tinker, 1987). Repeated observations of measurable effects of instructional technology are rare, and the researchers have tried to single out the critical success factor (Linn, Layman, & Nachamias, 1987). Probeware consists of a computer connected to probes that measure and log different physical phenomena, while simultaneously visualising the measured data in the form of digital meters, oscilloscopes, graphs, or tables. In contrast, Graphs & Tracks is a purely virtual environment that simulates the motion of a ball and represents this motion in different graphs. Mokros and Tinker (1987) suggested four possible reasons for the effectiveness of probeware: The use of multiple modalities; the real-time pairing of events and their representations; the genuine scientific experiences that are made available; and the elimination of the drudgery of graph production. However, after twenty years of research in this area, there is still a lack of convincing evidence as to why probeware leads to better scores on conceptual tests than other similar activities.

The main purpose of the present study, then, is to explore *why* students' performance improve when working with probeware. We do this by scrutinizing some critical differences between how students do kinematics in the two learning environments. In order to address this issue, we analyse how the students communicate, how the graphs become a part of the interaction, what concepts from kinematics are used and, finally, what aspects of the assignment become focal.

The data used in this study are taken from an introductory course in physics at a Swedish university. Twenty-two pre-service teachers participated in four labs, each lasting about four hours. The analysis builds on video-recordings from the first two labs, in which the students worked with kinematics by using the two different learning environments. In line with other video-based studies of technologies and social interaction (Heath & Luff, 2000; Jordan & Henderson, 1995), the students' interactions in the lab are scrutinised as *practical achievements,* and analytical attention is directed to the methods and resources on which the students rely in order to produce actions and to make sense of the situation.

By making a comparison between the students' interactions in the two environments, we are able to demonstrate some central aspects that could explain why students perform better after working with probeware in comparison to simulations or other similar activities. The results point to the importance of designing activities where students are forced to focus on relevant aspects of the task in order to complete the assignment; in this case, activities where students make the relation between representation and the represented a central part of their interaction. When acting in the probeware environment all the students developed an increasingly refined way of describing and conceptualising the graph. This however, did not occur in the work with Graphs & Tracks. Here, the activity was mostly characterised by the iterative procedure of trial-and-error. The analysis suggests that this difference was due to the demands of the assignment – with probeware there were no other *easy* ways of achieving a satisfying result, while the work with Graphs & Tracks was much more open and permitting.

STUDY IV – SEEING THROUGH THE SCREEN: HUMAN REASONING AND THE DEVELOPMENT OF REPRESENTATIONAL TECHNOLOGIES

The overall aim of this study is to investigate some of the relations between representational technologies, perception, cognition and action. The evolution of digital technology has expanded the possibilities of visual expression, bringing to representations dynamic and multimodal qualities. The transformation of established representational forms, such as maps, into new interactive and dynamic forms could also be seen as resulting in new challenges, in addition to the possibilities. The question is what such challenges could look like. With the aim of acquiring an initial understanding of this issue, this study scrutinized what happened to children's reasoning, when confronted with an unfamiliar and dynamic representation, by examining what discursive strategies and resources the children used in their argumentations.

This study can be seen as a continuation of the work done by Schoultz, Säljö and Wyndhamn (2001) and Ivarsson, Schoultz and Säljö (2002, i.e., study I this volume) in bringing a cultural and historical perspective to the research on conceptual change. In line with the earlier studies, the empirical data were collected through interviews in schools, and 19 children, aged six to eleven, took part. The interaction was audio recorded and later transcribed. A specially designed computer program was used as a basis for the interviews. The program mainly consisted of a large picture of the earth, and the issue scrutinized in this study was about the movements of a depicted aeroplane on this display.

The general impression of the analysis of all the interviews was the increased problems the children faced in their reasoning compared to the two earlier studies. Even though this program could be described as more powerful than a traditional globe or a map – in that it incorporated and visualised information dynamically – several children had trouble coordinating what they saw with what they already knew. In the analysis, three analytically distinctive forms of reasoning are illustrated. It is argued that these differences in reasoning are related to differences in perception of the graphical representation. And also, that the reasoning presented by the children is related to culturally established modes of representation (Wartofsky, 1979). The results thus illustrate a way in which perception and understanding can be closely interlinked with such cultural modes of action.

DISCUSSION

The theme of this book has been the role of representational technologies in the trust, transmission and transformation of human knowing. Central to this discussion is a number of interrelated concepts such as *artifacts*, *representations/renderings* and *mediation*. As the observant reader may have noticed, these concepts are used in slightly different ways. This implies that part of the criticism, previously aimed at a number of studies of technology in education, could be directed at the very framework of this thesis. One way to proceed, and arguably to avoid some problems, is through *empirical investigations* of practical actions and practical reasoning performed in technology-saturated environments. Here, I wish to discuss some of the ways in which artifacts are embedded in practices of reasoning. The empirical studies will be reviewed with a primary focus on their possible contributions to the move from general theorising to a more particularised understanding. Analogously, this closing chapter will begin with the more theoretical issue of the origins and development of human knowing, and end in a more methodological discussion on conditions for analysing learning environments.

RECONSIDERING COGNITIVE DEVELOPMENT

A recurring topic in this work is the question of how to conceive cognitive development and, in line with my theoretical preferences, I have argued for a special understanding and use of this concept. *Development* (as an analytical concept) requires a norm according to which the change in the investigated phenomena can be measured or made visible. A common understanding of *cognitive* development has been in relation to a biological species-specific norm. The theorists prominent in this thesis, though, mostly discuss development in relation to historically changing social and cultural norms. Accordingly, cognitive development is understood as being relative to various technologies and different forms of social life (Luria, 1976). For example, the ability to tell time and the sense of time that develops from the use of a watch are different from the analogous actions/activities based on the sun. From the perspective taken here, we cannot regard the emergence of the former kind of faculties, without also considering artifacts. Looking at the actions of the individual or the technologies alone is, as put by Latour, »like watching half the court during a tennis game; it appears as so many meaningless moves« (1992b, p. 247). To focus only on one side of this relationship is to seriously impoverish the concept of cognitive development.

Furthermore – and this is one of Wartofsky's (1983) more important arguments – if the norms by which we judge development are historically changing, then the developmental process must itself be subject to change. This implies, that, at the same time as new technologies are created and new social practices become established, the developmental trajectories of individuals may be altered. In the early 1930s, Vygotsky and Luria made a series of studies among peasants in Uzbekistan, when the region was experiencing a radical restructuring of the socioeconomic system and culture (see Luria, 1976). The authors showed how the responses to a number of perceptual tests were linked to differences in access to newly emerging practices of schooling. Thoroughly studying the role of historical change as a fundamental factor in perceptual and cognitive development, though, is no easy feat; the conditions observed by Vygotsky and Luria do not occur at regular intervals (nor should we try to create them experimentally).

Even if changes in society as a whole are difficult to get at, changes in activities where technologies are central are easier to come across. Although, I do not make any pretensions to having made any substantial analyses of the role of historical change, some observations from the studies resonate with the ideas of Wartofsky and Luria. For instance, the very *perceptual activity* of some of the children in Study IV differed from that of the other children. The reasoning was not random and, in the study, we argue that it more or less corresponded to two culturally established modes of pictorial representation. Even the use of probeware (Study III), as well as the activity of programming (Study II), involved what one could regard as historically recent *architectures* for perception (Goodwin, 1994). This concern for the employment of new instructional technologies in educational practices could afford the opportunity of giving further empirical accounts of *how* perception is connected to changing forms of social and technological activity, that is, detailed descriptions of perception as historically variant.

APPROACHING ARTIFACTS

The first study concerned the nature of children's reasoning when dealing with the issues of the shape of the earth and gravity. As in the study by Nussbaum and Novak (1976), the use of structured interviews of various kinds has been a principal method for generating data on children's beliefs and competences in the research on conceptual change. In view of our findings, some of the ways in which interviews have been analysed are highly problematic since they disregard the role of artifacts. If artifacts are included in the interviews, and analysed as part of the activity, one will get a completely different picture of children's competences and struggles. This makes the empirical observations from Study I most relevant if seen in relation to much contemporary research on conceptual change. To a sociocultural research tradition, however, these particular findings are not strikingly new. That reasoning is dependent on available artifacts has become a part of the theoretical premises for this line of work. The contribution to this tradition is connected to what one, as an analyst, can get out of such specific arrangements, as the structured interview, when focusing on the nature of the interaction and communication.

In comparison with the observations from the preceding study by Schoultz and colleagues (2001), Study I presents additional findings that refer to the interview situation as a communicative event. According to Schoultz et al., the general idea of the globe as a representation of the earth appeared obvious to the children in their study. In relation to the questions about the shape of the earth and the related concepts, the globe seemed to support the children in their reasoning in a straightforward fashion. I believe that this concordance, between the artifact and the children, represents an extreme case that works better on a rhetorical level than as a general model for mediation. One possible reading of this study (which I am sure the authors would oppose) is that artifacts *directly* endow us with new skills; a picture which is too simplistic and which fails to consider the larger complexity of mediation.

Säljö and Wyndhamn (1987) conducted an empirical investigation of how pupils solved arithmetic problems under conflicting premises for communication. They explored the relationship between the students' interpretations of the pedagogical situation and their problem-solving strategies. The authors argue that how the pupils defined and dealt with the tasks had more to do with their capacity to decipher the ambiguous communicative situation than with how well they had mastered any mathematical algorithms. Thus, their problem was largely a communicative one. In a similar vein, the communicative problem of defining the pedagogical situation in Study I seemed greater than in the study by Schoultz et al. (2001). In contrast to the use of a globe in the interviews, the use of a map from an atlas introduced an additional obstacle for the participants. When the children were asked what the object in front of them was, they faced the trouble of discerning which was the expected type of discourse. The object as such could be used and talked about in countless ways but the only three suggestions the pupils arrived at were *book*, *map* and *earth*. At a glance, these responses could seem trivial, but one must remember that they are all reasonable choices given the school context (no-one explored the possibility that the object should be seen as a fly-swatter, a support for rickety furniture, a flower press, etc.). The actual variation in responses shows that how the artifact should be talked about was not obvious, only more or less probable given the circumstances.

The relation between activities and actions has been scrutinized in detail in all four studies, and it has been shown that the kind of resources the participants drew on, in order to make both the activities and the technologies meaningful, varied extensively. There is an important lesson to be learnt from this. Given any educational material, representational technologies or otherwise, we cannot *take for granted* that pupils/students will approach them in the manner intended. Performing the (institutionally) appropriate contextualisation must be considered part of what one is supposed to learn. Especially when we are dealing with things that are new, in one way or another, for the participants, there is reason to be cautious. This further complicates the design of studies focusing on the possible effects of instructional technologies and the use of learning environments.

ANALYSING LEARNING ENVIRONMENTS

That people use technologies in different ways is an important premise for this work. The question of *how* students use and perceive representations, however, has been the common focal point of all my empirical investigations. In both the second and the third study, we adopt a critical stance towards wide-ranging claims on the characteristics and effects of instructional technologies. As the typical argument goes, some general feature (visualisation, interactivity, real-time, hands-on, etc.) of an instructional technology is supposed to provide a structure that gives the interaction a desired direction and, in the end, a positive learning outcome (e.g., Mikk & Luik, 2003). The findings from Study II and III provide evidence rebutting this line of argument. For example, in the third study, two learning environments, which shared many structural similarities, turned out to present different opportunities for learning. The experiences the students made in the environments also varied considerably. Hence, coarse descriptions such as those above only amount to simplifications, and they are of no help in finding educational potentials of representational technologies.

In addition to these methodological implications, the detailed investigations have resulted in findings with direct relevance to instruction. Both Study II and III point to the significance of giving the renderings provided by the learning environments the additional dimension of a conceptual language. The analyses show that even if the representational technologies could be said to embody scientific concepts and distinctions, it is essential that the students themselves both *make use of* conceptual resources and find the conceptual resources *useful* for completing their tasks. As long as the scientific concepts do not equal the *necessary means* for solving a task, we cannot presume (only hope) that students will initiate this specific way of talking and acting. This is a true educational challenge, and in Study II, I argue for the role of the teacher in helping this to come about. The third study explores some of the conditions under which technology can help in this task. In Study III, we claim to have shown *why* students' performance often improves when working with probeware in comparison to similar activities. We argue that this result originates from a combination of how the technology was constructed and the demands of the tasks the students had to solve. Without alternative means of achieving a satisfying result, the students more or less *had to* turn to the taxing, but rewarding, employment of scientific concepts and distinctions.

FINAL REMARKS

As stated at the outset, one aim of this thesis is to go beyond the use of general categories and abstract analytical concepts when discussing technologies and learning. I have argued that they oversimplify and conceal much of the variation that can be found within each category/concept. The outcome of my empirical investigations – of the use of renderings in practices of reasoning – are illustrations of some of the aspects that can go unnoticed.

The findings speak to different groups of professionals; researchers as well as teachers and developers of instructional technology could find arguments and observations in this work relevant to their respective practices. The four separate studies have somewhat different target groups, though. Studies I and IV mostly treat philosophical and theoretical issues. While Study I presents a contribution to an ongoing research debate, Study IV aims to develop the theoretical discussion on representational technologies and human knowing. In Studies II and III, on the other hand, the theoretical perspective is taken as a premise, and the examinations addressed issues of greater relevance to instructors and designers. Both studies discuss students' interaction with the technology and what is required of their interaction if the pedagogical expectations are to be met. Some concrete aspects of the interaction with explicit pedagogical consequences are illustrated. With more descriptions of this kind, we will be better prepared to set up learning environments that present similar qualities in other knowledge domains. Consequently, in my opinion, the development of instructional technology would benefit from more naturalistic observations of students' interaction with technology.

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Part Two

THE STUDIES

STUDY I

MAP READING VERSUS MIND READING

REVISITING CHILDREN'S UNDERSTANDING OF THE SHAPE OF THE EARTH*

For centuries, the question of how to conceive human cognition was an issue that mainly concerned philosophers. During the 19th and 20th century, however, new disciplines emerged, and researchers within areas such as psychology, anthropology, linguistics, neuroscience, artificial intelligence and educational science joined this lively debate. Although its roots go further back, the one perspective that has been dominant in recent decades, or at least up until recently, is the one represented by cognitive psychology. The traditional focus of cognitive psychology is to posit cognition as a fundamentally individual process. The assumption is that human mental functions are located in individuals and can be modelled accordingly as mental entities such as memory systems, thought processes, and cognitive structures. The empirical approach that resonates with this conception usually explores allegedly basic cognitive and perceptual processes (thinking, memory, problem-solving, perception, etc.) by attempting to unpack the basic mechanisms of mental processes and/or the conceptions of the world that people hold when reasoning. The focus is on cognitive systems and thought processes that – as the metaphor goes – underlie reasoning at the level at which it is visible externally in linguistic and physical activities.

* Co-authored with Jan Schoultz, Department of Thematic Studies, Linköping University, and Roger Säljö, Department of Education, Göteborg University. Published in M. Limón & L. Mason (Eds.), *Reconsidering conceptual change. Issues in theory and practice* (pp. 77-99). Amsterdam: Kluwer. (2002) Reprinted with kind permission of Kluwer Academic Publishers.

A major challenge to this tradition comes from a sociocultural and discursive perspective inspired by Vygotskian and Wittgensteinian views of human cognition and communication (Vygotsky, 1986; Wertsch, 1991, 1998). The sociocultural tradition places human cognition in a historical and situated perspective. Cognition is conceived as a problem of how people use tools – physical as well as conceptual/discursive. This is as much an interactive process as an individual one; in fact, it is very much in the middle as joint and mediated action. And even when reasoning on their own, people do not do this in social isolation – human action is always situated. An important assumption is that such cultural tools form an integrated part of cognitive processes. There is no sense, following such perspectives, in assuming that there is a level of thinking that is *pure* and that underlies reasoning in human practices. We cannot separate thought processes, say in the context of doing geometry or playing chess, from the conceptual tools that are applicable to such activities. Thinking is the use of tools. Or, as Wittgenstein so suggestively put it in the context of the use of language; »When I think in language, there aren't ›meanings‹ going through my mind in addition to the verbal expressions: the language is itself the vehicle of thought« (1953, § 329).

Although it would be tempting to create syntheses between traditions, our preference is to keep them apart. They build on conflicting assumptions regarding the nature of human cognition and action that have a long history in western philosophy, and the difference between them is of a paradigmatic nature that cannot be easily resolved by appealing to empirical data. However, on some issues the critical differences between these traditions should be explored. The particular area that we will be considering in this context is that of learning and conceptual reasoning. In these areas, the views of these traditions differ very clearly, and these differences have apparent implications for how one conceives human learning and conceptual knowledge and also for establishing what is difficult in such activities.

STUDYING HUMAN COGNITION

A critical point of departure in any research on human cognition, and one which deserves to be taken seriously, is that the object of inquiry is somewhat elusive. As scholars we are forced to consider that the observations we are attending to in our analyses are symptomatic and have, as it were, an indirect relationship to what we are interested in. Cognitive phenomena can be described at many different levels, for instance, in terms of neural signals and reactions, blood flow in the brain and all the way up to how people reason and interact in complicated everyday situations. The relationships between these levels are complex, to say the least.

Since the object of inquiry is contested and ambiguous, one has to consider how various paradigms construe their studies, design experiments and relate theory to observation. Rather than arguing about thinking and learning in general, one should scrutinise precisely how the empirical studies are carried out in various paradigms in order to establish in what sense the observations can be seen as valid indicators of human thought processes and reasoning. When looking at the area that we shall be exploring – children's understanding of the shape of the earth and certain concepts from elementary astronomy (such as gravitation) – these differences between theoretical traditions are obvious. In the following, we shall give a brief introduction to research in this area from a cognitive psychology and sociocultural perspective, respectively. We do not pretend to cover all the research. Rather, in order to address our main question about how children understand the shape of the earth and some related matters, we will give a brief summary of relevant studies with the ambition of illustrating the clear differences in how children's competences and learning trajectories are portrayed. But before embarking on this presentation, we shall say a few words on the notion of conceptual change.

CONCEPTUAL CHANGE IN A SOCIOCULTURAL PERSPECTIVE

Central to a sociocultural tradition is the idea of mediation and tool-mediated action (Wertsch, 1991). Language, and its conceptual resources, is the most important tool, and it is also unique to the human species – it is the *tool of tools*. Concepts and categories thus mediate the world for us in real world activities, and they are, in fact, basic to our perception, reasoning, remembering, and any kind of cognitive activity. Seeing an object as *a square* or *a circle* relies on, and reproduces, a certain, socioculturally generated, set of categories for describing and thinking about objects. However, concepts are not just mental entities that reside inside our heads, they are part of human social practices. People use concepts to do things in a world of physical and intellectual actions; discourse is an important aspect of practical action. The judge uses the concepts of the legal system such as *intent*, *fraud*, and *assault* when passing a sentence on a suspect. The construction engineer uses the conceptual tools of mathematics, mechanics and other specialised scientific areas when designing a new engine. Thus, and this is one of Vygotsky's (1986) fundamental insights, concepts (or as he referred to them: psychological or intellectual tools) are used by people when thinking (i.e. intramentally) as well as when communicating with each other (i.e. intermentally); thinking in this perspective is conceived as a kind of silent and private dialogue where people use the conceptual resources of their society for reasoning. In this sense, our thinking is sociohistorically produced as we have already alluded to.

So, how does one conceive conceptual development in such a perspective? When regarding concepts as tools (and not just abstract, internal representations of the world), a critical feature of conceptual development is how people come into contact with various kinds of tools that exist in a society. Concepts are elements of discourses that are used in various practices in society. Everyday reasoning relies on conceptual tools as much as does any other kind of activity. But an important arena for the communication of more specialised kinds of conceptual tools is schooling. It is here that the individual encounters scientific (or, more generally, institutional) forms of reasoning that may not be familiar or widely used outside institutional settings. When learning physics, for instance, we have to familiarise ourselves with new modes of reasoning that build on concepts such as force, velocity, momentum, acceleration and so on that are defined in particular manners. And learning to use these in an insightful manner (which is not the same as being able to define them in a formal sense) can be a long and complicated learning process.

But what, then, is the nature of this process? This is a critical question from a psychological and communicative point of view. Vygotsky (1986) originally suggested that learning and conceptual development could be seen as a process of internalisation by individuals of conceptual tools. However, this is a problematic position, since this formulation somehow recreates a boundary between thinking and communication that Vygotsky was eager to do away with. The point of much of his argumentation is that conceptual tools are used in both these types of human actions, and it therefore seems more fruitful to avoid reintroducing the Cartesian split between *the outside* (communication and physical action) and *the inside* (thinking).

Alternative modes of formulating the processes of conceptual development have been suggested by, for instance, Rogoff (1990) and Wertsch (1998). The traditional preference has been to view learning and conceptual development in terms of appropriation of mediational means. Appropriation, as used here, implies that the individual gradually familiarises herself with a set of conceptual tools and begins to realise how they are used. For instance, Saxe (1991), who studied Brazilian children acting as candy sellers, observed how the young children with a low or no formal education performed complex calculations that involved the awareness not only of proportional relationships between goods and price, but also included consideration of the problems imposed on the activities of selling and buying by hyper-inflation. Appropriation thus implies that the individual is able to reason and act in situations by means of a certain conceptual tool. This does not imply that the tool is appropriated in all its details. This is probably rarely the case. Even if one understands and is able to use the concepts of force or energy when solving physics problems, there are many aspects and potential uses that may take years of further study to appropriate. In a similar vein, the candy-sellers in Saxe's study had not appropriated the concept of inflation in the same sense as an academically trained economist. Yet, in some settings they were able to take this highly complex phenomenon into account in quite a sophisticated manner. In this sense, appropriation implies an increasing familiarity with how a tool can be used for different purposes. Recently, Wertsch (1998) has suggested that it might be useful to make a distinction between appropriation and mastery, a suggestion which is interesting in this context. The latter concept is developed in the context of observations made by the Estonian psychologist Peeter Tulviste (e.g., 1994), who studied the learning of history in Estonia under Soviet rule. In these studies it was shown that the students in school and at universities learned the officially sanctioned explanations and accounts of history and historical development in the Soviet-Marxist tradition without appropriating the conceptual tools or the worldviews these accounts implied. Sometimes the students even mastered these accounts to perfection, but they never used them in any other settings as conceptual tools. So, mastery of a particular kind of tool may be seen as something different from appropriating a tool in order to actively use it. This is a fascinating perspective on human cognition, but we shall not go deeper into this matter here.

There is another layer to this argument about the tool-dependent nature of thinking, which is essential to the research reported here and has to do with conceptual knowledge. In a sociocultural perspective, the intimate relationship between concepts (i.e. intellectual tools) and physical tools (i.e. artifacts) is emphasised (Bliss & Säljö, 1999; Säljö, 1998). Thus, calculators, calendars, computers, instruments for measuring entities such as distance, volume, pressure, etc. are seen as physical embodiments of human conceptual constructions such as number systems, units of measurement and so on. This implies that when reasoning with artifacts, the tool serves as an aid to thinking in the sense that it represents the world in relevant conceptual categories. This is an important aspect of the role that artifacts play as support and prosthetic devices for thinking, which we will come back to below (see also Wyndhamn & Säljö, 1998). But before going into this, let us review some of the work done on the particular issue of children's understanding of some elementary astronomical and/or geographical concepts.

STUDIES OF CHILDREN'S UNDERSTANDING OF THE SHAPE OF THE EARTH AND GRAVITATION: A COGNITIVIST PERSPECTIVE

The interest in studying children's learning and understanding these matters goes back quite some time. In the cognitivist, and Piagetian, tradition a series of empirical studies have examined the nature of the conceptual problems that children have in this area, and the conceptual change that takes place as they develop (Mali & Howe, 1979; Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou, 1994; Vosniadou & Brewer, 1992, 1994). A major theme of this line of research has been the illustration of the apparent difficulties children have in understanding that the earth is a sphere. These difficulties were clearly outlined in the pioneering studies by Nussbaum and colleagues during the 1970s. Their findings have later been refined and elaborated but are still, by and large, confirmed by more recent studies. Since these early observations, considerable effort has been put into describing in detail the different constructs children hold (cf. below), and the transitions in conceptual understanding that take place during ontogenesis. Vosniadou and Brewer (1992), two of the recent leading specialists in this area, suggest that the reason for the problems children have is that information about the shape of the earth contradicts the child's basic ontological presuppositions. That is, the scientifically appropriate model is contradictory to the beliefs held by the children, beliefs based on years of convincing everyday experiences. According to Vosniadou (1994) these experiences form the foundation of our knowledge base. A revision of this base is not easily achieved, and, when this happens, it will have profound implications for subsequent knowledge structures.

MENTAL MODELS

In the cognitivist paradigm, the analyses of conceptual change are closely linked to the assumptions of the existence of mental models. Following Vosniadou (1994), mental models are intermediate phenomena that exist between the overt (verbal or written) responses given by children in empirical studies, and something that she refers to as underlying theoretical constructions or, to use her language, framework theories. Although the specific, individual, mental model may vary in its relations to the underlying structure, it is believed that the generic aspects of a mental model can provide information about these underlying so-called framework theories.

> Mental models are dynamic and generative representations which can be manipulated mentally to provide casual explanations of physical phenomena and make predictions about the state of affairs in the physical world. It is assumed that most mental models are created on the spot to deal with the demands on specific problem-solving situations. Nevertheless, it is possible that some mental models, or parts of them, which have proven useful in the past, are stored as separate structures and retrieved from long-term memory when needed (Vosniadou, 1994, p. 48).

Having taken a brief look at the conceptual foundations, we shall now, following our previous argumentation, take a closer look at some of the elements of what has actually been studied in this line of research.

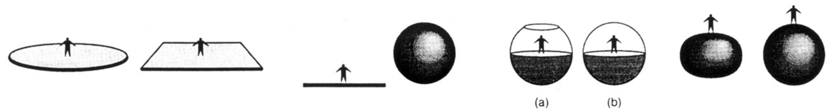

Figure 1. Mental models of the earth (adapted from Vosniadou & Brewer, 1992, p. 549)

MENTAL MODELS AND CHILDREN'S REASONING

The methodology used in these studies varies, as do the modes of analysing data. One prominent method for generating data on children's mental models/framework theories, though, is the structured interview in the Piagetian tradition of the méthode-clinique (Piaget, 1929). The nature of the responses generated has also varied. In some cases, children have responded verbally, in other cases they have been asked to draw a picture or even to construct physical models using clay or other resources. At any rate, the basic assumptions are that the questions have a potential to unravel the mental models students have.

The general results obtained within this tradition of research on children's understanding of the earth can be summarised by means of the study reported by Vosniadou and Brewer in 1992. Here the »mental models of the earth« that children use are depicted as illustrated in Figure 1. At one end we find various kinds of flat entities that are described and/or drawn by children. These are followed by so-called combined models (where the earth may take on different shapes) to hollow spheres, and, finally, we end up with versions that are close to the scientifically correct one. According to this cognitivist perspective, all children seem to follow the same line of development. The demands placed on them – the cognitive conflict – to integrate the culturally accepted view of the earth as a sphere with their everyday experience force children to go through a number of steps in which they hold different conceptions of the earth. What is not entirely clear is where these models come from, an obscurity that seems to be a general problem for this tradition. In fact, as it has been argued, »cognitivism remains perennially unable to resolve such thorny problems as the origin of ideas or concepts« (Gergen, 1985, p. 270). In this case, it seems as if the models are constructed anew by each child on the basis of personal experience and essentially without cultural support. The ontological presuppositions (i.e. the framework theories) are constraints that the children simply have and that they have to struggle with.

The procedure of inferring a level of mental models on the basis of observed responses is not uncommon within the cognitivist perspective. In fact, Gardner (1987) describes this mode of working as one of the major accomplishments of cognitive science. Nevertheless, we believe there is good reason to be cautious. This practice of introducing such an intermediate level in explanations implies a shift from specific observable events to generalisations and abstractions on a totally different level, a jump between logical types (Bateson, 1972, 1979). Also, such a strategy introduces not only theoretical and epistemological problems but also ontological ones; what is the ontological status and psychological reality of mental models?

Having pointed this out, we would like to emphasise that we do not deny that the children in the studies commented on above are reasoning *in terms of*, for example, a disc shaped or hollow sphere earth. But we are far less convinced that there is anything to be gained by saying that children *have* mental models of these kinds. We believe that a distinction can be drawn between having mental models and reasoning in terms of them. The latter assumption avoids making ontological assumptions and makes a clear distinction between the researcher's perspective and analytical tools on the one hand, and mental models that children allegedly have on the other.

SITUATING CHILDREN'S REASONING IN THE INTERVIEW SETTING

A point that needs to be emphasised here is the fact that the children in the cited studies do not reason in a vacuum. In many studies (Mali & Howe, 1979; Nussbaum, 1979; Nussbaum & Novak, 1976; Sneider & Pulos, 1983; Vosniadou, 1994; Vosniadou & Brewer, 1992) participants have been asked to express themselves using physical objects, pictures or drawings (cf. Figure 2). The status of such physical artifacts and drawings is not taken up in any of these studies. The drawings, for instance, are only regarded as expressions of underlying conceptions, and never as resources in themselves that contribute to and co-determine the process of reasoning.

Very few of these studies present their data in a manner that makes it possible to discern how these drawings are produced and what role they play in children's reasoning. However, one point that is worth exploring is if children can be assumed to always be clear about the relationship between the drawing and what it is supposed to model (the earth as an astronomical object). It does not seem far-fetched to suspect that the rela-

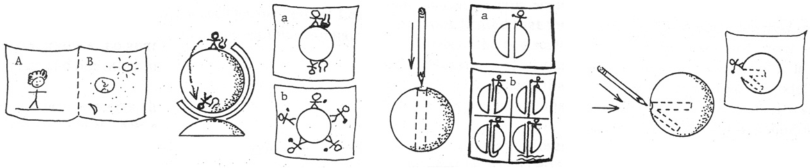

Figure 2. Objects used in interviews (adapted from Sneider & Pulos, 1983, p. 209)

tion between the (physical) model and its referent is lost from time to time in these interviews. An observation from Vosniadou (1994) illustrates this. Here, we find the girl Kristi being asked to draw the »real shape of the Earth«. Kristi draws a circle and is then asked to reason about what happens if one walks in a straight line for many days.

> Kristi (first grade)
> E: What is the shape of the Earth?
> Child: Round
> E: Can you make a drawing which shows the real shape of the Earth?
> C: (Child draws a circle.)
> E: If you walked and walked for many days in a straight line, where would you end up?
> C: You would end up in a different town.
> E: Well, what if you kept on walking and walking?
> C: In a bunch of different towns, states, and then, if you where here and you kept on walking here (child points with her finger to the "edge" of the circle which she had drawn to depict the Earth) you walk right out of the Earth.
> E: You'd walk right out of the Earth?
> C: Yes, because you just go that way and you reach the edge and you gotta be kinda careful.
> E: Could you fall off the edge of the Earth?
> C: Yes, if you were playing on the edge of it.
> E: Where would you fall?
> C: You'd fall on this edge if you were playing here. And you fall down on other planets. (Vosniadou, 1994, p. 51)

In this example, Kristi makes active use of the drawing as a resource for her reasoning as can be seen. She repeatedly points to it to make explicit and support her arguments. However, what is interesting here from the point of view of her cognitive performance is that this drawing of the earth is nothing but a thin line; it *de facto* contains something that in some sense is the »edge of the earth«. If we assume that Kristi for the moment is talking about her drawing, and temporarily disregards the fact that it is a model of something else, it seems quite logical to assume that one can fall off the edge. Also, the approach of the interviewer in this excerpt is anything but neutral and passive (which is how interviewers in research generally are described as). Rather, s/he can be read as signalling that s/he is not satisfied with the response given by the child in line six (»You would end up in a different town«). By insisting on this topic of what would happen if »you kept on walking and walking« in her next contribution, the child might be seen as being provoked into saying something different rather than merely repeating the same response.

In our view it is essential not to go abstract at too early a stage. Children's reasoning in situations of this kind are better studied as situated practices where the dynamics of the context, the dynamics of the interviewing, and the tools available, are decisive for what children say or do.

STUDIES OF CHILDREN'S UNDERSTANDING OF THE SHAPE OF THE EARTH AND GRAVITATION: A SOCIOCULTURAL PERSPECTIVE

Physical tools originate in collective cultural practices, and human cognition is socialised through participation in activities where tools are used for particular purposes. A very important dimension in sociocultural development is the increasing sophistication of tools that occurs over time. Powerful intellectual distinctions and resources are built into tools that are used for a wide range of purposes when performing activities such as calculating, navigating, communicating, reading, analysing substances at microlevels, playing games and so on.

The attitude towards thinking that characterises this perspective thus emphasises the intimate links between cognition and the use of tools in situated practices. There is no such thing as *pure* cognition that can be accessed per se as we have already pointed out. Even in interview situations, such as the ones commented on above, the terminology used, the manner in which questions are formulated as well as the drawings and artifacts used, mediate people's reasoning. To reason with a physical object as a model is one thing, to reason without such resources represents another situation with very different cognitive demands.

This view of cognition as the use of tools was the background of the study on children's conceptions of the shape of the earth and gravitation carried out by Schoultz, Säljö and Wyndhamn (2001). The main idea behind this study was to analyse how children reason about elementary astronomical concepts when doing this in the context of an artifact, a globe. The interviews were conducted in a Piagetian fashion and to a large extent modelled on the studies in the cognitive tradition summarised above. The children (aged 6 to 11 in grades 1 to 5) were first asked to identify and name the object in front of them (which all children did without any problem). All children also realised that the globe was a model of the earth. The results show that when using the globe as a resource for reasoning, the children were surprisingly knowledgeable and sophisticated. Even amongst the youngest, there were several who argued in terms of a concept of gravity (sometimes without using the term) as an explanation of why things fall to the ground. None of the children considered it possible to fall off the earth. Even when put under considerable pressure by the interviewer, who pointed at countries such as Argentina and Australia visibly located on the downside of the globe, and explicitly asking if people would not fall off, did any of the participating children agree to the possibility that people *down under* might fall off the earth. None of the children suggested that the earth might be flat, hollow or take on any of the shapes that have been found in previous research (cf. Figure 1).

The authors conclude that the differences in outcome testify to the mediated nature of reasoning. The globe was obviously a familiar artifact for the children. When reasoning with this tool as a resource, the children were in a completely different situation as compared to when being interviewed or when making drawings on their own. For instance, they could read the names of the countries on the globe, and they knew from other sources (media and friends) that people live in Australia and other countries that appear to be on the downside of the earth. This information was enough for them to realise that people do not fall off the globe irrespective of whether they could explain why this does not happen. The globe in this sense is doing concrete discursive/cognitive work by supporting certain kinds of reasoning and by positioning the children differently in comparison to a situation without such a tool. It served as an orienting device that gave the children something concrete to refer to when reflecting on the questions. It also served as an aid to memory by operating as an inference-rich tool that reminded them of other sources of information.

Carrying this line of reasoning further, one conclusion is that if one considers the unit of analysis to be *children operating with mediational means* (Wertsch, 1998) in the form of intellectual and physical artifacts, the image of children's knowledge that is produced in empirical research will be very different. In the study by Schoultz, Säljö and Wyndhamn (2001) above, basically all the conceptual problems that have been pointed to in the cognitively grounded research seem to disappear when the globe is available. Cognitive development cannot be exclusively, or even predominantly, conceived as changes in mental models or cognitive structures. Rather, it seems better captured in terms of the increasing mastery of mediational means that might be intellectual or physical, or, as in the case with the globe, that are simultaneously both. Artifacts thus *re*-present in material form certain conceptual distinctions, and this is precisely why the globe served as such a powerful tool for thinking for the children.

An interesting question in this perspective, then, is to what extent the children's considerable sophistication when reasoning with a globe present can be seen as limited to the use of this particular tool only. The three-dimensional nature of a globe makes it a rather powerful model of the earth. What will happen to their reasoning if they encounter these issues of the shape of the earth and gravity in the context of another mediational means, the map? This is the question that will be pursued in the present study. But before presenting our analysis of how the children reasoned with the aid of a map as an intellectual tool, it is helpful within a sociocultural perspective to consider somewhat the sociogenesis of this particular tool and the conventions built into it.

THE SOCIOGENESIS OF MAPS

Every artifact has a history. In the case of maps this sociogenesis is quite complicated, and it is related to the development of concepts, insights and improvements in representational technologies. The interesting point from a sociocultural perspective is the extent to which these concepts and distinctions are perceived by the present-day user, and how they are appropriated when using the tool.

In the history of the Western World we know that the earth was recognized as being spherical at about the time of Aristotle (384–322 B.C.) (although this did not become the accepted view until much later in history). The evidence for this conclusion varied. From an empirical point of view, it was evident that ships seemed to »come over« the horizon when sailing away or towards the observer. From the point of view of ideas and cultural beliefs, there was an assumption that the sphere was the most perfect form. Early calculations of the size of the earth were carried out by both Eratosthenes (ca. 276–195 B.C.) and Posidonius (ca. 130–50 B.C.). Although the methods used were correct, the assumptions and the precision of the observations were not. These errors, however, tended to compensate each other. Since the calculations were based on a unit called *stadia,* we cannot be entirely sure of the exactness of the estimations. It seems, though, as if they overestimated the size by only 12 to 15% (Robinson, Sale, & Morrison, 1978).

The early history of the representational tool that we know as maps seems somewhat disputed. Some (cf. Harvey, 1980) claim that the topographical map developed quite late in our cultural history, while others (cf. Fremlin & Robinson, 1999) maintain that the topographical map was conceived already in prehistory. Irrespective of these differing views, one can find occasional references to maps in the classical Greek literature. This, according to Robinson, Sale and Morrison (1978), makes it possible to infer that mapping was not an uncommon practice at this time. On the other hand, none of these maps appears to have survived. The writings of Claudius Ptolemy (ca. 90–160 A.D.), however, did survive. In his production there was one book, simply called Geography, which covered what was known about the earth at the time. Among other things, the Geography included a treatise on cartography in which Ptolemy described how maps should be made. He commented on the problems of presenting the spherical surface of the earth on a flat sheet, and he clearly recognised the inevitability of the deformation that must follow in such a process (Robinson et al., 1978). Although refined and developed throughout the centuries, many of the techniques used in the construction of maps of the earth seem to have been recognised rather early.

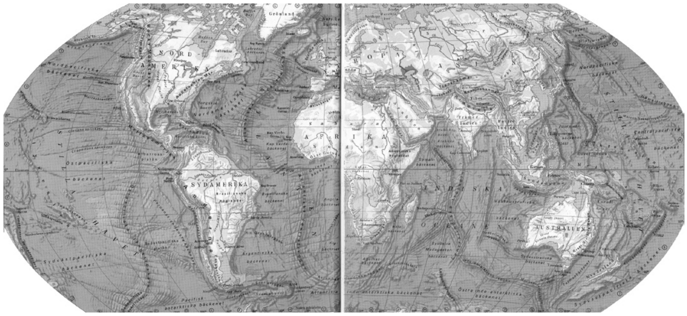

Figure 3. Map used in interviews (size 40 x 18 centimetres)

Maps of today carry with them many conventions. Some of these have changed through the course of time, others have stayed more or less the same for long periods. In medieval times, most maps of the known world – *mappa mundae* – were drawn with Jerusalem at the centre and paradise at the top. Paradise was believed to be found beyond the farthest area known, the Orient. It is from this practice that we have derived the expression »to orient« a map. Today we orient our maps towards the north instead of the east, but the practice as such is the same. Another example is given by the geographical coordinate system, which is the procedure of dividing the sphere into latitude and longitude. This system was introduced some 2200 years ago and has not been changed since (Robinson et al., 1978).

METHOD

The present study, thus, is a continuation of the interest in how children reason when using culturally meaningful mediational means. The map (see Figure 3) we have used thus gives a two-dimensional image of the earth. The map is taken from a type of atlas frequently used in schools.

PARTICIPANTS AND ANALYSIS

The empirical data were collected through interviews in schools. Eighteen children, aged 7 to 9, participated. In accordance with the study by Schoultz, Säljö and Wyndhamn (2001), the interviews were conducted in a Piagetian fashion and lasted between 10 and 20 minutes. The central questions were approached by talking about different countries, colours on the map etc. The interaction between the interviewer (JS) and the child was audio recorded and later transcribed in full. The analysis is based on the transcripts.

RESULTS

In this first part, we will show how the interviewer and the children reach a common understanding of the artifact and the purpose of the encounter. This is a coordinating activity that precedes the discussion of the main topic of the interview – the questions about shape and gravity. The precise manner in which the map functions as a prosthetic device for reasoning will be discussed in the second part.

COORDINATING THE ACTIVITY: IDENTIFYING THE ARTIFACT AND CONTEXTUALISING THE ISSUES

Being introduced to the atlas, the children thus face a complex artifact with a long history. The artifact is well known to all of them, which per se is a sign of their position in a sociocultural sense. But in spite of the familiarity of the artifact, it is not clear to the children how it is going to be discussed in the interview setting, especially at the start of the encounter. There are many options. The artifact in front of them could be temporarily discussed as a book of a certain type, that is, one could focus form rather than content. It could also be discussed as a map with different colours, names and states, etc. A third option would be to talk about the artifact as a model of the earth.

Although one might refer to these three approaches as *levels of abstraction*, they are better conceived as different forms of situated talk relying on different interpretations of what is of interest. These three alternatives are all reasonable manners of discussing in a school setting, and there is initial uncertainty when the interviewer asks the question »What is this?« with reference to the artifact. The problem for the child is to identify what is the expected type of discourse.

Excerpt 1. David 2nd grade

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1  I      Do you know what this is?
2  David  A book
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3	I	And what is this supposed to be?
4	David	A globe
5	I	A globe, do you recognize any countries?

Excerpt 2. Anton 1st grade

25	I	But now Anton I'm going to ask you some questions. Then, of course, you know what this is?
26	Anton	A map
27	I	What does it represent?
28	Anton	The whole earth
29	I	The whole earth. Do you recognize any places or countries or something you ... you can read if you want to.

Excerpt 3. Anna 2nd grade

1	I	What is this?
2	Anna	It's the earth
3	I	Why is it drawn like this? [Points at the corners of the map]
4	Anna	It's round

We emphasise this problem of the choice of discourse in order to illustrate that the multitude of manners in which it is possible to carry out a discussion is a concrete problem for the child. The difficulty with the questions asked does not reside solely in what the object in front of the children *is* in a factual sense or the conceptual issues that are involved in interpreting a map. The problem for the child is also to identify what the questions are all about, and how one is to contribute to the conversation. This is thus primarily a communicative problem and not a conceptual one. This is illustrated in Excerpt 4, where the uncertainty expressed clearly refers to the interview-situation.

Excerpt 4. Paul 2nd grade

3	I	Do you know what this is?
4	Paul	Nope
5	I	This?
6	Paul	A globe ... noo
7	I	Is it that?

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8    Paul  Yes
9    I     If we assume that this is a globe,
           why is it drawn round like this?
10   Paul  The globe is round
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When being asked if he knows what is in front of him, Paul responds with an initial »Nope«. This cannot be taken as evidence of the fact that he does not know what the artifact is. Rather, it seems likely that he is uncertain as to what is a relevant way of talking in this situation. After the following utterance by the interviewer, he argues that it is »a globe«. We have to be aware of the fact that an interview is a communicative and interactive project. Without appropriate guidance from the adult, who is the dominant party in this interaction, the child will often respond in a vague and non-committal manner (which is also a common strategy in other conversational settings when people are uncertain what the purpose of an utterance is).

It is an interesting problem if the ability to identify an artifact as a *globe* or as the *earth* is itself indicative of having a particular mental model. There is, of course, always the option of making such an assumption by introducing an object of inquiry at this intermediate level. But the critical question is what is gained by such an explanation. To refer to these modes of talk as indicators of *conceptions* or *mental models*, and to locate them in the head of the individual, will not help us understand why people choose one or the other.

If we instead focus on the actual interaction, the choice of explanation should be made on the basis of what can be observed. We believe that the manner in which the topic is discussed is not a discrete act but a process that unfolds, a process that is both possible to study and to understand. Dialogical as it is, in the sense of building on the contributions of both parties, the interaction can be conceived as a mode of talking and thinking that is not only temporally distributed, but also distributed among the participants. This makes the method of looking for conceptions *behind* answers even more problematic. If not even answers can be fully attributed to individuals, how could we possibly consider them primarily as mental constructs and give them priority as explanatory concepts?

Excerpt 5. Carl 3rd grade

5	I	It's difficult to know. Well I have a question for you. What is this?
6	Carl	The earth
7	I	Does the earth look like this?
8	Carl	Yes, perhaps
9	I	Perhaps, it does. What does the earth look like in reality?
10	Carl	Round
11	I	Round like a ball
12	Carl	Mm
13	I	But if you're going to make it like a map you have to do it like this right
14	Carl	Mm
15	I	And then you have to make some bends like this. Why does it look flattened? Why does one draw it like an egg do you think?
16	Carl	You can look at the whole around
17	I	No, that's right you can't see the backside otherwise. You can imagine taking the ball and cutting it open

Excerpt 5 illustrates what can be seen as a distributed answer. We believe that it is more appropriate to say that the answer to the question posed in line 5 is to be found between lines 6 and 17 rather than in line 6 alone. The question initiates a dialogue, and the genuine answer sought for is not merely what kind of label one would put on the object, but rather how one should conceive of this object and its properties/functions. In this passage, it is clear how the interviewer is an active co-constructor of meaning, and that he sometimes elaborates the children's contributions considerably. In some traditions, this would probably be regarded as an improper procedure for an interview, a confounding variable as it were. From our dialogical perspective on communication, however, we regard this as a natural and realistic attitude to interaction, perhaps even necessary in order to maintain a joint focus. The ideal of the passive partner in interview research probably hampers the progression of the interview in many cases.

Furthermore, participation in certain discursive practices presupposes that one focuses on some aspects. When talking about a map, the thickness of the paper is seldom relevant. Varying artifacts and discourses also presuppose familiarity with certain concepts or pieces of information. On a political map, for instance, colours signify something different than topographical cues. This kind of awareness of the specific rules that should serve as premises when reading maps is an important feature of a person's ability in our material. It is most striking how conscious the children seem to be of the artifact as being a form of representation. Bearing in mind the young age of the participants this is not something that should be taken for granted, rather it is something that should be looked into more carefully. It is important to consider how the artifact supports thinking. For the interviewer and the children to end up with a shared understanding of the object under scrutiny, however, some time needs to be invested. Excerpt 6 provides a prototypical example of what this process looks like.

Excerpt 6. Tim 3rd grade

3	I	I would like to ask you about this. What is this?
4	Tim	A map, the globe
5	I	Why does it look like this? [Elliptical]
6	Tim	Because it's round
7	I	Does the earth look like this?
8	Tim	Yees
9	I	So it does
10	Tim	But it's more round
11	I	And then?
12	Tim	It's more even, not long like this
13	I	No, why do you think you draw it like that and not rounder? Why can't you do that?
14	Tim	Because you can't draw the backside

In Excerpt 6, the interviewer and the child come to the conclusion that they are dealing with a map of the earth projected on a flat piece of paper. We can follow the discussion on the transforming processes involved in producing this kind of projections. When dealing with an object like this, the participants can make active use of its physical properties, something that is done in line 12. Here, Tim refers to the stretched look of the map and calls the interviewer's attention to the fact that this is a by-product of the process of mapmaking. By using an observable property like this, he shows awareness of some of the conventions of map-making, and he is also very clear about the distinction between the model and what the earth looks like as a physical object.

Although the interpretations of the questions may differ between the interviewer and the children, as we will discuss below, the referent of the map as a model of the earth remains a reasonably shared focus throughout the discussion. However, we should like to emphasise that this coordination of perspectives is an achievement (Rommetveit, 1988, 1992), and not something that can be taken for granted. The children can be made to share this perspective, but it has to be established as the one intended for this particular discussion. However, this can be efficiently done without the interviewer adding further pieces of information or explanations.

COGNITION AND REASONING: UTILIZING THE ARTIFACT AS A COGNITIVE PROSTHESIS

As we have shown, the interviewer, in co-operation with the interviewees, initially establishes the artifact as being a map of the earth and that this is what is of interest in the following discussion. This is followed by a discussion of what the different colours on the map signify. When this is over, the interviewer follows his agenda and turns to the main problem of the interview, namely if one can fall off the earth (which, in a sense, is the question about gravity, framed in a particular way borrowed from previous research). The question is paraphrased as whether humans can inhabit the whole earth (or, in a later step, if they can live »down there«). Although all the children answer the initial query with a unanimous «no«, the answers do not mean what they at first would seem to mean. The question presumes that one talks about the earth as an astronomical body, where gravity is the principle explaining why objects fall to the ground and why there is no up and down on the earth. Scrutinising the children's responses, however, we find that they bring in new topics such as political and geographical conditions. This is a shift in conversational focus that illustrates the polysemic nature of the questions. A typical example is given by Excerpt 7.

Excerpt 7. Eric 2nd grade

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43  I     Can people live down here, then?
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44	Eric	Nope
45	I	Why not?
46	Eric	Because it's so far down
47	I	Why isn't that possible, then?
48	Eric	Mm perhaps you get an inflammation of the ear
49	I	Why would they get an inflammation of the ear down here, then?
50	Eric	Perhaps it's cold

What this and the following excerpts illustrate is a conversational problem that Lemke (1990) refers to as a matter of *thematic continuity* in interaction. The interviewer takes the astronomical framing of the issue for granted (the interview is organised so as to be about the earth as a celestial body and about gravity), while the children choose other categorisations. In Excerpt 7 above, Eric refers to unfavourable climatic conditions and the risks of catching ear infections as a reason for why one cannot live »down there«. In the following excerpt, the boy Jakob in a more general sense refers to the fact that there are places where it is too hot or too cold to live.

Excerpt 8. Jakob 3rd grade

37	I	Mm, can people live all over the earth? What do you think?
38	Jakob	Nope
39	I	Where can people not live?
40	Jakob	Where it's cold
41	I	Anywhere else?
42	Jakob	Where it's hot

From Excerpts 7 and 8 one could argue that the children never understood the meaning intended by the question. And in a sense we agree, they did not overtly consider the option that one cannot live on the down side of the earth. There is a clear difference in how the interviewer and the interviewees read these questions. But, it is also quite possible that the children consider the option that one could fall of the earth as absurd. They therefore construe, on the spot, a response to why one cannot live everywhere that might serve as a reasonable suggestion.

The line of reasoning found above could be seen as an issue of the problems the children have with identifying the precise nature of the topic of discussion and how to proceed with the dialogue. This problem of thematic continuity, thus, is not located in the conceptual knowledge of the child. It seems better conceived as a problem that has to do with the fact that the agenda is partially hidden from the child, while it is clear to the interviewer. The problem of thematic continuity should therefore preferably be studied from both an interviewer and child perspective, respectively. The children are not given a sufficiently clear indication that they should stick to the astronomical framing.

Being engaged in a conversation obliges the participants to follow a number of more or less tacit interactional rules. Mastering these rules is an important element of the process of becoming a competent member of our society. For example, failing to provide a response when being asked a question is a sharp violation of these rules. Another important rule is to regard our conversational partners as being intelligible and coherent. In an interview-situation these guiding principles tend to be of utmost importance for the interviewee, sometimes followed *ad absurdum*. What we find, then, in this material is the children proving to be qualified language users. When the interviewer hints that there exists a problem, the interviewees read him as being intelligible. The only way they can do this, supposing that they *do not* hold it possible that one can fall off the earth, is to change the topic or extend it in a reasonable direction and this is precisely what the children seem to be doing in the excerpts we have used.

A further point, which supports our line of reasoning, is that when the question about gravity is explicitly expressed, not a single child accepts the claim that it is possible to fall off the earth. On the contrary, most children show a remarkable ability to participate in a discussion on this difficult topic and to make meaningful contributions. Excerpt 9 illustrates how educated a conversation a pupil in the first grade can accomplish if only given a bit of support in the interaction.

Excerpt 9. John 1st grade

124	I	Of course one can live in South Africa, one can live in South America. Don't you fall off the earth down here then?
125	John	No
126	I	You don't
127	John	If you come like this outside you don't fall off if you walk outside the earth

128	I	But if you walk far down here in the south, then? Don’t you think it’s strange that you can live down here? What if they just slip and fall off the earth?
129	John	No, they won’t do that
130	I	Why won’t they do that then?
132	John	They think they’re walking in their way. They’re more used to walking like that or something
132	I	Oh, I see
133	John	But actually you walk ... it feels as if you walk straight ahead and then you walk around the earth if you go too far
134	I	So you can’t fall off the earth?
135	John	No, it’s almost as big as anything

Given all the research within the cognitivist perspective illustrating the apparent difficulties children have with understanding the shape of the earth and gravity, one would not expect to find any satisfactory explanations of why it is impossible to »fall off« the earth. But notice in line 133 how seven-year old John in a very exact way resolves the supposed conflict between the information about the shape of the earth and his »basic ontological presuppositions« (Vosniadou, 1994, p. 49). He is clearly able to distinguish between what happens on a psychological or personal level and what happens on a physical level: one can walk »straight ahead« and still walk »around« the earth. This is quite an amazing insight for a seven-year old.

Having arrived at this point, we will conclude this part by commenting on one general feature of the empirical material. Our impression is that in order to maintain the dialogue the participants have to reach temporarily shared contextualisations (Rommetveit, 1992). The children, operating under the specific conditions provided here, have to coordinate their way of conceptualising the activity with the one represented by the dominant party in the interaction. Posing a question is maybe not enough to put the child in a communicative situation where the contextualisations of what is talked about are sufficiently shared. Perhaps this problem of coordination is a more important feature of learning contexts than is generally recognized; it is by being supported in the complex task of adopting and sharing specific perspectives that one learns to talk and think under the guidance of a more experienced partner.

CONCLUSION

The results of this study in many respects confirm the general observations made in the previous work where the globe was present in the interview situation. The conceptions about the earth as a flat object, as hollow, etc., do not appear in this material either, in spite of the fact that this study involves the use of a two-dimensional artifact. The claim that children hold such mental models (or framework theories) seems questionable and appears primarily as a product of the methods used. When children are interviewed without any support in the form of a meaningful artifact, they obviously express views that disappear completely when there is a map present.

In a similar vein, none of the participants in this study accept the view that one can fall off the earth. Not even when being explicitly asked, in quite a provocative manner, what happens if one is *down under* on the map do they suggest that this would be possible. This is a strong indication of the familiarity on the part of the child with the map as a cultural artifact and of the efficiency with which it serves as a prosthetic device for reasoning. What is it, then, that so clearly differentiates this study from the studies made within the cognitivist perspective? Methodological differences regarding what are legitimate inferences of what children mean by what they say aside, two major factors stand out. The first element is the use of a physical artifact with a long history. The map is a powerful device that carries a number of conceptual distinctions with it, many of which may be totally unknown to the children. With a more competent conversational partner to help them, though, this map functions as an effective resource for reasoning. The map helps create what Latour calls »a meeting ground, *a common place*« (1986, p. 8). Due to its *optical consistency* in Latour's sense the two-dimensional surface of the map will provide the same *windowpane* for any observer who is familiar with this particular piece of technology. The map affords viewpoints and information. In this study, it is clear that both children and interviewer make active use of this optical invariance as a resource for their reasoning (cf. Excerpts 3, 4, 5, 6 & 9). They go back and forth between thinking, talking and consulting the artifact.

The use of a physical artifact alone, however, is not a sufficient condition, as is illustrated by the multitude of objects used by, for example, Sneider and Pulos (1983) (cf. Figure 2) in their study. The children also have to know what they are supposed to talk about. The second factor, differentiating this study from many others, is therefore associated with the way the artifact, and the whole interview situation, is framed (Goffman, 1974) in a communicative sense. How one is supposed to talk about an object is not self-evident, which is illustrated in Excerpts 1 to 3. It is necessary that the interviewer and the interviewees reach some sort of common understanding of the artifact and, in this case, its relation to its referent. Given the uncertainty initially expressed by most children regarding the status of the artifact and the point of the interview-situation as such, we believe that the map can be seen as a *boundary object* (Star & Griesemer, 1989). The concept of boundary objects, as developed by Star and Griesemer, is an attempt to describe how objects may help create mutual comprehensions across intersecting social worlds.

> This is an analytic concept of those scientific objects which both inhabit several intersecting social worlds *and* satisfy the informational requirements of each of them. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across time. They are weakly structured in common use, and become strongly structured in individual-site use. (Star & Griesemer, 1989, p. 393)

Although boundary objects have different meanings in different social worlds their structure is common enough to more than one world, to make them recognizable. In their description, Star and Griesemer portray four different types of boundary objects. Of these, the *ideal type* is the one most in agreement with our map. The ideal type of boundary objects, such as a diagram or an atlas, is abstracted from all domains and may remain rather vague. Due to this vagueness it can be adapted to a local site and function as a means for communication. This adaptation of the map to the local context is exactly the process we have observed (cf. Excerpt 6), and we regard such adaptation as necessary for the communication to function properly. Following Star and Griesemer, »boundary objects act as anchors or bridges, however temporary« (1989, p. 414) between contexts and persons, and this, we believe, is the reason why the interviews in this study have a rather stable character, why the relation between the map and the earth can be sustained in spite of the low age of the participating children.

As has already been pointed out above, the main theme of this study is the assumption that there is no baseline for cognition. Although we admit that there are phenomena that can be labelled *mental processes*, we cannot accept the claim that these are possible to study independently of cultural tools. There is nothing to be gained by positing such a level of inquiry as the one implied by a notion of pure cognition underpinning our thinking. Our mental functioning is irrevocably intertwined with a vast array of cultural tools. When we, for example, do mental calculations, no visible or otherwise apprehensible borders can be found between the human as an *information processor* (Ashcraft, 1994), and the multiplication table as a cultural artifact. This is the reason why we prefer to change metaphors and, instead, talk about cognition as the use of tools.

Although it has been common practice in the educational area to test the abilities of pupils, stripped of most of their ordinary tools, we do not feel the need to import this thinking into scientific inquiries. On the contrary. There is no sense in saying that functioning without support in the form of physical artifacts is the more natural or basic state of human cognition, or that such an approach provides a more correct measure of an individual's competence.

From our perspective, an important part of cognitive development is the gradual appropriation and/or mastery of mediational means. Early in this process, when the mediational means are unfamiliar and still poorly under control, one is more open to influence and more in need of communicative support. Under such conditions, the unit of analysis (children operating with mediational means) is in a sense less stable or less coordinated. This is why studies, using somewhat different methods, can come up with results that vary. Provided with various forms of artifacts and varying levels of support, children of the same age span will present responses within a very large spectrum. This is not particularly surprising.

Consequently, we do not propose that the children in this study have presented their »normal« functioning or that this is necessarily how they reason in their everyday lives. We would, rather, like to point out the flexible nature of human cognition and the potentialities that exist in this area; how understanding and reasoning are not so easily confined within the boundaries of a single individual, but how mental activities instead, metaphorically speaking, interact with artifacts and other people. The distinction between cognition of individuals, communication between individuals and tools must be regarded as blurred. What we have shown is that given favourable conditions even young children *can* accomplish rather complicated forms of reasoning and make distinctions between what they see in front of them and what applies in a physical world and when looking at the earth as an astronomical object. In some fascinating sense, the distinctions made by these children would have been impossible for the most advanced scholars a few hundred years ago to make. This is a strong indication of the intimate links between culture and human reasoning, and, ultimately, between culture and human development.

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STUDY II

KIDS IN ZEN

COMPUTER SUPPORTED LEARNING ENVIRONMENTS AND ILLUSORY INTERSUBJECTIVITY*

»Zen teaches nothing; it merely enables us to wake up and become aware. It does not teach, it points.« *Daisetz Suzuki*

In the introductory quote, Daisetz Suzuki, the chief emissary of Zen to the West, articulates a distinction between *teaching* and *pointing*. Although this distinction might not be valid as a general principle, it serves a purpose in this particular context. It applies to the following work in that it makes us aware of the fact that we are able to accomplish many things only by pointing, without conceptualizing the object that is being pointed at. This non-conceptualization is very fundamental to some practitioners of Zen. In fact, the prominent method of Rinzai Zen is to provide each student with something called a *koan*. The koan is a form of riddle, often built on a paradox, whose function is to short-circuit the intellectual and conceptual system of the student. This rational *cul-de-sac* is considered the true starting point in the study of Zen (Suzuki, 1991).

This should be contrasted schooling practices which aim to deepen and expand the student's conceptual understanding of the world. Such practices are well established and can be seen as the current norm. For instance, the curriculum for the Swedish compulsory school states that all students should come to know and understand basic concepts and contexts within the natural sciences as well as within technical, social and humanistic areas of knowledge. Tools of various kinds have always been involved in this

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process, but today information technology has seriously entered the stage as a rather new actor.

Information technology has, as it were, already been incorporated into school practices by large Government subsidies. Many now ask the question whether the millions of Euros spent contribute to better learning. Some educational researchers seek the answer to this question by analysing the *technology* (i.e. Allinson, McKechan, Ruddle, & Michaelson, 2001; Jonassen, 2000), others try to explore what *modes of cooperation* that best promotes learning with computers (i.e. Bielaczyc, 2001; Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2001). Instead of contributing directly to the perpetual debate on what learning really is, or surveying the affordances of a specific technology, this work aims at investigating the intricate relationship between learning and technologies, not forgetting the historical dimension of what one *has to* learn.

What people have to learn is never constant but changes over the course of time. It is often associated with the development of new technologies. But new technologies are not the sole determinant of how people come to act. For example, the practice of navigation has changed its methods many times throughout the centuries and thus repeatedly made new demands on succeeding generations of navigators. In the late fifteenth century, the method of navigating with the aid of the quadrant, stars and latitudes developed. Although more efficient than the previous practice of sailing in a circle (the so-called *volta*), these new tools did not themselves guarantee their successful use. »The new method of navigation proved difficult for most mariners. Only the most up-to-date sailors attempted its practice, and there is evidence that Columbus, among others, understood it only imperfectly« (Law, 1987, p. 126). In order to make the instruments, the inscriptions (latitudes), and the stars effective parts of the practice of navigation, a new social group had to be established. Such a group emerged, in Lisbon in the early sixteenth century, through the *teaching* of astronomical navigation to pilots (Law, 1987). In a similar fashion, one could suspect that the educational potentials of information technology have to be materialized through the founding of specific educational practices.

During the twentieth century, the pace of technological changes accelerated in a way unparalleled in the history of humankind. This trend continues and it constitutes a great challenge to learners of today. Today, we demand more from our young children than the seafaring nations in the fifteenth century possibly could have demanded from their already skilled navigators. Related to the domain of education, modern information technology has thus become an issue of immediate interest to examine. This is so, not only because it is associated with large financial investments, but also because it represents a significant feature of socio-cultural development.

STUDYING LEARNING WITH COMPUTERS

From the perspective of the theoretical tradition guiding this work, learning is always, to some extent, unpredictable. Learning is seen as dependent on interpretation and not as the straightforward acquisition of facts. The indeterminacy associated with the act of interpretation actually holds a potential for new development. If learning were the mere copying of old forms of knowing, development would come to a halt. But what happens to the scope of interpretation with the introduction of such means as digital media? One interesting feature of interactive computer-based learning environments is that they afford a number of actions beyond the purely linguistic. Besides describing, for example, physical phenomena, the student can manipulate and influence the processes in progress. The expectation is that activities of this kind will provide instant feedback and, hence, make learning less abstract. In some cases, the digital environments also come enlarged with physical peripherals. Taken together, such environments constitute rich fields of potential actions of various kinds. As a consequence, what students do, and learn, in these environments may vary to a large extent.

The theoretical background to the present study is the large number of studies addressing the area of computer supported collaborative learning, from a sociocultural and/or situated perspective, that has emerged during the last decade. These studies has tackled issues like: gender and IT (Kafai, 1996; Light & Littleton, 1997; Littleton & Bannert, 1999); different educational potentials of the new technology (Hennessy & O'Shea, 1993; Roschelle & Pea, 2002); how computers can support collective thinking and knowledge-building (Mercer, 2000; Scardamalia & Bereiter, 1994; Säljö, 1999) et cetera. Common for most of these studies is the principal interest in communication. Language is seen as the primary means for cognitive development and it is argued that it must be analysed accordingly.

In analyses of collaboration in interactive learning environments, the concepts of ZPD (Zone of Proximal Development) (Vygotsky, 1978), scaffolding (Bruner, 1985) and affordances (Gibson, 1979) are frequently utilized. However useful as general ideas, they lack the acute sensitivity to the communicative events that is sometimes needed. In an attempt to unravel some of the complex interrelationships between students and technology, the present study will adopt additional resources from thinkers deeply concerned with *language in use*. Building on the theoretical position set out by the late Wittgenstein and followers like Rommetveit, the analysis will make use of methods from ethnomethodology (Garfinkel, 1984) and interaction analysis (Jordan & Henderson, 1995). This kind of video-based studies of technologies and social interaction are, so far, most often found in workplace studies in the field called Computer Supported Cooperative Work (CSCW). This approach is driven by a number of analytic concerns and assumptions, helpful in the investigation of how people use technologies. Part of this methodology is the treatment of »talk, bodily conduct, the use of tools, technologies and the like, as ways in and through which participants accomplish actions and activities; actions and activities which rely upon, and embody, social organisation« (Heath & Luff, 2000, p. 23). There is also a concern for the resources in and through which participants themselves produce their own actions and recognise the actions of others.

LEARNING CONTEXT AND THE AIM OF THE STUDY

The technology used in this study – LEGO-dacta – is an example of an interactive computer-based learning environment. The product originates from collaboration between the company LEGO and researchers at MIT Media Lab. The rhetoric accompanying this kind of products is extensive and mixes results from research and visions of the future with more or less well-founded sales arguments. According to the Swedish retailer, LEGO-dacta is supposed to function together with problem-based learning. The students are supposed to acquire knowledge by adopting an experimenting way of working. Furthermore, it is claimed that the software (TechnoLogica) »gives understanding of the foundations of computer science, such as structured programming, recursion (reiteration), open and closed loops in programming« (Elevdata, 1999, my translation). When studying learning and the use of computers however, one must remain neutral to assertions of this kind. What students actually do when they have access to these computer-based environments is an open question.

The aim of this study is to give a contribution to the large and general discussion on learning and technologies, with observations of local and specific practices as its point of departure. For this work, a detailed description of a single case will be used. The case is a short sequence in which three students, together with two supervisors and supported by technology, reason about one of the fundamental principles of computer science. This sequence comes from an extensive body of empirical material (see below), and the selection is made with the purpose of giving a concrete example of a discussion on a complicated matter. The interest concerns what students do when they are working in this environment, what the nature of the communication is and what resources the participants utilize in their interaction.

EMPIRICAL STUDY

The material presented here derives from a study where thirty-two pupils in the sixth grade[1] had the opportunity to work with the equipment called LEGO-dacta during a period of two weeks. The class was divided into ten groups, who worked with the technology on three separate occasions. The sessions lasted for about thirty to sixty minutes and took place during regular school hours. To help them, the students had two researchers (Jonas and Patrik) who functioned as teachers. The main part of the sessions was recorded with two video cameras plus a VCR capturing the computer screen.

The results presented here, are based on an analysis of a *single case*, a short sequence where three students are introduced to a new problem – recursion. In relation to the students' current level of education, the complexity of the problem is very high, something that makes this sequence all the more interesting to examine. Normally, this problem is first introduced at a university level; nevertheless, it seems as if the students quickly grasp the nature of the problem and try to contribute to its solution. From an educational perspective, this is very fascinating. How is it that these young students suddenly manage to reason about such sophisticated logical issues? It is surmised that the technical environment is used as an important

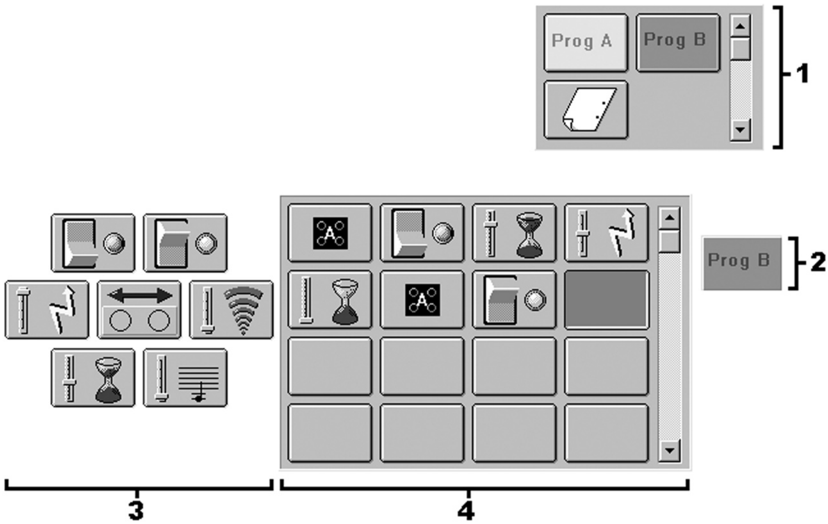

Figure 1. Utilized parts in TechnoLogica

resource and the analysis aims to thoroughly scrutinize the course of events in order to elucidate the different roles played by the participants and the technology. But before we can do this, the reader must be acquainted with both the technical equipment and the problem the students face.

THE TECHNICAL ENVIRONMENT

The LEGO-dacta technology is a further development of LEGO Technic, which can be controlled by electrical motors. Accompanying the building bricks and motors is a range of input and output devices such as light sensors, pressure sensors, thermometers, angle sensors, lamps and loudspeakers. The peripheral equipment is connected to an ordinary PC by a set of cables. To control the interaction between the mechanical parts, a graphical icon-based programming language is used (TechnoLogica, see Figure 1).

In TechnoLogica, the user can create small *functions*[2] (1 in Figure 1). Every function is made up of two parts, its *name* (2 in Figure 1) as well as its *content* (4 in Figure 1). The content is arranged in the form of a list and normally contains a number of *instructions* (3 in Figure 1).

Simply dragging and dropping instructions onto their desired position constitutes the actual programming procedure. When the user is finished,

Figure 2. Pictures in pictures

the function can be executed, and when this is done, the computer reads through the list of contents from left to right, like a text.

RECURSION AS PROBLEM

In the example analysed in this study, three students in the sixth grade are reasoning about a problem that could be characterized as being about recursion. If one looks up the word recursion in a dictionary one might come upon such explanations as; »To define something in terms of itself« or, in more laconic wording, »***Recursion***; see recursion«. These definitions, however, are not very informative, especially not when it comes to such issues as how the concept is used in practice. One way to give an initial description is to use a visual metaphor. Figure 2 can be described as a visual recursion. The picture contains, as an element, a copy of itself – or somewhat differently expressed – a reference to itself. This miniature picture itself contains a smaller copy, and so on. Accordingly, this results in several different levels of pictures. Since the visual recursion is dependent upon the resolution of the picture, there is a finite number of levels. In principle, though, there is no need for any further limit to the repetitions, the recursion could go on forever.

Recursive pictures are not entirely uncommon and occur in various contexts. Recursion as a phenomenon in mathematics and computer science, on the other hand, is something that most people normally never come into contact with. One reason for this is probably that the first introduction of the problem normally occurs at university level. It is interesting to note that this introduction of the concept, for example, in courses on programming, is sometimes considered to be a critical stage, requiring much time and energy. In spite of this, many textbooks still rely on formalized language in their explanations. Here is an example from a manual for (LISP) programming.

> By *recursion* we mean an algorithm that in its definition refers to itself. A *recursive function* is a function that in its definition makes a call to itself, either directly or indirectly via other functions. . . . Every recursive function must have a terminating condition. Normally, it is one of the formal parameters that in some way is counted as matching the terminating condition. If this were not the case, we would have an *infinite* or *interminable* computation. (Haraldsson, 1993, p. 36, my translation)

In this quote, the author warns against the *infinite recursion*. By and large, this is the same thing as the repetition depicted in Figure 2. In a picture, this is not a problem, but if one wants to write a functioning program however, the computation cannot go on forever. From a methodical point of view, recursion is portrayed as a natural way of describing and defining many problems (Haraldsson, 1993), and it can also be applied to other domains (e.g. biology) (Bateson, 1979).

THE LOCAL DESIGN OF THE PROBLEM

The aim of the activity studied was to *introduce* and *discuss* some problems associated with functions that refer to themselves. To facilitate the reading of the interaction that took place, the local design of the problem will first be introduced.

During the first part of the session, the students had created a short function (here called *ProgA*). Figure 3-A illustrates the end of this function with six visible instructions. When the function is executed, the instructions are carried out from left to right, one row at a time, and then come to a stop. Creating functions in this manner, with one main function containing a number of instructions, is the most basic way of using the soft-

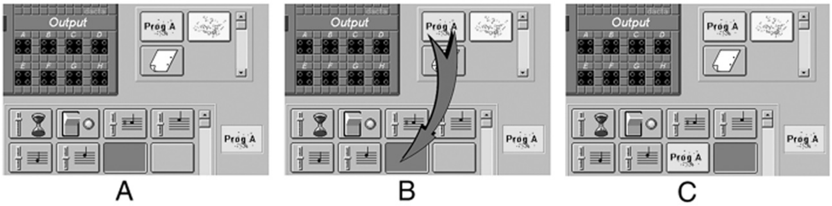

Figure 3. Modification of the function

ware and it was also the way the students had been using it. TechnoLogica does, however, like other more advanced programming languages, allow functions to contain other functions. Not only can a function contain other functions and instructions, it can also contain its own name. If *Prog A* is modified (see Figure 3-B) to look like Figure 3-C, we have a more complex algorithm. The function *Prog A* now contains a reference to itself and, accordingly, it becomes a recursive function. When this new function is executed, the computer carries out the instructions in the given order until it reaches the last icon, it then runs the same function from the beginning and so on. Since there is no terminating condition this can be described as an *infinite recursion*. It was this form of self-reference and its associated problems that comprised the topic for the discussion between the students and the teachers.

FINDINGS

The example presented here comes from the latter part of this group's first session. The group has finished the formal exercise and a negotiation arises concerning what should be done during the rest of the time. Together with the two teachers Jonas and Patrik, the students agree to examine a new and unknown problem, which is then demonstrated by Jonas (see Excerpt 1)[3].

Excerpt 1.

```
1    JONAS    if one were to put this program ((points at
              prog A)) (.) at the end there
2    Isaac    here
3    Michael  there
4    JONAS    there that's right. what do you think will
              happen then?
```

In the formal exercise, the students had created a short function, which is used here as a basis for the new problem. Jonas encourages the students to place the name of the function (Prog A) at the end of its own list of contents (»if one were to put this program at the end there«; cf. Figure 3). This instruction is expressed in the form of an unfinished question, something that highlights the importance of the manipulation of the function. The question format prepares the students for the fact that this action will be significant in the subsequent task. The students implement the instruction, whereupon Jonas finishes his question (»what do you think will happen then?«).

The problem, which is introduced here, rests upon a rich conceptual world and can be understood in relation to specific ideas with a long history in computer science. For the teachers, this is a *concrete example* of recursion as a *general principle*. It is noticeable, however, that this is not how it is described to the students. The communicative resources used in this sequence are first and foremost the layout of the computer screen and the function already constructed, together with pointing gestures and simple words like *here* and *this*. There is nothing in the conversation to indicate that this might be an example of any mathematical notion or the like. On the contrary, the problem is presented in common parlance, something that hides any potential connections to other contexts.

Excerpt 2.

5	Michael	[well it will run-
6	Isaac	[it will run once more
7	JONAS	then it will run once more yes
8	PATRIK	what happens th- [will it ever stop-
9	JONAS	[but then it will come to the same place=
10	Isaac	=where it stopped
11	Anna	going to go like that [the whole bloody time, then
12	Michael	[going to go round
13	JONAS	that's right
14	Michael	cool

This excerpt clearly shows how quickly the students can respond to the teacher. The argumentation clearly points to some form of appreciation of the local problem. Jonas' question (»what do you think will happen then?«) is immediately followed by simultaneous answers from Michael and Isaac. The teacher confirms these answers but he also problematizes them further (»but then it will come to the same place«). Isaac, finishing Jonas' sentence, shows that he is deeply involved. Both Anna and Michael then formulate the consequences of placing the name of the function at the end of its own list of contents. And again, doing this at the same time, they reveal how well coordinated they are in relation to the problem.

The communication articulated by the students very much mirrors the expressions used by the teachers. Their conversation is carried on with words that have a strong connection to the situation. There is, however, an important difference from the (theoretically motivated) argumentation of the teachers. The answers given by the students seem to be motivated by the present situation and their recently acquired knowledge of the technical environment. Unlike the teachers, the students cannot benefit from earlier experience of situations beyond this one. At this point, there arises a question concerning the role of the technology in the interaction. Since all participants have access to the computer screen, this surface can be used as a common point of reference. With such simple means as pointing gestures and words like *this*, *there* and *it*, they can communicate about the immediate surroundings and objects on the computer screen in particular. In view of the fact that the problem is visually illustrated, much of the communicative work is restructured, with its main focus shifting from linguistic descriptions to the technology.

Excerpt 3.

15	Isaac	if you take one of those, then ((places the cursor on the icon with an open switch))
16	Anna	no, °get real°
17	JONAS	m: would that be possible?
18	Isaac	no you can no-
19	Anna	no
20	Michael	[ye:s after there
21	Isaac	[but we c-
22	Anna	no:

In this third excerpt, the students try to solve the problem with the looping function by means of local resources. In this manner, they are trying to

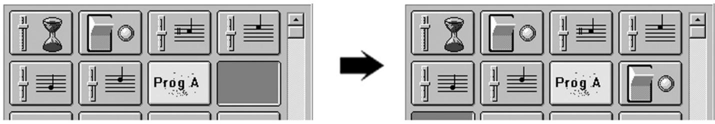

Figure 4. Proposed alteration of the function

use once again the building blocks from the technical environment they have just encountered and mastered. This environment and the possibilities it affords, provide the basis from which the students now draw resources in order to solve the problem. An example of such a resource is the icon portraying an open switch. The purpose of this instruction is to interrupt the current that is fed to the Lego models. Isaac points at this icon and asks whether it can be of any assistance (»if you take one of those, then«). This initiative is the starting-point for a negotiation between the participants and several viewpoints are aired. Isaac later withdraws his proposal, possibly a consequence of the somewhat threatening response he receives from Anna (»no, get real«). An alternative interpretation of this sequence is to describe the students' mode of talking as something Mercer and Wegerif (1999) call *exploratory talk*. With this expression, they have in mind a way of talking where arguments are launched without the speaker having yet decided on their relevance. It is clear, though, that Michael jumps at this idea and suggests that the instruction be put at the end of the list of contents (cf. Figure 4). A possible way of describing technology, and in this case the program TechnoLogica, is in terms of accumulated experiences inscribed in the form of distinctions (Latour & Woolgar, 1986). Some of these distinctions have been shaped like instructions (icons), which in turn are easily accessible to the users. By simply referring to or using some of these icons, the students can utilize the underlying distinctions, without understanding how they operate. When Isaac presents his proposal (in line 15) he uses the phrase »one of those« together with a circular gesture with the cursor. He does this in order to call attention to the icon with the open switch. The use of this expression is a good example of how much of the communicative work can be transferred to the screen or delegated to the other participants. Isaac does not necessarily need to know what the icon is called or how it operates. Neither does he have to remember what instructions there are in order to come up with this suggestion. Nearly every feasible action in the program TechnoLogica is represented on the screen in the shape of icons. Given this fact, the students can assume that the manipulation of these icons is all that it takes to solve the task in question. None of the students discusses the problem on a more general level or tries to widen the scope of the situation. They are completely engrossed in finding a solution to the problem, given the framing that was established during the first part of the session. This narrow attitude should still be considered reasonable since there have been no indications from the teachers that this activity should or even could be related to other activities.

Excerpt 4.

23	PATRIK	will it ever c- will it ever come to the step after that one?
24	Isaac	m:
25	Michael	ye:s
26	Isaac	[no:
27	Michael	[no:
28	Anna	why would it not do that?
29	PATRIK	'cause if you think when it if it goes through the whole program
30	Anna	yes
31	PATRIK	then it will tell it to run the program again, kind of, and then it will enter the program again

From his earlier experience with recursive functions, Patrik can immediately detect the shortcomings of the newly proposed function. Since the computer works sequentially, doing only one thing at the time, it will always enter a new copy of the function before it can reach the end that Michael had in mind for the switch. Every instruction located after the function's call to itself can be regarded as non-existent. By formulating the question »will it ever come to the step after that one?«, Patrik problematizes the students' solution. His phrasing, however, renders the objection nearly impossible to apprehend as being of a general kind. Instead, it is taken as a critique against the locally suggested function. Just like earlier, the general mathematical principle is mediated by the LEGO-dacta technology and is presented in common or local parlance. Consequently, it is restricted in its range of application.

What happens in lines 24 to 27 is especially interesting. With some hesitation, Michael repeats his earlier view when he responds to Patrik's question. But he soon shifts position and in unison with Isaac exclaims »noo«. Anna, however, remains doubtful about this change, and her question »why would it *not* do that?« motivates Patrik to give a more detailed description of what will happen when the function is executed.

How is it that the students so quickly discover the consequences of the newly proposed design? Michael and Isaac seem to need very little help in order to see that the function will never come to a halt. And here, emphasis on the word *see* is needed. The visual and interactive character of the environment gives the students good support for their reasoning. Without this rich visual base, it is unlikely that the students (who are to be considered as beginners) would have come up with such fast response to the sophisticated question (line 23).

Excerpt 5.

```
32   Michael   then we'll put a
               [stop
33   Anna      [m: *ye:s*
34   PATRIK    then it will never reach the
               [step after that one
35   Michael   [*it can't be done*
36   Anna      [m:
37   Michael   [oh yes, at the beginning a stop at
               the very beginning
38   Isaac     well?
39   JONAS     what will happen then?
40   Anna      but then the program will stop
               [you have to think
41   Michael   [but- he's telling it after there to start.
               if you put it before the A. like that
42   PATRIK    try it out and see what happens
```

In excerpt 5, the students continue the discussion and modify the design. They are trying to place something they call a »stop« (i.e. the icon with the open switch) in a section of the sequence that they know, from the previous discussion, will execute. Their aim is to stop the function from running. This has never been of interest earlier during the session, when all functions ran from beginning to end. As mentioned earlier, the purpose of the instruction is to interrupt the current being fed to the Lego models. This is the only way they have been using it and it is also the only way it can be used. The reasoning exhibited here can be described as a trial-and-error attitude and contains nothing qualitatively new. The students fail to discover that this problem has a logic that exceeds that of the other problems they had been working on earlier. Consequently, they continue to work within the framework that was established during the first part of the session.

The attempt to use the instruction (»stop«) in this unusual manner could be seen as a manifestation of creativity. An alternative way of looking at the matter is that it is a consequence of the student's lack of conceptual tools. It should be noted that they do not have access to the specific distinction between *current* and *function*. Without this distinction, it is hard to realize a priori that the instruction operates only with one of these categories and not the other. Although aware of the shortcomings of the new design, Patrik encourages them to execute their plans, in order to have something new and concrete as a platform for further reasoning.

Excerpt 6.

43	Anna	[don't think it will work though
44	Isaac	[then you have to re- remove this one
45	Michael	no
46	Isaac	place this one here
47	Anna	just <u>take</u>- ouch
48	Isaac	remove
49	Anna	just take <u>Isaac</u>
50	Isaac	eh yes. now I should press (.) this one?
51	Anna	m:
52	PATRIK	now look at the steps to see what it's doing
53	Isaac	it's doing it all over again

In this excerpt, the students make the alterations to the design that Michael had suggested. When they are about to execute the function, Patrik highlights a certain section of the screen (»now look at the steps to see what it's doing«). This window shows exactly what instructions the computer is executing at that moment (i.e. a *debugger* in computer jargon). Isaac then declares that they have failed when he points out that the function has restarted (»it's doing it all over again«).

Excerpt 7.

54	JONAS	it did stop there but then you turned it on again
55	PATRIK	what was it- what was it that stopped there. when you added the stop. it just shut off the current there, then. it didn't st- it never stopped the program, right?
56	Isaac	m:
57	Michael	no

Jonas tries to elucidate what happened when they executed the function. He gives a description of the course of events that happened too quickly to be perceived visually. Somewhat indirectly, Patrik then introduces the necessary distinction between current and functions. This is the first occasion where the teachers try to make the session more abstract or conceptually oriented. Irrespective of this change, the discussion ends here, since Anna, having lost interest, successfully introduces a new topic.

DISCUSSION

To begin the discussion, a short recapitulation of the results is needed. In the excerpts analysed, mainly three themes have been salient. The first of these is about how the interactive and visual character of the technical environment affords a specific way of working and talking, a communicative style dominated by demonstrative words and gestures. This kind of communication reflects what researchers call *deixis*[4] (see below). The second theme involves the possible conflict between this (deictic) language and more theoretical knowledge. And, finally, the last theme revolves round how this conflict is concealed from the participants by the wider scope of interpretations provided by the demonstrating expressions. These topics will be examined separately before the discussion is concluded with some general remarks on the role of this technology in science instruction.

DEICTIC DOMINANCE

When we are using language, we employ expressions that, in order to be interpreted correctly, depend on the context or what has been said before. This dependence is essential when it comes to certain expressions, which linguists call *deictic* (Allwood & Andersson, 1993; Rommetveit, 1974). Typical examples are references to time (now, today, yesterday), spatial references (here, there, left) and pronouns (I, she, it).

Why, then, are such common words of any interest to this study? One of many problems one faces when analysing interaction is to account for how the participants make use of the context. For instance, does it make any difference whether a discussion under scrutiny takes place within the setting of a school or at home? Video material increases the possibilities of moving towards the perspective of the participants, but it is still up to the analyst to account for exactly what in the surroundings is relevant to the participants. One approach to this complex issue is to study the deictic terms. By focusing on these words, the analyst gains access to sequences where the participants themselves actively refer to objects in the present situation. In line with this argumentation, Hanks (1992) describes deixis as something that organizes the field of interaction into a foreground upon a background. It creates a Figure-Ground relation, where the thing referred to is highlighted for the other participants and thus ends up in the foreground.

In the case studied here, a large number of deictic terms can be found. The participants often communicate in a way that involves the concrete environment. This frequent use of deictic references is an observation that corresponds well with earlier experiences of this environment (Ivarsson, 1999; Lilja, 1999). That this mode of communication is connected to the technology seems reasonable, but the question is how. One hypothesis is that the visual and interactive aspects of the technology facilitate this kind of language. The visual representations can be seen as restructuring the communicative patterns among the participants and thus contributing to the creation of other forms of activities. Not having to rely on linguistic descriptions to the same extent enables even younger students to take part as more central participants. In these activities, the use of deictic reference also becomes a functional and convenient way of reaching transitory agreements.

ISOLATED ACTIVITY

When the teachers present the problem of recursion, they use the visual representations as a basis and articulate the specifics with the aid of deictic terms. This creates an approach to the problem that the students can easily follow. Given the complexity of the problem, in relation to the students' level of education, this could be seen as a skilful achievement. The question remains, however, whether the students are given any possibilities of handling this problem at a conceptual level. If this episode remains an isolated event in relation to their normal education, one could seriously question its value. The risk of such isolation is considerable and one of many reasons for this is the kind of local language used.

The different kinds of experiences the teachers have of recursion vary in character. One kind is not unlike the situation facing the students, involving palpable manipulation of symbols. Another kind, more theoretical in character, comprises particular ways of talking about these phenomena and involves specific linguistic distinctions or *concepts*. One of the advantages of theoretical concepts is that they, in their capacity as linguistic tools, can be used in different contexts with some meaning preserved. Or put more correctly, since they maintain a relation to earlier contexts, the meaning of concepts can more easily be recreated in new situations, a process sometimes referred to as recontextualisation (van Oers, 1998). When using specialized terminology, one can connect to theoretical traditions and thereby associate with situations and events beyond this one, both past and future. This is in sharp contrast to the deictic expressions, whose meanings are produced with more local means.

In the examined excerpts, it is obvious how the students consistently work with the digital environment as a basis. The technology functions as a point of reference to whatever knowledge is brought to the fore. From an educational perspective, the danger of this is that the students may do the work, without ever considering facts that apply to the world beyond the screen. The activity lacks an overall language that points towards a future, towards a possible continuation and connects this activity to other contexts. Or, to use Wittgenstein's sententious words; »Teaching which is not meant to apply to anything but the examples given is different from that which ›*points beyond*‹ them« (Wittgenstein, 1953, § 208). In the case studied, the students concentrate on the example, but never aim beyond it.

ILLUSORY INTERSUBJECTIVITY

Another aspect of the presented material concerns the character of the cooperation that goes on. For any cooperation to take place there has to be a certain amount of mutual understanding or, as it is also called, intersubjectivity. Some researchers are of the opinion that this mutual understanding is never complete; we can never fully understand each other. It is, rather, a question of sufficient understanding for the moment, sufficient enough to move on in the interaction that takes place (Rommetveit, 1974; Wittgenstein, 1953). This way of looking at the matter corresponds well with the communication examined here. It is reasonable to say that there exists some intersubjectivity, or common comprehension of the situation between the students and the teachers, but not more than is enough to keep the conversation moving.

Returning again to the deictic language, this is very open (Rommetveit, 1974) and may allow a number of interpretations. In this case, the consequences are that the participants fail to recognize how far apart they stand. The students are never given the possibility to observe any distinctions that could be of vital importance in future encounters with recursive phenomena. Instead, they are temporarily trapped in a local and non-conceptual world. At the same time, the teachers risk interpreting the students in theoretical terms (Wyndhamn, 1995), as if their actions were about the concept of recursion. The latter becomes a form of over-interpretation that disregards the perspectives of the students.

The reasoning being performed by the students and the teachers, respectively, can be seen as two almost separate lines of reasoning. These lines converge in the deictic expressions and the actions that are connected to the activity of programming. What makes these lines of reasoning so different from each other is that the students and the teachers have access to differing resources for their interpretations. In the material, the students almost exclusively use earlier experiences from the technical environment when struggling with the problem at hand. The teachers, on the other hand, can benefit from earlier experiences and ways of talking about recursion in other situations.

CONCLUDING COMMENTS

The most important contribution of this study is to offer a critical voice, to the common expectation that, aided by equipment of this kind, students gain *practical experience* of complex processes. In the light of the results described above, this argument is not supported. If these complex processes are not accompanied by a theoretical language, the aspects that are *advanced* will end up on the same level as those that are trivial and arbitrary. Nothing will necessarily stand out as more important to the students – the colour of the icons could be of the same relevance as their way of functioning. In spite of the many advantages of digital technology, this study constitutes an example of a situation where the technology cannot provide the students with the guidance necessary. This observation is not entirely new however, Levinson and Murphy (1997) makes the same remarks when discussing conceptual development in a design and technology project. The novelty here is (hopefully) the detailed description of what such a process can look like.

In connection to this theme, the constructivist position that states that students themselves will *discover* the underlying principles built into the technology (Jonassen, 2000; Papert, 1993), seems somewhat awkward. This position takes for granted that every student, in a few years, could discover principles that have taken philosophers and scientists millennia to sort out (Säljö, 2000). From the theoretical perspective guiding this work, such a stance is most problematic, and the counter argument would be that we must take short cuts. One of these short cuts is language and, with the aid of this, our theories. In this respect, learning about recursion (i.e. beginning to regard a certain phenomenon as a recursive process), can be seen as a gradual participation in specialized practices – it is to become a member of practices that already have established ways of talking and acting, with reference to a limited part of the world (Roth & McGinn, 1997; Säljö & Bergqvist, 1997).

Finally, in defence of the technology stands the observation that the experience students gain from working in this environment could form a good basis for further reasoning. Actually, it seems as if the visualizations in this case could offer students access to mathematical worlds far beyond those furnished by normal textbooks. This, however, requires an active and attentive teacher mediating the activity. Someone has to help students overcome the local character of things. Abandoning this task in favour of technology might transform the learning environments into *digital koans*, interactive riddles that keep our students in local and non-conceptual worlds – a condition somewhat jestingly described as »kids in Zen«.

NOTES

(1) 12–13 years of age

(2) For the reader not familiar with programming, a function could be likened with a recipe; the name would then be the course in question and the instructions would be the ingredients and the manners in which they should be prepared.

(3) Excerpts 1 to 7 are all parts of the same sequence. With respect to the interested reader no utterances have been omitted.

(4) The word deixis stems from the Greek word for *showing* and *pointing out* (Rommetveit, 1972).

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STUDY III

WHAT MAKES THE SUBJECT MATTER MATTER?

CONTRASTING PROBEWARE WITH GRAPHS & TRACKS*

Instructional technologies seldom have any clear-cut effects on educational practices, or learning for that matter. One technological innovation, however, that somewhat contradicts this general characterisation is *probeware*. For over two decades, this technology has attracted the attention of science educators and researchers, as it is suggested that it offers a possible remedy to students' conceptual difficulties in mechanics as well as in other areas of science (e.g., Beichner, 1990; Bernhard, 2003; Thornton & Sokoloff, 1990; Tinker, 1996). Euler and Müller (1999) even claim that probeware is the only computer-based learning environment in physics education that has a proven general positive learning effect.

Although many share the view that this technology can be a helpful tool, the »mechanisms governing success« of probeware (Linn, Layman, & Nachamias, 1987, p. 252) have been, and still are, contested. In an early and influential study, Mokros and Tinker (1987) suggested four possible reasons for the effectiveness of probeware: the use of multiple modalities, the real-time pairing of events and their representations, the genuine scientific experiences made available and the elimination of the drudgery of graph production. These suggestions have been supported, opposed, and expanded in the continuing dialogue on probeware (cf. Beichner, 1990; Brasell, 1987; Thornton & Sokoloff, 1990), and during the last decade sev-

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eral studies point to the importance of using probeware in carefully designed activities in order to achieve positive results (e.g., Bernhard, 2003; Nakhleh, 1994; Newton & Rogers, 2001)

Today, after twenty years of research in this area, there is still a lack of convincing evidence as to why the use of probeware regularly leads to better scores on conceptual tests than other similar activities. Some see this lack of results mainly as a consequence of the pretest/posttest procedures that are used in many studies (e.g., Berger, Lu, Belzer, & Voss, 1994). Some years ago, Roth, Woszczyna, and Smith (1996) called for a change in educational research: from treating the technological intervention as an external factor towards an approach where students' interaction with technology is investigated. In the last few years, there has been such a change and, as Russell, Lucas, and McRobbie (2003) point out, an increasing number of researchers in the field of science education are now turning to qualitatively oriented methods. Several studies have focused on the investigation of students' *work* with instructional technologies (Choi-Koh, 2003; Kelly & Crawford, 1996; Nemirovsky & Noble, 1997; Roth, 1999; Russell et al., 2003). For example, by shifting focus from representations as an external influence to the practice of graphing (Cobb, 2002; Roth & McGinn, 1997; Roth & McGinn, 1998)

One possible drawback of this second approach is the usual lack of contrasting material offered in the analysis. The use of contrasts is an important principle in various experimental designs, but it is less commonly found in studies focusing on technologies and social interaction. In this latter kind of studies, it becomes necessary to extract the benefits of, for instance, probeware without having something immediate to compare potential findings with, which can make it hard to single out critical differences between different but similar learning environments.

In this study, we will combine a detailed interaction analysis with the advantages of using contrasting materials (cf. Silverman, 2001). We will do this by observing a course in mechanics, where the students participated in two different learning environments, *probeware* and *Graphs & Tracks*, designed for the learning of kinematics. The aim is to explore some critical differences in how students *do* kinematics in the two learning environments. Thus, we want to contrast two learning environments in order to find critical differences between these learning environments, and, in doing

Figure 1. Probeware. Two students interacting with the motion sensor (left) and the interface (right).

this, highlight aspects of the interaction with probeware that, we argue, are central for the success of this particular learning environment.

PROBEWARE AND GRAPHS & TRACKS

Probeware, also referred to as *computerised data-logging* or *microcomputer-based labs*, consists of a computer connected to probes that can measure and log different scientific phenomena. The software visualises the measured data in the form of digital meters, oscilloscopes, graphs or tables. For instance, in a kinematics lab students can be instructed to replicate a position-time graph by moving in front of a motion detector (see figure 1). Probeware can be used to carry out traditional recipe or verification labs, where the students are supposed to show the correctness of some formulae or principles (see Bernhard, 2003, for a critical discussion of this use). The alleged potential of probeware, however, is often connected to the possibility of collecting and presenting data in real-time, making it possible for students to immediately interpret a graph in relation to an observed or enacted phenomenon in an exploratory way (e.g., Beichner, 1990; Brasell, 1987).

In contrast to probeware, Graphs & Tracks is a purely virtual environment that does not involve »physical reality«. The simulated world of Graphs & Tracks is idealized and therefore free from friction and other sources of

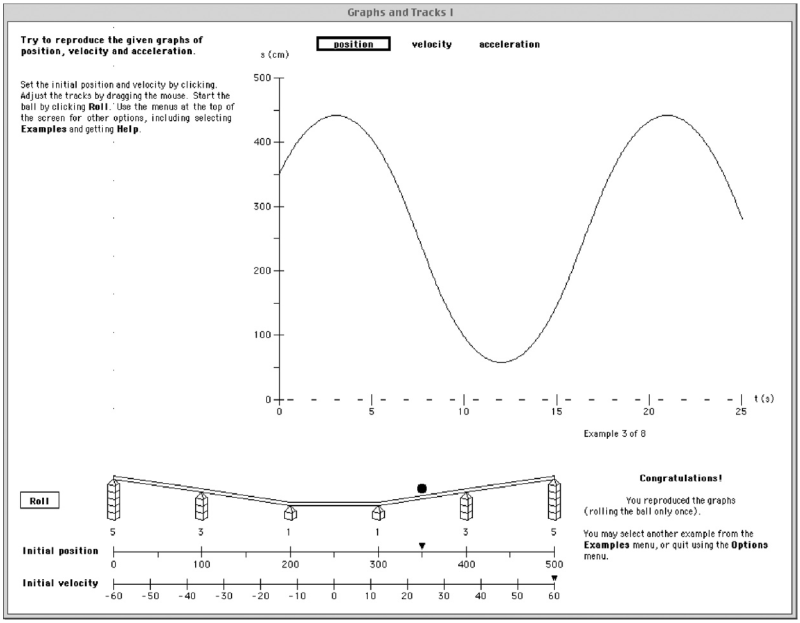

Figure 2. Graphs & Tracks. The (position-time) graph and the track match each other.

noise. The program involves the motion of a ball rolling on a stylized set of tracks, which can be configured in different ways. For each problem, the computer presents a position versus time graph, a diagram of a ball on a set of tracks and a number of initial conditions (see Figure 2). The students can also choose to observe the corresponding velocity-time and acceleration-time graphs. Six posts support the five segments of the track and the user can alter the height of these posts. The simulation starts when *roll* is pressed at which time the ball rolls down the track and the resulting graph is generated. The general task is to arrange the track and the initial conditions in a way that makes the motion of the ball correspond to the predefined graph. The evaluation is automated, and the computer displays a message when the correct solution is reached.

Our comparison between the use of probeware and Graphs & Tracks is *not* based on the assumption that these two environments are comparable in terms of to any *essential* similarities. As is clear from the descriptions given above, the two learning environments have somewhat different characteristics, and they have been designed in different ways. In our view, however, there are sufficient connections between them to make a comparison both reasonable and interesting. Both environments, in the case we examine, are used to reach the *same goal* and to cover the *same subject matter*, that is, to promote understanding of a motion and its representations. Furthermore, the strengths and characteristics of these two environments are described in similar terms: they are claimed to promote student-directed exploration, to provide a link between a phenomenon and its representation, and to support collaboration (cf. McDermott, 1990; Thornton & Sokoloff, 1990). Thus, the two environments are similar enough to make a comparison – which highlights critical differences – interesting.

METHODOLOGY AND RESEARCH DESIGN

The approach taken here, of video-based studies of technologies and social interaction, can, in line with Jordan and Henderson (1995), be called *interaction analysis*. In the analysis, we have been guided by research that shares an interest in the situated nature of human conduct, such as *ethnomethodology* (e.g., Garfinkel, 1967; Heritage, 1984; Hester & Francis, 2000; Suchman, 1987), analyses of *interaction in the professions* (e.g., Goodwin, 1997; Heath & Luff, 2000; Sarangi & Roberts, 2000), and *situative approaches* to learning and cognition (e.g., Brown, Collins, & Duguid, 1989; Greeno, 1997; Lave & Wenger, 1991). We have also been influenced by studies that use the *constant comparative method* (Silverman, 2001), where provisional hypotheses are tested by using a contrasting case (e.g., Silverman, 1981, 1997). Even more importantly, however, we build on an emerging research tradition that focuses on interaction in science and mathematics education (e.g., Greeno & Goldman, 1998; Lampert & Blunk, 1998; Nemirovsky, Cornelia, & Wright, 1998; Roth, 1999; Säljö & Wyndhamn, 1990).

Because our primary goal is to examine differences in how the students do kinematics in the two learning environments, we have been using methods for analysing interaction rather than theories of learning. Thus, it could be argued that we are investigating central characteristics of *learning environments* rather than *learning per se*. Instead of trying to find out if the students learn a particular subject matter, we have explored what the students do and which resources they use in their interpretation of tasks. In other words, the students' interactions in the lab are scrutinised as *practical achievements,* and our analytic attention is directed at the methods and resources on which the students rely in order to produce actions and to make sense of the situation.

STUDENTS AND LEARNING CONTEXT

The data used in this study are primarily taken from an introductory course in physics at one of the larger universities in Sweden. The 22 pre-service teachers participating in the study were all attending a thematic education course. Most of them had a background in social science and in the humanities, which meant that they had little previous experience of natural science. In the course, the students participated in four labs, each lasting about four hours. The students worked in eight groups of two, three or four. The instructor had considerable experience of working with probeware; he had also written a number of texts on how to use probeware as a *cognitive* rather than *technological* tool (e.g., Bernhard, 2003). In the papers, Bernhard argues that activities involving probeware should be designed as interactive-engagement activities – where carefully written instructions guide students through an inquiry focusing on conceptual issues – rather than as cookbook activities, where students are instructed to verify some textbook equation by following a step-by-step recipe. In this course, many tasks could be characterised with the predict-observe-explain (POE) procedure (Kearney, Treagust, Yeo, & Zadnik, 2001; Linn & Songer, 1991; White & Gunstone, 1992). In these tasks, the students should state a hypothesis, then observe the results and afterwards discuss discrepancies between the hypothesis and the outcome.

The analysis builds on the first two labs, in which the students worked with kinematics. During the first lab, the students were instructed to use probeware to construct graphs of position, velocity and acceleration with the help of probes. One week later, in the second lab, they were asked to investigate the relationship between graphs by using Graphs & Tracks. According to the instructions, the goal of the labs – and the purpose of the use of both probeware and Graphs & Tracks – was »to give a basic understanding of the representation of motion in the form of a position/time, velocity/time and acceleration/time graph and give an understanding of the relationship between position, time and acceleration«. One additional goal, as regards the work with probeware, was to »introduce computerised data logging«. The instructions were written by the teacher, who also continuously highlighted the goals for the students.

DATA ANALYSIS

The main data source consists of videotaped interaction complemented with participant observation and discussions with the teacher. One stationary camera per group was used and all the groups were videotaped during the four labs, resulting in approximately 130 hours of recorded interaction. The entire video material has been surveyed, but in order to explore the issue of how the students worked with kinematics in two different technological environments, we have delimited the analysis to cover only the first two labs, since these two labs dealt with the subject of kinematics.

In the first stage of data processing, all interaction in the two labs were jointly viewed by both authors. During the analysis of these 60 hours of video, a number of recurrent differences in the ways the students handled the tasks in the two learning environments could be observed. A number of preliminary sequences were selected and later examined in data sessions with eight to ten members of our research team with the aim of acquiring a basic understanding of the ways the students acted in the two consecutive labs.

In the second stage of analysing the data, we selected the material that will be used in this study. We wanted to make a cross-section, unaffected by our initial understanding of the differences between the groups. To achieve this, it was decided to pick out *one task* from each lab and to analyse how *all eight groups* solved the tasks on the two occasions. This selection (about three hours in all) was transcribed using the conventions of conversation analysis (Hutchby & Wooffitt, 1998). The following analysis was performed collaboratively and individually in turns, thereby corroborating our observations. After the iterative procedure of viewing and analysing the videotapes and transcripts, a number of different ways of acting in the environments had been identified. The analysis below will focus on the most salient courses of actions the students took in the two labs. We will, however, also account for other ways of completing the labs.

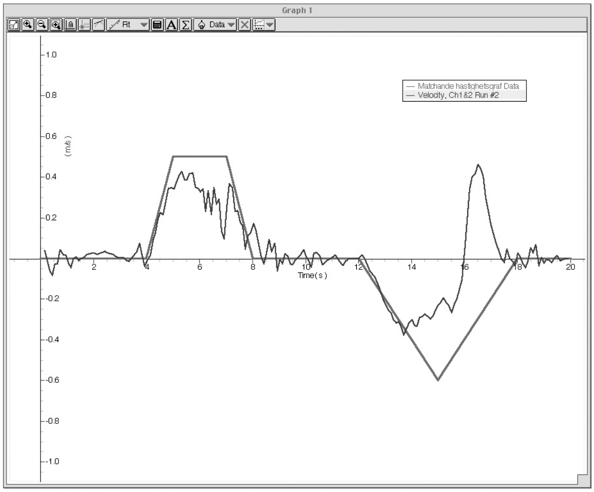

Figure 3. The pre-defined graph used in the task and a graph produced by a student. When constructing the graph, the student changed direction instead of decreasing the velocity, which resulted in the anomaly represented in the right part of the graph.

RESULTS

Below, we will first discuss what conceptual distinctions and ways of conduct that became prominent during the students' interaction when using probeware. Then, we will turn to the second lab and perform the equivalent analysis of the students' use of Graphs & Tracks. Although the individual descriptions may be interesting in their details, they also point to a more general pattern. Unless explicitly pointed out, the excerpts illustrate representative courses of action, which frequently occurred during the two labs.

THE FIRST LAB: PROBEWARE

Students' actions in the first lab will be exemplified by a task where they were instructed to walk in front of a motion detector in such a way that a graph similar to a velocity-time graph specified by their tutor would appear on the screen (see Figure 3). The computer program calculated the velocity by registering the students' distance from the detector over time. The graphs, which the students created by moving in front of the detector, were plotted on top of the pre-defined graph. This made it possible for the students to see discrepancies between the two graphs while they moved. When the students were satisfied with a constructed graph, they were asked to print it out and give it to the tutor.

The matching tasks in this material were often carried out in three phases, which we call *prediction*, *performance* and *evaluation*. In the prediction phase, the students tried to reach an agreement in terms of how they were going to move in front of the detector to replicate the graph given by the teacher. To do this, they used their previous experience of graph interpretation and graph production. The pre-defined graph, i.e. the graph that they were going to match, was translated into verbal descriptions, movements, and gestures. One such verbal description, which gives a detailed account of a movement that corresponds to the graph presented in Figure 3, can be found in Excerpt 1.

Excerpt 1.

```
 34.   Eric:    first you stand still (.) then you
                accelerate backwards (.) then you continue
                to walk backwards at a constant speed (.)
                then slo::w down (.) then you stand still
                again (.) then you change direction and
                accelerate towards the detector (.) then
                you s- slow down and finally you stand
                still.
```

In the performance phase, the students turned the sensor on and walked towards and away from the detector, trying to match the pre-defined graph. As previously noted, the students received direct feedback from the computer screen, which they could then act on. Finally, in the evaluation phase, the students discussed similarities and dissimilarities between the two graphs, they also decided whether to make a new graph or to print out the graph they had made and hand it in to the instructor. The students in this material usually constructed between four and fifteen graphs, with a mean of seven, before they continued with a new task. During this time, they developed an emerging sense of graph interpretation and graph production using interpretive resources of different kinds.

In the analysis of this first lab, we will present three interrelated themes relating to the students' use of graphs and which could be seen as both typical of and central to the completion of this task. In the first section, we highlight something Nemirovsky et al. (1998) call *adopting a tool perspective*. Before they could continue with their task, the students had to know what the motion-detector registered. The instructions gave them some clues to this, but, as we will show, these instructions were not enough, and some groups tried several different ways of verbally describing the graph and moving in the room before they came to a conclusion. In the second section, we will show how the students developed an emerging sense of the relationship between verbal concepts, motions in space and graphical representations by making some *conceptual distinctions*. Finally, in the third section, we will show and discuss how the graph was translated into a kinaesthetic and/or verbal *sequence with increasing refinement*.

Adopting a tool perspective
Before working on the task discussed here, the students' experience of the motion sensor was limited to the production and interpretation of a single position-time graph. With this limited experience, they were not sure what the motion detector was designed to measure or what they had to do to produce velocity-time graphs. They were also uncertain about how the sensor responded. In Excerpt 2, we can see one group having trouble relating the recent movement in front of the detector to the constructed and pre-defined graph. The reason for their problems was related to their interpretation of a horizontal line as representing a constant position instead of constant velocity, as if they were dealing with a position-time graph. This was the first velocity-time graph they had constructed, and they expressed concern about how to get the graph »to stay up«. Thus, they initially made sense of this task by using previous ways of interpreting the graph where horizontal lines very concretely meant standing still. Because of the real-time graphing, the students, when performing the movement in front of the detector, could immediately observe that standing still did not produce a graph that corresponded to the pre-defined one. Thus, the students are presented with a problem they have to deal with in order to complete the task.

Excerpt 2. Group 1

```
22.   Alice:     m:: [it can't sta:y up there like that
                     [((points at the part of the graph
                       that represents constant positive
                       velocity))
```

23	Jens: (Lab assistant)	[so this is, this is a constant [((points at the part of the graph that represents constant positive velocity))
24.		(3.6)
25.	Betty:	you have to- [you should move to the side, [((points at the part of the graph that represents constant positive velocity)) sideways [a little bit *like this* [((stands up and moves upper body to the left))
26.	Alice:	no but you can’t move sideways ‘cause then you disappear out of the picture

In the excerpt, Betty suggests that they should move sideways as a solution to the problem of staying up. Here, it is obvious that Betty’s previous experience of graph production in this particular setting, where a horizontal line instructing the students to stand still, is intertwined with their current problem of preventing the results in the graph from dropping to the x-axis. Alice responds to Betty’s suggestion of moving sideways by saying that this would not present a proper behaviour, and that she would »disappear out of the picture«. Thus, Alice highlights what the tool measures or, to use an anthropomorphic metaphor commonly used by the students, what it could »see«. Developing and adopting such a perspective on what the sensor measured – and consequently what became central to the task – was one of the goals of the lab and something that was more or less necessary to consider if the students were to complete the lab in a satisfactory way. It was also something all the groups in this study explicitly dealt with. Later in this task, Betty suggested that they should walk on the spot as a solution to the stipulated problem of moving without going forward or backward, a suggestion that was paralleled in other groups.

The students did not only have to struggle with ideas about linear motion in their completion of the task. Other things that became central for the students included: how far they could walk until they were out of the range of the sensor, how their steps influenced the appearance of their graph, and how a thick sweater made the ultrasonic sounds from the motion detector reflect in another way, thus resulting in anomalies in the graph. In this way, the students had to reason about which aspects of their movements were central in the production of the graph and what kind of noise was inevitable. By becoming increasingly sensitive to what the tool actually measured, the students also approached kinematics and graphing in refined ways, i.e. they become more sensitive to the distinctions that were central to accomplishing the task, something we will explore further in the next two sections.

Making distinctions and using concepts

The conceptual differences between position-time and velocity-time graphs, and between the communicative and scientific concepts of position and velocity, create problems related to the difficulties in realising that the detector measures linear motion. In the data, these differences became central to the task, something all groups in different ways brought up in their completion of the task. As mentioned in the previous section, many things could influence the production of graphs, and it was not until the students expressed specific conceptual distinctions that they were able to make graphs approximating the pre-defined one.

Excerpt 3. Group 7

```
1.   Hannah:  ((reads the instructions and opens the
               file)) so this was velocity (0.9) time
2.            (1.9)
3.   Inez:    I kno- [what was the first one we did?
                     [((looks at the instructions))
4.   Hannah:  well it was-
              (0.7)
5.   Inez:    it was only motion
6.   Hannah:  posi:tion and time
```

In the excerpt above, Hannah and Inez start on the task by highlighting the difference between position and velocity. This distinction between the two graphs later became a central resource in the interpretation, construction and evaluation of this task. Here, Inez also introduces the somewhat vague expression »only motion« (turn 5). One drawback is that it makes it hard to discriminate between position-time and velocity-time graphs. Another problem is that the term does not discriminate between walking with an increased velocity, walking with a constant velocity, or even walking sideways (see Excerpt 2). In response to Inez' utterance, Hannah draws attention to the difference between the two graphs by dividing the graph into two dimensions, pointing out that the last graph represented »position and time« (turn 6), which contrasts with the earlier description of the graph as »velocity time« (turn 1). Seeing, or rather (en)acting, this difference was necessary for the completion of the task: in this course, all eight participating groups managed to make the difference after some struggling.

In Excerpt 2, we gave an example of how two students, Alice and Betty, had great trouble realising what kind of motion was central (i.e. walking on the spot and walking sideways were not relevant actions in this activity). Below, we present an excerpt from a group, which has similar problems interpreting and constructing the horizontal part of the graph that represents constant positive velocity. The group presented in Excerpt 4 had tried to match the graph (in Figure 3) five times, every time they interpreted the constant positive velocity as if they should stand still. During their fifth attempt, they began to realise why there was a discrepancy between the graph they had constructed and the pre-defined graph, why their graph »goes down«, as they put it.

Excerpt 4. Group 5

```
220.   Emily:     [backwards (0.3) a::nd
                  [((takes a step backwards and stops,
                  the graph rises and drops))
221.   Felicia:   *o:ps*
222.   Emily:     *but what's it doing* (0.7) yeah but it
                  [is
223.   Felicia:   [yea:h
224.   Emily:     ='cause you stand still here
225.   Felicia:   no::
226.   Emily:     then it [goes down to zero
227.   Felicia            [yes you shouldn't stand still
228.   Gina:      =no
229.   Felicia:   =no it's the velocity that should be
                  [constant
230.   Gina:      [cons- yea:h
```

As shown in the excerpt, Emily walks backwards while watching the graph on the computer screen. Then she stops, and the graph drops to the x-axis. Emily responds verbally to the graph in a questioning way, but she then continues and relates the graph to their actions (»it is 'cause you stand still here«, turn 224). Subsequently, she draws the conclusion that the graph »goes down« (turn 226) because of this. Felicia responds very excitedly to Emily's utterances by proposing that they should not stand still, and that the velocity should be constant. Thus, by referring to the movements and to how these movements resulted in certain behaviours of the graphical representation, they establish a distinction between position-time and velocity-time graphs. Consequently, it is through the practical task of making a certain graph by moving in the room that velocity – as a concept contrasting with the undifferentiated notion of motion or speed – becomes a central and helpful resource for the students. In a similar way, the students deal with negative velocity and the difference between acceleration and constant velocity.

As we can see in the excerpts above, the students intertwined different interpretative (and communicative) resources as well as different experiential domains, such as graphical shapes, with verbal accounts of past actions when interpreting, performing and evaluating the graph and the movement. The most obvious intertwinement in this material is between the *graph as a shape* and the *graph as a response to action* (see Nemirovsky et al., 1998). This means that the students, when trying to make sense of the graph and complete the task, could be seen as putting themselves both into the world of physical movements and the world of graphical representations. This was something characteristic of all the groups and during almost all the tasks using probeware. Thus, it was often by way of movements in space that the concepts of kinematics became relevant.

Refining descriptions through sequential translations

When verbally analysing the graph, the students had to translate the graphs into discrete sections. Such an interpretation, where the student splits the graph into several episodes, is presented in the excerpt below.

Excerpt 5. Group 8

```
 2.    Julia:  so first we stand still (0.2) >right here<
               then we go backwards (0.8) then we stand
               still (0.2) then we go towards. (0.4) you
               can't go (1.8) it feels like you'll end
               up- at- (0.5) the starting-point (1.0) then
               you should stand still then you move even
               closer
```

Julia's description could be seen as a verbal translation of the graph (pictured in Figure 3) separated into six sections. The sections she mentions do not correspond well to the movement they should perform when attempting to replicate the graph (for such a description, see Excerpt 1). Although the description may be seen as less compelling than other descriptions, it is not arbitrary. Julia divides the graph into approximately the same sections as many other groups; she translates the graph from left to right, and her interpretation has much in common with the interpretations in previous excerpts, where the graph was treated as a position-time graph. A couple of turns later, after struggling with the latter part of the graph (representing negative velocity), and realising that the graph did not represent position and time but velocity and time, Julia and Kylie revise their previous description and make a new interpretation. Together, both students construct a new account of the graph that corresponds to the represented movement in a better way.

Excerpt 6. Group 8

```
15.    Kylie:  no. no you don't do that or do you? (0.6)
               no (0.6) no you can't do that,
               [you (0.5) stand still, and then
               [((points at the beginning of the graph))
16.    Julia:  you go [backwards
17.    Kylie:         [you go backwards (0.8)
               [and then you continuously increase
                your speed
               [((points at the graph where they
                  should accelerate
18.    Julia:  m::
19.    Kylie:  [then you walk at the same speed
               [((points at the constant velocity))
20.            (1.2)
21.    Kylie:  at that velocity the whole ti- or in
               ((laughs)) two seconds then.
22.    Julia:  yeah that's right you have to walk there.
               it's yeah
23.    Kylie:  [yes (0.5) and then you decrease
                the velocity
               [((points at the decreasing velocity))
```

In the excerpt, the students make an interpretation of the first part of the graph (the part where the students move away from the sensor). Again, the students separate the graph into discrete sections and, again, they translate it into a verbal account of a two-dimensional movement. Thus, in both cases, the students are oriented toward the practical problem of graph production and they translate the graph into a verbal description with a focus on qualitative changes in velocity and direction, which could be used as a resource in the production of a graph similar to the pre-defined one. Even though it is not as structured and tidy as the earlier account (which took place in a single turn), it could be seen as a more compelling description of the movement they are instructed to perform. Compared with the earlier interpretation, this includes »increased velocity«, »constant velocity« and »decreased velocity« instead of »only motion« (or non-motion) with a particular direction. By doing this, the students introduce one more dimensions (change of velocity) that – as we already have shown – could be seen as central both to the interpretation of graphs and in the completion of the task.

In excerpts 5 and 6, we have presented two examples of students' verbal, and sequential, translation of the graphs, but the ways the graph could be translated into a verbal description are in principle (although not in practice) infinite. For instance, one of the groups' readings of the graph at first focused on quantitative aspects of how they had to walk before they changed the velocity or speed. Thus, the students in this group did not focus, as did the other groups, on the qualitative aspects of the graph, but instead on the exact distances and velocities. After they had calculated the different distances, they put small pieces of paper on the floor, signifying distances and points where they should change velocity. Later, however, when they had constructed one graph by moving in front of the detector, they started to use real-time graphing as a resource for their actions and interactions instead of calculations of the distances from the detector. They found it complicated to look at the pieces of paper on the floor, and it was easier to look at how the graph was plotted on the computer screen. Much of the task is a about timing the movement, and even if the bits of papers indicated *where* the students should change their movements, the students did not get any visual aid in evaluating the *speed* of the movement.

Trying to use strategies, other than real-time graphing, was not something special for this group. Attempts to use more quantitative ways of interpreting the graph were explored and abandoned by most of the groups. Thus, the most important findings, from the empirical observations, are that the task of graph matching made some resources and some distinctions more useful than other resources and distinctions, and, furthermore, that the sequential translation of the graph eventually became fairly uniform between the groups, with the students focusing on approximately the same things, dividing the graph into the same sections, and using the same concepts.

We have now highlighted three evolving themes connected to the students' courses of action that were characteristic of the work with probeware: The adoption of a tool perspective, the emerging use of conceptual distinctions and the making of increasingly refined descriptions of the graph. Not only were the strategies and resources adopted during this lab helpful for the students, but these three themes can also be seen as progressive in the sense that the following theme builds on the former. With this last point in mind, we now turn to the analysis of the second lab. The aim is to show an example how a lab, which has the same goal, is directed toward the same content as the previous lab, and uses a tool that – at least on a superficial level – has many structural similarities with probeware, can lead to very different courses of action. As we will demonstrate, what the students do, what they focus on and what interpretative resources they use to complete the lab are quite different from what we found in the previous case. To show this, we will again characterise typical and central features of the students' courses of action in this particular lab.

THE SECOND LAB: GRAPHS & TRACKS

The second lab on kinematics took place about one week after the first hands-on activity. This time, the same eight groups of students worked with a simulation called Graphs & Tracks, which was new to them. The purpose of this lab was the same as the previous one and it was emphasised that the program had been specially designed to promote understanding of the connections between motion and its different forms of representation. As pointed out in the introduction, however, there were some differences between the tasks that included probeware and the tasks they were now going to perform with the simulation. Since Graphs & Tracks is a purely virtual environment, the students did not measure anything »real« outside the computer. Instead, the students, in eight tasks of increasing difficulty, were to arrange a symbolized track and some initial conditions in such a way that the motion of a ball corresponded to a predefined graph.

In the program, the five segments of the track are of approximately the same length and supported by six posts (see figure 2). The students could alter the height of the posts as well as the initial values for both position and velocity. In addition, there was the possibility of viewing the corresponding velocity and acceleration versus time graphs as they could provide additional information. At any time, the students could roll the ball and watch the computer generate the resulting graph. One of the easiest ways of solving the tasks is to use the position-time graph for the initial position, the velocity-time graph for the initial velocity, and the acceleration-time graph for the slope of the track. As we will show, however, this was not a strategy used by many students.

In the analysis, we will first discuss how some groups struggled with *discrepancies* arising between the different representations. Secondly, we will illustrate the frequent making of sequential translations, and how these translations could highlight *time* as a relevant concept. Finally, we will go into the problems of using an *iterative* course of action, and how the students' hasty conduct seems to impede progression.

Coordinating representations

Throughout the material, a recurrent difficulty for many of the groups was to find a match between the track and the predefined graphs. This could be seen as a trivial and hence not a surprising theme to find – matching the track and the predefined graphs is exactly what the students are supposed to do in all tasks that included Graphs & Tracks. What is interesting, however, is the different ways in which these difficulties were handled.

Excerpt 7. Group 5

```
 51.            ((the simulation is run))
 52.   Gina:     this is pretty good (0.2) but eh::
 53.   Felicia:  where does it go wrong then (0.6) *where
                 does it [fail*
 54.   Gina:              [*where does it fail* (0.2) I
                           don't kno:w (1.9)
                 [it's going down too fast
                 [((points at the discrepancy between the
                    two graphs))
```

Although the students in this group explicitly comment on their deviant graph, they are not certain about what resources to bring in to correct it. In order to establish relations between certain parts of the graph and the static sections of the track, a number of different resources could be employed. One hypothetical way to start this task would be to use real-time graphing, which in this case would imply relating the simulated rolling of the ball with the accompanying plotting of the graph. The simultaneity in this process could be seen as a natural basis in an examination of the interrelationship between the two representations. A small feature in the construction of the program, however, makes this possibility almost non-existent. Since the time it takes for the simulation to run is dependent on the speed of the computer, the simulation tends to be over in only a fraction of a second, especially when using up-to-date hardware. This causes real-time graphing in the simulation program to become an almost invisible, or at least a very marginal, event and only the traces remain.

In the next excerpt, the same group of students still grapple with the problem of coordinating the two representations and insists on using real-time graphing as a productive resource despite the problems. To overcome the swiftness of the simulation, they have to divide the actual observation between them and each focus on one single point of reference. By engaging in this procedure, the group manages to translate one point of the graph into one section of the track and vice versa.

Excerpt 8. Group 5

72.	Gina:	now I'm gonna see exactly (0.2) when I say no::w you check where the ball is
71.	Felicia:	m::
72.		((the simulation is run))
73.	Gina:	now
74.	Felicia:	now it's at four five

This example is a unique occurrence and not a representative course of action for the groups. It does, however, illustrate to what extremes the students have to go to in order to establish a singular translation in this environment. Doing this by means of the simulated event requires extensive coordinating work. Accordingly, focusing on these features in Graphs & Tracks is hardly rewarding, especially in comparison with the use of probeware where the simultaneity of graph production and motion is unavoidable. The aspects of the task, which are highlighted by the students in the process of completing the tasks, are different.

Making sequential translations

Instead of employing real-time graphing, most groups took the predefined graph and the traces of the simulation as their starting-point. Structured by the discrete sections of the track, the static graph was treated in a similar way as containing several smaller parts (although the graph could be see as continuous). When treated in this way, the graph was most often translated from left to right.

Engaging in the procedure of sequential translations took some groups further than others. Some of the groups soon ran into trouble and tried out other approaches (one of which will be discussed in the next section). For the students who held on to this strategy, time eventually became necessary to consider. This is exemplified in Excerpt 9. Here, the two students have arranged three of the five sections of the track correctly but are now struggling with the fact that they have only managed to reproduce one fourth of the graph.

Excerpt 9. Group 8

```
73.   Kylie:  it doesn't feel like
              [they're enough for you
74.           [((points at the two rightmost
                 sections of the track))
75.   Julia:  no
76.           (5.6)
77.   Julia:  well (0.5) no never mind
78.   Kylie:  sure it feels like it should
              [move like that for quite a while
79.           [((points along the declining part of
                 the graph))
80.   Julia:  ye:s and then it's going up he::re and
81.   Kylie:  ye:ah
82.           (4.2)
83.   Julia:  but here eh- (0.8) I have trouble thinking
              should we run it once and see
```

One of the students highlights the two rightmost sections of the track by pointing at them and commenting on the problem of temporal duration. The specific problem these students are facing is that the predefined graph represents a pendulous motion. Thus, the track has to be used more than once and the correct design looks something like a dish (see Figure 2). From a curricular perspective, the kind of discussion found in Excerpt 9 is interesting. The exercises are deliberately constructed in order to highlight issues like this. For the group in question, the problem was eventually overcome when they discovered what a dish-like construction would imply. It is important to note, however, that the design of the program in no way automatically kept the students focused on the problem. Instead of struggling with such incongruities by means of joint reasoning, one could just as easily switch to strategies of repeated trials, something that will be explored further in the next section

Solving the problem by trial-and-error

Although the production of graphs and the tuning of the track in the exercises are actions that are dependent on concepts from kinematics, the kind of kinematics that the students were doing was not determined by this inherent connection. This is exemplified by a trial-and-error attitude fostered in most groups. Rather than suggesting hypotheses and reasoning about possible outcomes, an activity that requires a certain amount of effort by the students, the simulation was run and the calculations were left to the computer to perform. In the process, repetition became a very important resource for reaching the correct configuration. One group using this strategy needed as many as forty trials while another group, using a different strategy, solved the same task in five trials.

Excerpt 10. Group 3

```
150.  Carol:  think it should down (0.5) a little bit
              (1.3) what happens if it is like this (0.6)
              oops (1.6) why no °I am pulling upwards°
              (5.3) did we have it like that?
151.  Diana:  no:: I don't know
152.          ((the simulation is run))
153.  Diana:  well (.) it's not that bad
154.  Carol:  but no: it was up at five before right?
              (1.2) then it was better. (1.2) should
              these be equal then?
```

Excerpt 10 shows a group, which had made many small adjustments previously and has now returned to an earlier configuration. The group members do not remember whether or not this track is similar to an earlier trial, and they try to consult each other about this. Even in other cases, when repetition was used as the primary means, it affected how the students progressed.

In Graphs & Tracks, it is very easy to make small corrections to the track, run the simulation and then watch the result. The new result can quickly be compared to the previous trial, and the students often highlighted the difference between attempts. In spite of this, the effect of this strategy is not cumulative and as a result, many groups forgot what adjustments they had already made, something found to be both frustrating and boring.

The use of sequential translations and trial-and-error were the two most prominent courses of action in this lab, but there where also other ways of solving the task. Two groups at some point made use of the possibility of switching graphs in order to extract additional information, and one of these groups used physical reasoning as a productive resource. In addition, one group asked the teacher for help, and still another group simply skipped the task.

DISCUSSION

With this empirical account of the students' activity as a basis, we can now turn to the comparison. The aim of this comparison is, as stated earlier, to acquire a deeper understanding of why probeware often results in better scores on conceptual tests than other similar activities. The most important issue here is what kind of kinematics emerged in the two environments, that is, the question of how the representations and phenomena where interlinked during the two labs.

MERGING OF RESOURCES

One interesting aspect, present in both environments, is that different interpretative resources were *merged* or *intertwined* in the co-ordination of actions and in the completion of the tasks. It is important to note, however, that the intertwinement of resources was quite different between the two environments.

When using probeware, it was the intertwinement of physical movements, the predefined graph and the creation of a new graph, which became the most important way of solving the tasks. These three layers were collapsed into a *graphical space* (Nemirovsky et al., 1998; Ochs, Gonzales, & Jacoby, 1996) with special indexical characteristics. The space could be referred to by synchronised pointing gestures and verbal descriptions of prospective actions. When dealing with this space, the students almost all the time, and in different ways, deal with motion. The graph is not just an abstract symbol system, but also something that is talked about in terms of *velocity* or *speed* and acted upon by moving in front of the detector.

In Graphs & Tracks, the idea of merging different representations is central to the design of the program (McDermott, 1990). One of the purposes of the simulation is that the students should move between the three different graphs and, in this way, compile information about the motion of the ball. Nevertheless, very few students used this possibility as an interpretative strategy when tackling the task. The prototypical strategy was to avail oneself of mainly one graph, usually position or velocity, and work with this until finished. Upon completion, however, all the groups always examined the two remaining graphs to find out what they »looked like«. This struck us as quite surprising, since the result ipso facto was identical to the predefined graphs. Perhaps this behaviour points to the unclear status of the interrelationships between the three graphs in this environment. This shows that interrelating graphs and examining variables had not been established as stable procedures in this particular activity.

Although Graphs & Tracks is intended to provide a tool for the pooling of multiple representations of the same phenomena, this feature of the software is not mandatory. Consequently, as illustrated above, most students in this study managed to solve the tasks by employing other methods. When using probeware, on the other hand, there was no easy way of escaping this intertwinement of represented and enacted movement.

THE NECESSITY OF DISTINCTIONS

In using probeware, the graphs were often translated into a verbal description, prescribing how the student should move. These descriptions developed over time and gradually began to involve an increasing number of physical concepts and distinctions. The probeware environment is designed to be used by dyads or smaller groups, and this was reflected in the need of co-ordination among the participants. Even though probeware is a very rich environment appealing to several senses, the students often *had* to co-ordinate their behaviour verbally in order to produce a graph that approximated the predefined graph. As shown in excerpts 2 and 3, it was essential to separate velocity-time from position-time graphs. This difference was the result of a struggle between previous experiences of position-time graphs and the current graph presented by the computer. Furthermore, the students had to make distinctions between constant versus changing velocity, and between positive and negative velocity. Not only did they have to make these distinctions discursively (as communicative means), they also had to enact them physically with their own bodies. The students had to relate all this to the sensor in certain ways, something that often led to discussions about the actual process of data collection and possible sources of noise.

This developing use of relevant distinctions and physical concepts when using probeware stands out as an important observation, especially as the successful solving of tasks in the second lab did not *necessarily* involve any relevant distinctions. In the work with Graphs & Tracks, the language had a more subordinate role in the sense that progress could be made more silently. This could be seen as a result of the design of the software. A single user can easily handle Graphs & Tracks, and there is nothing in the design that encourages collaboration. When working together on these tasks, the students most often talked about adjustments of the track, but they hardly ever used any concepts concerning *motion*. The verbal communication was more directed at specific details, like the height of individual posts or the inclination of a certain section, and it was never about the overall character of the represented motion. The tasks could be solved by everything from initiated physical reasoning to trial-and-error, »cheating«, or sheer luck. Some groups managed to solve the tasks using only the position-time graph, while other groups only used the velocity-time graph – a fact that indicates that a distinction between these two graphs was not a prerequisite for solving the tasks.

Remembering that we have studied the same groups of students, these discrepancies illustrate how two designs, which share the same goals, can be used very differently with respect to the »same« subject matter. We believe that this difference is of crucial importance for what experiences the students had and, hence, for what they learned.

CONCLUSION

By making the comparison between the students' interaction in the two environments, we have shown some central aspects that could explain why students perform better after working with probeware, in comparison to simulations or other similar activities. The focus of this study has been on how the students handle the content of kinematics in two different computer-based learning environments. The original problem was students' difficulties in handling graphical representations.

The results suggest that any designer, trying to deal with this issue, needs to ensure that students' *interaction* with the technology involves connections between the phenomena (e.g., motion) and its graphical representations and, in addition, that these connections are mediated by the appropriate conceptual apparatus (cf. Säljö, 1999). That the technology itself embodies such interconnections is in no way a sufficient condition. The real educational challenge lies in promoting the students' use of conceptual resources when working on the tasks. And it is on this point, we argue, that one can begin to understand the success of probeware. Although both probeware and Graphs & Tracks have been described as having almost the same set of characteristics, the analysis shows that there are huge differences in how the students approach and enact kinematics in the two environments. Connections between motion and graphs were made in a satisfactory way in the case of probeware, but not in the case of Graphs & Tracks. Without such connections, the phenomena and the representations will remain detached from each other, and one could question whether such an activity should be regarded as dealing with kinematics at all.

In addition, an interesting question could be raised in relation to the students' educational background. Would not students more experienced in kinematics turn the lab with Graphs & Tracks into a more productive exercise than the one observed here? Such a scenario is most likely. But again, we argue, that these observations, of students with limited experience of kinematics, are important because they accentuate the role of the learning environment. As educational researchers, our focus should be on those students more prone to conceptual difficulties, or the population as a whole, since the group of »better« students seems to get by more or less regardless of the conditions. Odd as it may sound after decades of constructionism and free exploration, our conclusion is that one should try to make the technology and the tasks imperative. By necessitate a certain way of solving the tasks, students had to explore conceptual issues. After all, when using probeware all students *did* develop an increasingly refined way of describing and conceptualising the graph. In our view, this was due to the demands of the task in combination with the properties of the technology – there were no other *easy* ways of achieving a satisfying result.

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STUDY IV

SEEING THROUGH THE SCREEN

HUMAN REASONING AND THE DEVELOPMENT OF REPRESENTATIONAL TECHNOLOGIES*

Material artifacts play a prominent role in most social practices. Humans learn and develop not only in a world of social relationships, but also in a world of things. In spite of the ubiquity of physical objects in all that we do, most theoretical accounts of learning and development downplay, or even disregard, the fundamental manner in which our actions, insights and modes of knowing are dependent on familiarity with, and use of, things. By failing to consider the role of such resources in human activities, most theoretical perspectives simultaneously downplay the role of artifacts in the cumulation of knowledge and skills in society at large.

In addition to the centrality of tools in most human practices in general, a large portion of the objects that figure in children's activities (e.g., various kinds of toys, games, books, computer software) in many societies is specifically manufactured with the ambition of developing cognitive and communicative skills of various kinds.

In a sociocultural perspective (Vygotsky, 1986; Wertsch, 1998), artifacts can be seen as objectifications of human intentions and insights. »What the child learns to see, to touch, to move around, to throw is a range of artifacts that already has a human significance for even the very young child«, as Wartofsky (1983, p. 13) puts it. As children relate to these objects in social practices, caregivers will provide guidance where the signifying functions

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of artifacts are central. In *guided participation* (Rogoff, 1990) children, thus, appropriate socioculturally prominent interpretations of the world around them through the use of artifacts. They learn about such diverse matters as techniques for counting, writing and drawing, about gender roles, and how to compete in various kinds of games. Cultural psychologists and sociocultural theorists argue that cognitive development is not universal but will depend on the specific social practices, and the tools and technologies that children are exposed to, and learn to use as mediational means (Cole, 1996; Leont'ev, 1978; Vygotsky, 1986).

In a technologically complex society, children develop skills in using a range of symbolic artifacts. These symbolic tools are intimately related to physical tools. In fact, it is in most cases not easy to make a distinction of this kind. Written language and counting systems are obvious examples of symbolic systems that are implemented by means of physical objects. But there is a wealth of artifacts that embody symbolic systems and notations including maps, graphs, charts, drawings and tables, to mention some examples. In a historical perspective, the trend seems to be fairly clear; people are exposed to an increasing number of such artifacts, and we expect them to be competent users of them at an early age. As will be examined further in this chapter, such intellectual tools must be seen as mediating perceptual activity. Our very seeing, and understanding of the world, are in a fascinating sense related to the development of symbolic and technological systems.

In what follows, two issues will be explored in the context of children's use of the particular kinds of representational tools that are built into information technology. First, how can we understand the relationships between these cultural artifacts and the cognitive development of children? Second, how will the very nature of human cognitive and communicative development itself be affected, or modified, by social and technological development? The former question has been investigated in a number of studies, taking both cultural and historical factors into account (e.g., Greeno & Hall, 1997; Roth & McGinn, 1998; Säljö, 1996). In contrast, the second question of the very nature of the interplay between developmental trajectories of individuals and the introduction of new artifacts/social practices in society has received little attention. In the following, both questions will be considered by means of an exploratory case study of the introduction of a certain kind of digital representation to a number of young children (aged between six and eleven) growing up in the digital age. What we will attend to is the nature of reasoning they engage in the context of digital representations, and how this reasoning is coordinated with the technology at hand.

REPRESENTATIONS AND SCIENTIFIC REASONING

Issues of the relationship between children's reasoning, scientific concepts and visual representations are very general and have been investigated from different theoretical positions. The immediate background of the present research, however, can be found in two earlier studies by Schoultz, Säljö and Wyndhamn (2001) and Ivarsson, Schoultz and Säljö (2002). The common interest in these two studies was to analyze children's reasoning in the area of elementary astronomy. Both studies were conducted to critically dialogue with the research findings in the tradition of studying *conceptual change* within a cognitivist tradition. In the latter kind of study, children (from 5 years and up) are typically interviewed about their understandings of the shape of the earth and elementary concepts such as gravity. The results generally show that children have various *mental models* of the earth as flat, hollow and so on, and that they often claim that people can fall off the earth or that they can only live on top of it (Nussbaum, 1979; Nussbaum & Novak, 1976; Vosniadou, 1994; Vosniadou & Brewer, 1992).

As much of the earlier research that we wanted to dialogue with had used the structured interview, in the Piagetian tradition of the méthode-clinique (Piaget, 1929) to gather data, this method was largely maintained in our previous studies, although with some significant modifications. One of these modifications concerned the analytical attitude in relation to the empirical material. Instead of regarding the interview situation as a privileged context in which the mind can be tapped of its conceptual content, the interviews were analyzed as concrete social and discursive encounters. A second modification concerned the resources made available to the participants. The children in these studies were given the possibility to reason about elementary astronomy with the support of well-known artifacts such as a globe and a map, respectively. The studies showed how a globe or a map supports the reasoning of even very young children to accomplish rather complicated accounts in which sophisticated knowledge about the shape of the earth and gravity was introduced. Contrary to the earlier research, these two studies contained no reports of children saying that one could fall off the earth, a fact that was attributed to the familiarity with and physical presence of the representational objects. Also, there were no suggestions that the shape of the earth was flat or had any other form. Thus, these artifacts seem to serve as quite efficient prosthetic devices for reasoning, if one is interested in studying how children are able to use fairly abstract explanations and approximate scientifically acceptable accounts.

From such culturally established artifacts as globes and maps, this study takes the step to the digital medium and representations of a related, but at the same time, less familiar kind. In a modern society, children will meet a plethora of visual representations in many walks of life; in movies, games, books, toys and so on. The cognitive socialisation needed to handle these new, rich and dynamic representations must be very different from the one that was valid, let us say, fifty years ago or so. This is the general issue which underlies the observations we will report in what follows. Two specific questions will be addressed: first, what happens to children's reasoning when confronted with an unfamiliar and dynamic representation, and second, what discursive strategies and resources will children use in their argumentations. These are, of course, very generic questions, and we can only exemplify some aspects of them. To simplify the understanding, we will keep to the same context as in the studies above: children's reasoning about gravity and the shape of the earth.

Before turning to the empirical material, a theoretical framework, suitable for the kind of analysis we will present, will be briefly articulated.

PERCEPTION, REPRESENTATION AND ACTION

A fascinating theory of the nature of visual representation, and one which is firmly grounded in an attempt to take human practices as a starting point, has been developed by the philosopher Marx Wartofsky (1979). Traditionally, philosophy and psychology have studied and conceived perception as a biological capacity and as a characteristic of the species. Consequently, even though the contents of perception obviously have varied historically, its structures and modes have been understood as *a*historical and determined by our visual system as a biological entity. Wartofsky sketches an alternative view of perception, and knowledge more in general, which he refers to as a *historical epistemology*. His general argument is that the forms, or modes, of perception, their very structures, are historically variant; they change historically in accordance with changes in our social or cultural practices.

Following this line of reasoning, several reinterpretations of human perception are necessary. For example, *seeing* will be understood not primarily as a physiological act, but as a social and cultural *activity*. Furthermore, Wartofsky argues that »the specific feature of perception as a mode of action is that it is mediated by representation« (1979, p. 189). This notion of mediation is compatible with the one developed in the Vygotskian tradition (Vygotsky, 1978, 1986; Wertsch, 1998). As an interesting contribution, and maybe even extension of this tradition, however, we may view Wartofsky's insistence on the idea that »it is by the variation in *modes of representation* that perception itself comes to be related to historical changes in other forms of human practice, and in particular, to social and technological practice« (1979, p. 189, emphasis added).

To clarify Wartofsky's notion of a historical epistemology, such a position can be contrasted with Piaget's genetic epistemology and his theory of developmental stages. An illustrative example, connected to the previous discussion of representations, comes from Piaget and Inhelder (1969) in their analyses of how children construct representations of the world through drawings of their own. Through the works of Luquet[1], Piaget and Inhelder claim that »until about eight or nine a child's drawing is essentially realistic in intention, though the subject begins by drawing what he *knows* about a person or an object long before he can draw what he actually *sees*« (1969, p. 64, emphasis in original). This stage is referred to as »intellectual realism«, where the drawing depicts the conceptual attributes of the model without concern for the visual perspective of the observer. An illustration of this intellectual realism is that in the drawing of a child, »a face seen in profile will have a second eye because a man has two eyes« (p. 64). At about eight or nine years of age, »intellectual realism« is allegedly succeeded by »visual realism,« and »the drawing now represents only what is visible from one particular perspective. A profile now has only one eye, etc., as would be seen from the side, and the concealed parts of objects are no longer visibly represented« (p. 65).

It is exactly this kind of theory of visual perception that is called into question by Wartofsky in his argumentation for a historical epistemology. According to him, such argumentation builds on an anomalous, seventeenth-century mechanist model of perception that we know as geometrical optics.

> What I take to be anomalous here are precisely the mechanist feature of the model which confuses a particular theory of geometrical optics – i.e. a theory of the transmission, reflection and refraction of light, especially through lenses, – with a theory of vision, and in particular, with a theory of visual *perception*. (Wartofsky, 1979, p. 192)

This difference between a scientific theory of optics and vision as part of human practices is important in a sociocultural perspective. Wartofsky further argues that both the theory of geometrical optics and the theory of perspective drawing are recent historical developments, which have now become an integral part of our visual understanding, or of our visual *common sense*. The visual realism that Piaget and Inhelder refer to is not a universal realism that the child simply acquires, it is a sociohistorically derived model of representation according to which we view objects. However, by carrying on unaware of the relations between developments in science and changes in common sense, and »thereby taking today's common sense to be the universal and unchanging common sense of the species, such philosophy of perception«, according to Wartofsky, »remains blissfully ignorant of its own historical limits, and the historical datedness of its models« (1979, p. 192).

There is no reason to doubt the empirical observations reported by Piaget and Inhelder (1969), but their theory of *stages* fails to acknowledge any historical or cultural dimensions and transformations that impact on how we perceive the world. It is precisely because of this ignorance, to paraphrase Wartofsky, that they can report how these stages »attest to a remarkable convergence with the evolution of the spontaneous geometry of the child« (1969, p. 66). The solution to this problem – following Wartofsky, and, we would claim, Vygotsky – is to refer the change from *intellectual realism* to *visual realism* to a socioculturally *learned* mode of representation that came with the introduction of perspective drawing.

According to Wartofsky, the manners in which representations are arranged, the so-called *modes of representation*, mediate our perceptions. Thus, in such a conception seeing is understood as guided by our culturally adopted modes of representation that have emerged over time in the context of various human practices. However, not all modes become canonical (i.e. culturally accepted and dominant). The establishment of what Wartofsky calls *canons of representation* must be understood as a historical act, which involves the adoption and acceptance of certain interpretative rules for what counts as a relevant and accurate representation in the context of a particular medium. A visual representation becomes a »conventionally adopted specification, which looks ›right‹, or is a ›proper‹ representation, by virtue of our acceptance of a certain ›vocabulary of forms‹« (1979, p. 181). Thus, the theory of perspective drawing cannot be seen as an unequivocal premise for a true visual realism that objectively represents the world. Rather, this theory suggests, and endorses, a particular *vocabulary*, and one that has been made canonical in most parts of the western world. Yet, and this is important, for the individual its rules and conventions have to be learned through a process of cognitive socialisation.

For the individual, familiarity with relevant canons of visual representation is necessary in order to perform certain actions and to see certain things. Knowledge is intrinsic to the way we represent things, and this conceptualization makes Wartofsky's theorizing highly relevant for the study of learning in educational settings (and elsewhere). His argument calls for an awareness of the existence of different canons of representation in various practices, and the possible conflicts between them. This position seems even more important to consider in present-day society with an increasing exposure to new media and the new modes of representation that are introduced, for instance, through the use of computers in instructional settings. For, as suggested by Healy and Hoyles (1999) and many others, something interesting has happened to visual representations as they have become integrated with digital technology.

> Images now can be externalized through computer constructions, rendering more explicit previously hidden properties and structures. A visual image can be made open to inspection, an object of reflec-

> tion, which can serve as a building block in an argument – something more concrete rather than transitory and fleeting. Once constructed on the computer, images are manipulable: They can be debugged, reconstructed, transformed, separated or combined together, following sets of procedures with something like the reproducibility and rigour previously limited to symbolic representation. (Healy & Hoyles, 1999, p. 59)

The authors further argue that given these developments, the role of visual representations in schools must be explored in order to reach a better understanding of the potentials of the new media and technologies for teaching and learning. It should also be pointed out that we need to know more about how children relate such pictorial and graphic displays and how they manage to incorporate these into their argumentation when »talking science« (Lemke, 1990). This is the issue we will explore.

RESEARCH DESIGN

The present work should be seen as exploratory. It connects to the earlier research mentioned above about children's understanding of gravity and the shape of the earth through the interest in studying the tool-dependent nature of human cognition and communication. Our ambition is to compare some features of children's reasoning in the context of multimodal digital representations with their reasoning when supported by other forms of representations. What is in focus in this line of research is the interest in children's familiarity with the canons of representations which such multimodal and dynamic digital resources embody.

PARTICIPANTS AND ANALYSIS

Interviews were held in a Swedish school during regular school days. Participation was voluntary and, in all, 19 children took part. However, in the present analysis excerpts from four children will be included, and we will use these as exemplars illustrating variations in children's reasoning. These children were aged 6 (preschool) to 11 (fifth grade). The interviews were carried out in the same manner as in the case of the studies by Schoultz, Säljö and Wyndhamn (2001) and Ivarsson, Schoultz and Säljö (2002). The purpose was not to find out what the children knew in any general sense. Rather, the idea was to explore the interrelationship between their reason-

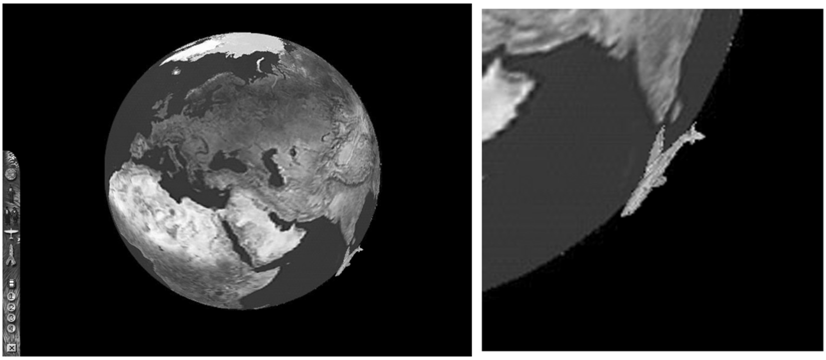

Figure 1. The constructed program with the discussed aeroplane

ing and the use of some multimodal representations. The interview sessions started with a brief, introductory discussion during which a digital, three-dimensional atlas was used. The children were asked about the meaning of the different colours, and whether they recognized any countries. As about half of the children were immigrants, mostly from the Middle East, these discussions often involved the location of a specific country, and how one would travel to get there. Other children talked about holiday travels or relatives living on a different continent. After these initial discussions, the interviewer changed to a program specifically designed for this study. The sessions lasted between 10 and 20 minutes and were audio recorded. All recordings were later transcribed in full.

THE GRAPHICAL REPRESENTATION

As a basis for the main part of the interviews, a specially designed program had been constructed using Macromedia Director. The program mainly consisted of a large picture of the earth, which was a composite of many satellite images without clouds. There was no geopolitical information (see Figure 1). This image was a two-dimensional version of the atlas initially used in the interviews. On the left side of the screen, there was also a panel containing various icons. With the help of these icons, different objects could be placed on the earth: a boy, a girl, an aeroplane, and a rocket ship. These two-dimensional figures could be moved with the mouse, and they had been assigned different behaviours with reference to how they should orient. The issue that will be scrutinized in this study concerns the children's reasoning in the context of the movements of the object representing an aeroplane. This object had been selected because it was believed that it would prove a more challenging topic when discussing gravity and the shape of the earth than that of people living on different parts of the earth. The plane was always oriented with its underside towards the center of the screen, thus representing gravity. In the interviews, the interviewer controlled the computer program. The plane was first located in the northern hemisphere and later moved towards the Far East and India. The figure was kept close to the edge of the earth, and the children were asked if it would be possible to travel in the manner suggested by the representation (see enlargement in Figure 1).

RESULTS

The general impression from the analysis of the interviews is the increasing difficulties the children had when reasoning about gravity and the shape of the earth in this context in comparison to what was found in the two earlier studies using a globe and a map, respectively. For instance, when the interviews were based on such familiar artifacts, no single child accepted the claim that it would be possible to fall off the earth. Instead, these artifacts seemed to function as cognitive prostheses, making even young children able to participate in complicated discussions about gravity, as we have already mentioned. In this study, however, the representational technology did not function in this transparent manner for the children. Even though this program could be described as more powerful than a traditional, static artifact such as the globe and the map in the sense that it incorporates and visualises information dynamically, several children had trouble coordinating what they saw with what they already knew. To illustrate this point, the analysis will focus on one particular issue: how the orientation of the plane on the screen should be understood.

In the following sections, it will be shown how the children picked out certain visual characteristics as significant for their reasoning. More specifically, we will illustrate how the term »upside-down« was used to signal something problematic with this particular representation. Four excerpts have been selected in order to illustrate three different ways of reasoning. This grouping is an analytical construction based on the manners in which the graphical representation was incorporated into the argumentation. Our point is to illustrate the kinds of difficulties children had in identifying the modes of representation that are relevant for this particular artifact.

In the first excerpt[2], Eric, who is about six years of age, reasons about aeroplanes and whether they can travel upside-down or not.

Excerpt 1. Eric preschool

111	I:	Does it look like this if we fly here ((moves the plane clockwise, starting from the northern hemisphere)) do you think?
112	Eric:	(1.1) No:
113	I:	Round like this-
114	Eric:	Then- then you are- then you see the sky, you don't see the sky when you are up in space=
115	I:	=Oh no so you have to travel about here perhaps((moves the plane closer to the edge))
116	Eric:	M:
117	I:	Ye:s (1.2) at the edge like that
118	Eric:	M:
119	I:	Y:es (4.1) but what about here, then? Could one go like this? ((seemingly flying upside-down, see Figure 1))
120	Eric:	N:o 'cos then- 'cos then the plane falls down on the ground=
121	I:	=>Do you think it falls down here< down into the water or? ((moves the plane in a northerly direction, towards the Indian ocean))
122	Eric:	(0.6) No
123	I:	Or where would it go then?=
124	Eric:	=Well if it would have flown in wate:↑r
125	I:	Yes
126	Eric:	And it would've been upside-do:wn it would've fallen straight down
127	I:	Aha (0.4) down here ((moves the plane to the bottom of the screen))
128	Eric:	M:

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129 I:      What's down there then?
130 Eric:   (1.5) Grou:nd!
131 I:      Is there ground there?
132 Eric:   M:
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In this interview, as in some others, the fact that the sky is not represented in the computer program constitutes a problem. Eric knows that planes travel in the sky and not in space. He makes a remark about this, and in lines 115 to 118, the sky is negotiated. Having established this common point of departure, the interviewer then restates his question somewhat more specifically: »what about here then? Could one go like this?« Eric's response is a prompt »noo« with an added justification that the »plane falls down on the ground«. This pattern, consisting of a short answer to the question plus a justifying account, is very common in the interviews. It is interesting to note that even at his young age, Eric knows that one can be held accountable for one's claims, and that one therefore has to supply a contextually relevant explanation to the claim made. On a more general level, this illustrates that Eric is familiar with one of the most elementary elements of scientific reasoning. Eric's argument that »the plane falls on the ground« is open to interpretation, and the interviewer tries to clarify through a suggestion that the plane would fall »down in the water«. Simultaneously, the interviewer (in 121) moves the figure of the plane *up* on the screen and towards the Indian Ocean. This act can be seen as a form of guidance or offer to render Eric's answer a scientifically acceptable one. Eric does not acknowledge this alternative interpretation and tries to clarify his position by saying that if the plane were *upside-down,* then it would fall »straight down«. Here again he introduces an argumentative resource by using the *if-then* structure. After that, the interviewer asks »what's down there, then?« and Eric's response (line 130) implies that it would fall to the »ground«.

In this brief exchange, Eric makes two important qualifications in the context of this particular representation. He first introduces the missing *sky*, and later he adds *ground* to the scene. Taken together with the plane, these three symbols constitute one of the most common ways of portraying an aeroplane: as flying in the sky high above the ground. In this sense, one could say that Eric is trying to reconcile what he sees with what he knows about how to represent flying aeroplanes. Or, alternatively, his argumentation can be interpreted as an attempt to re-create the *canon of representation*

(Wartofsky, 1979) that he is familiar with. This manner of representing, however, is challenged by the images presented by the computer program. Eric accounts for what he sees on the screen as a plane flying »upside down«. Thus, the rotation of the represented plane is not taken as something that is relative to the surface of the depicted globe (which would be the expected interpretation if one considers gravity); it is taken as a plane flying upside down.

In the second excerpt, Isaac confirms the interviewer's suggestion that it is possible to fly around the globe. Nevertheless, he objects to the way this is represented by the computer program.

Excerpt 2. Isaac 5th grade

73	I:	Can one fly around the whole earth
74	Isaac:	Yes=
75	I:	Would it be possible to fly like this ((moves the plane clockwise, starting from the northern hemisphere and ending up like Figure 1))
76	Isaac:	M: (0.5) but you don't fly upside-down but you can fly around the earth
77	I:	Yes (2.4) but if- if it is like this (0.4) does it fly upside-down then=
78	Isaac:	=>No:<
79	I:	(1.6) But the way it is in the picture then?
80	Isaac:	(1.4) There it flies upside-down but I don't think that it would do that for real
81	I:	No (8.5) if we go like this ((following the curvature of the globe))
81	Isaac:	M:
83	I:	Does it start to tu↑rn then do you think
84	Isaac:	(2.1) °No I don't think so°
85	I:	(1.4) Isn't it possible that the plane fo↑llows the earth
86	Isaac:	(2.2) >I don't know< I've never travelled in a plane myself so
87	I:	No:↓ no then it's a bit hard to know (3.1) but do you think that it could fall off here?
88	Isaac:	No I don't think so

In this discussion, the notion of the plane being upside-down is again introduced by the child. Isaac is clear about the fact that planes can travel all over the earth, but what he sees on the screen with the plane appearing upside down puzzles him (line 76). This excerpt illustrates a conflict between what is known and what is seen, a condition that Isaac is able to express very eloquently himself by saying: »there [in the picture] it flies upside-down but I don't think that it would do that for real« (line 80). Although Isaac is struggling with how to interpret the picture, the interviewer never really invites him to talk about the premises for the representation in this case. Instead, the interviewer keeps the representation of the plane as the topical focus, and from within such a frame of reference it is hard to resolve the conflict.

A very similar kind of argumentation is found in the discussion with Helen below. The main difference, in comparison with the previous excerpt, is that Helen manages to explicitly express some of the logic of the representation.

Excerpt 3. Helen 2nd grade

103	I:	If one travels in a plane like this (0.6) around the earth (2.6) would it be possible to fly <u>here</u> then? ((see Figure 1))
104	Helen:	(3.1) You can't fly upside-down
105	I:	(1.0) No: can you go upside-down or does it go upside-down when it's going like this?
106	Helen:	(1.5) No:
107	I:	(1.0) So it doesn't?
108	Helen:	(1.0) I don't think so
109	I:	No: (0.9) why does it look like this then?
110	Helen:	(1.4) Only because (0.8) <u>it's</u> <u>rou:nd</u>
111	I:	Yes that's right (0.7) so it only looks this way perhaps=
112	Helen:	=Yes
113	I:	(0.5) Yes
114	Helen:	But perhaps it really flies straight=
115	I:	=It actually travels straight yes that's right (2.1) so then it couldn't <u>fall</u> <u>off</u> like this ((moves the plane away from the earth))
116	Helen:	No

Like Eric and Isaac, Helen spontaneously introduces the term upside-down and signals her reactions to the image by saying »you can't fly upside-down«. As is the case with Isaac in Excerpt 2, she obviously has problems connecting what she knows with what she sees on the screen. When the interviewer picks up on her remark, she argues against the claim that the plane really is upside-down and says that she thinks that it is not. Next, the interviewer shifts the focus from the represented to the representation itself by explicitly referring to appearance: »why does it look like this, then?« This change of topical focus from the represented to the representation seems to be enough for Helen to come up with the answer that the appearance is due to the curvature of the earth: »only because it is round«. She then further resolves the conflict by stating that, »perhaps it really flies straight«.

A third kind of argumentation can be found in the fourth, and final, excerpt. Here, the representation enters the discussion somewhat differently in comparison with the other examples, in the sense that it does not appear as problematic to the child. This time, the term »upside-down« is introduced by the interviewer, as an attempt to challenge the reasoning of the child.

Excerpt 4. Oscar 4th grade

40	I:	Can one travel with aeroplanes all over (0.2) the earth?
41	Oscar:	>Yes<
42	I:	(1.9) Would it be possible to go like this then? ((moves the plane clockwise, starting from the northern hemisphere))
43	Oscar:	Ye:s
44	I:	(2.7) How about here (0.7) what happens then? (0.8) ((as in Figure 1)) would it be like this?=
45	Oscar:	=He's flying over the water
46	I:	Flying over the water (1.7) are you supposed to fly like this (0.4) when you are in (1.0) southern Africa?
47	Oscar:	(2.5) Yes
48	I:	(2.5) One isn't upside-down there then?
49	Oscar:	(1.2) Upside-down? (1.2) No: I can't see that

50	I:	(3.5) You only fly like this (4.5) ((completes a full circle and starts on a second lap)) but if I come here (0.2) again ((as in Figure 1)) (1.2) you wouldn't fall here then?
51	Oscar:	(0.2) No
52	I:	(1.7) Why wouldn't you do that
53	Oscar:	Because eh: (1.6) we:ll as I said before, that they think that the earth is flat so you can't- "we will fall down"- they thought a long time ago

Compared to the earlier excerpts, Oscar has very few objections to the images presented to him. Even though the underlying rationale for the questions is the supposed problems with gravity, Oscar does not seem to share these premises. He still tries to make the questions as meaningful as he can. In line 44, he gets the rather vague question »how about here, what happens then?« This is very close to a leading question, since it suggests that something *should* happen when the plane is in that particular position. Oscar responds by saying that the plane is »flying over water« (line 45), and through this he denies that there is anything remarkable in the picture. He responds to the next question (line 46) with a hesitant »yes«. Realizing that Oscar handles the representation seemingly without problems, the interviewer then changes tactics in his questioning. His next question – »one isn't upside-down there, then?« – is much more straightforward and focuses on the represented phenomenon as he uses the indefinite pronoun *one* together with the adverb *there*. Oscar opposes the implied proposition, and the particular manner in which he does this is very interesting. At first, he seems baffled, as he repeats the word »upside-down« with a questioning intonation, but then he adds, »no I can't see that«. His wording, in our opinion, is quite revealing: »upside-down? No, I can't see that«. *His* problem with this question seems to be that he cannot understand why it is asked in this particular manner. Since the interview implies an asymmetrical power relation, set within the school context, Oscar is obligated to take the questions as relevant and not arbitrary. By introducing his own perspective in the answer, he simultaneously denies that that the plane would be upside-down and implies that there may be other interpretations as well (e.g., the perspective implicated by the interviewer, and which he cannot identify).

An important element of the utterance in line 49 is the use of the word *see*. In Swedish, the word (»se«) does not share the same close connotations of *knowing* or *understanding* as does the English term and in this situation, it should be interpreted in the literal, i.e. visual, sense of the word. In the two earlier excerpts, the children's previous knowledge came into conflict with their reading of the visual representation. They obviously saw something – a plane seemingly upside-down – which they initially found somewhat confusing. In contrast, Oscar says he »can't see« how the plane could be upside-down. It is tempting to explain this difference by saying that Oscar has a better *theoretical* grasp of phenomena that relate to gravity. However, such an explanation risks being circular and begs the question of exactly why Oscar does not see the plane as being upside-down. In the following section, our discussion will focus specifically on these differences in reasoning and their relationship to culturally adopted modes of representation.

DISCUSSION

If a representation, as suggested by Wartofsky, is seen as a form of specification, then a certain set of adopted rules may be regarded as intrinsic to any representation – but only as long as we remember that »representing is something that we *do*, and that nothing *is* a representation excerpt insofar as we construct or construe it as one« (Wartofsky, 1979, p. xxi). Thus, it is important to keep in mind that any representation may refer to several practices, and the relevant interpretations of a representation between these may differ. This line of reasoning becomes clearer if illustrated by the case of the earth and its various representations.

When the earth is talked about as an astronomical body, which is one of the many ways we can discuss our planet, a number of details will be made relevant: the spherical shape, certain rules of gravity, and the somewhat strange fact that this massive body seems to »float freely« in space. If the particular representation of a *globe* is used in such an astronomical discussion, the spherical shape is physically present and does not have to be added. The concept of gravity, however, is not directly represented by the globe, and to explain various observations (such as that aeroplanes will not fall off the globe), the concept will have to be invoked or, at least, recognized by the speakers as a relevant premise. If, instead, the very same globe is used in a history class, while discussing the journeys of Columbus or the first attempts to sail around the globe, gravity will most likely not be an issue at all. In this case, the spherical shape of the earth, the location of different continents, and the navigational problems of finding passages, will probably appear as the relevant features to focus on. Thus, the globe affords a range of different perspectives and discursive practices that focus on different features.

When representations are embodied in a digital medium, the possibilities of incorporating conceptual distinctions increase significantly. Things that cannot be represented on a flat sheet of paper or through a mechanical construction can come alive in several modalities simultaneously, for instance through visual, aural, tactile, and proprioceptive[3] displays, or any combination of these (Biocca & Delaney, 1995). The representation used in this study differed from a globe in several respects. It was a two-dimensional image presented on a flat screen, but it was also interactively fixed (since it was a projection from a single viewpoint). On the other hand, it did model events on the basis of the concept of gravity through the dynamic orientation of movable objects. This whole configuration embodies a *mode of representation* that turned out to be quite challenging for some of the children, who had to struggle with what they saw. Above, we have shown three analytically distinctive forms of reasoning that are illustrated in the four excerpts. We argue that these differences in reasoning are related to differences in perception of the graphical representation. Let us recapitulate some of the observations and add some theoretical interpretations.

In the first case, Eric brought in what he saw as the missing elements of the image, i.e. »sky« and »ground«, in order to arrive at a picture of a plane over which he had some conceptual control. Through his reasoning, he actively construed a mode of representation that was not physically present, a mode illustrated by Figure 2[4] (which is a drawing by a child taken from a different context). If one considers the manner in which Eric considers these added elements necessary for illustrating how aeroplanes fly, the isolated aeroplane presented on the screen (see Figure 1) could be understood as upside-down. One important thing to realize in this context is that Eric was working very hard to make the discussion intelligible, in part by adding thematically relevant elements that had not been mentioned by the interviewer. Fur-

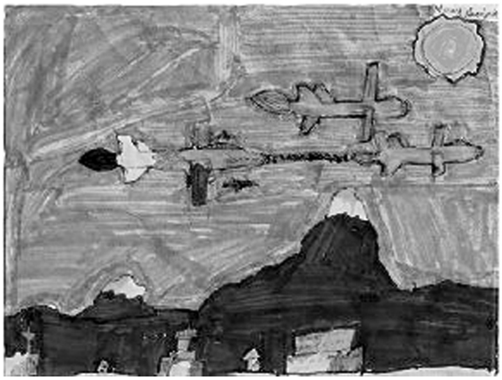

Figure 2. Child's drawing of planes

thermore, it should be noted that it was not only the interviewer who contributed with modes of reasoning that were theoretical in character. Eric's seeing was also theoretically informed, although by an alternative mode of representation. He displayed skills in reasoning, indicative of familiarity with a particular kind of scientific argumentation, through the use of an if-then structure, and by realizing that he would be held accountable for his claims. What Eric did not seem able to do – at least not in this discussion – was to go beyond his adopted frame of reference and realize some critical features of how this particular representation was designed. Unlike the interviewer, he was not simultaneously managing different canons of representation; however, this will not be discussed further here.

Turning to the talk with Isaac and Helen (excerpts 2 and 3), these discussions differed from Eric's line of reasoning mainly because they focused on a conflict between what they *saw* and what they *knew*. To Piaget, these excerpts would represent an intermediary, or perhaps unaccounted for stage, between intellectual realism and visual realism. But by following the argumentation of Wartofsky, it seems reasonable to assume that Isaac and Helen struggled with two alternative, and radically different, canons of representation at the same time. Both children noted and commented with some surprise upon the fact that the plane appeared »upside-down«. By further considering and discussing how aeroplanes fly, they were able to bracket their initial, visual interpretation of an aeroplane apparently flying upside-down, and reinterpret this appearance in line with a mode of representation premised on gravity. To take the next step of explicitly formulating this, however, both children seemed to need some mild communicative support and, as it turned out, only the discussion with Helen resulted in an explicit verbal resolution of the conflict between what was seen and what was known. Helen's coming to this conclusion must be construed as an interactive achievement, and it illustrates how reasoning with the support of others may take us further in our understanding of a given representation.

The practice of representing objects as following the spherical earth is a relatively recent one. It is also less frequent than the canon of linear perspectivity discussed earlier. Nevertheless, Oscar (Excerpt 4), representing the third way of reasoning, displayed a familiarity with this new representation, the same mode of representation that Eric never really dealt with, and that Isaac and Helen had only started to apprehend. Compared with the three other children, Oscar had the inverse problem when talking about the orientation of the plane. To him, »upside-down« did not seem a fitting description of what the image portrayed. On the contrary, he seemed so attuned to the mode of representation where gravity is visualized in a particular manner that he did not »see« how the plane could be described as upside-down. Most likely, even Oscar could be instructed to see the plane as upside-down, but he did not seem to consider this relevant in a discussion premised on the notion of gravity and the movement of objects around the earth.

On a general level, the development of reasoning and human knowing, schematically visible in the four excerpts, can be understood as related to the constant adjustment of human perception to evolving technologies. When human knowledge is transformed and given a material shape through externalizations in the shape of various symbolic representations, such resources will serve as active elements in the cognitive socialization of future generations of learners. Through this duality inherent to material objects embodying specific conceptual structurings, the insights and perspectives that have emerged through sociocultural evolution will live on in society. Thus, objects are not simply out there in the world. Rather, they are instructive and actively contribute to sustaining specific manners of reasoning and perceiving. In some cases, they will even be naturalized and assumed to perfectly match what they represent in a mirror-like fashion.

But the important point to keep in mind is that our modes of knowing are continuously transformed as technologies contribute to the reconfiguration of our practices.

CONCLUSION

The overall aim of this study has been to explore some of the relations between representational technologies, perception, cognition, and human action. The evolution of digital technology has opened up new possibilities for visual expression, and when these representations enter the classroom, pupils will face the problem of coming to grips with the conceptual premises of these representational tools. The question is how children disambiguate and manage to make productive use of such tools for understanding in the learning environment.

The point of our study is to contribute to a better understanding of the potentials of the new technology for teaching and learning. To address this issue, an unfamiliar and dynamic representation was introduced to a group of young pupils. The analysis focused on the scientific reasoning that took place in the context of such an artifact, and what discursive strategies and resources the children used in their argumentations. By grounding our analysis in the theoretical position suggested by Wartofsky (1979), we have attempted to illustrate how the pupils, in order to grasp the graphical environment, made use of distinctions and perspectives that are indicative of specific *canons of representation*. The results suggest that perception and understanding are closely interlinked with these cultural modes of action. And, furthermore, that it is through the successive adoption of these modes, that cognitive development itself becomes related to social and technological change.

NOTES

1. G.H. Luquet (1927) *Le dessin enfantin.* Paris: Alcan. Cited in Piaget and Inhelder (1969).
2. The transcriptions are made in accordance with Sacks, Schegloff and Jefferson (1974)
3. The human proprioceptive system registers the motion and position of both individual limbs and the body as a whole. The most easily recognised proprioceptive display would probably be the rollercoaster or other forms of theme park attractions.
4. Note that this illustration is taken from a different context. The drawing was done by Daniel Meyers, grade 6, and can be found at http://quest.arc.nasa.gov/aero/events/regimes/contest/Daniel-Mun-SS.jpeg

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Appendix

TRANSCRIPTS & TRANSLATIONS

TRANSCRIPT LEGEND

. A period indicates a stopping fall in tone, not necessarily the end of a sentence.

, A coma indicates a continuing intonation, not necessarily between clauses of sentences.

? A question mark indicates a rising inflection, not necessarily a question.

! An exclamation point indicates an animated tone, not necessarily an exclamation.

: A colon following a vowel indicates elonged vowel sound: `ye:s and then it's going up he::re`

- A single dash indicates a halting, abrupt cutoff: `Then- then you are-`

↑↓ Upward and downward pointing arrows indicate rising and falling shifts in intonation: `Does it start to tu↑rn then`

Underlining marks emphasis: `about` <u>`here`</u>

⋆⋆ Asterisks are used indicate a passage of talk which is pronounced with laughter: `*where does it fail*`

°° A degree sign is used to indicate a passage of talk which is quieter than the surrounding talk: `°I am pulling upwards°`

> < When part of an utterance is delivered at a pace quicker than the surrounding talk, it is indicated by being enclosed between "less than" signs: `>Do you think it falls down here<`

( ) A single parenthesis is used to mark pauses, in seconds and tenths of seconds: `(1.3)`

(( )) Double parentheses are used to add information about the conversational scene: `((points at the beginning of the graph))`

= When there is no interval between adjacent utterances, the second being latched immediately to the first (without overlapping it), the utterances are linked together with equal signs:

```
Jonas: then it will come to the same place=
Isaac: =where it stopped
```

[left-hand brackets indicate the start of overlapping speech:

```
Jonas:     what do you think will happen then?
Michael:    [well it will run-
Isaac:      [it will run once more
```

EXCERPTS FROM STUDY I

As noted in study I, the analysis was based on the transcripts. These are the original Swedish transcripts that were used for this analysis.

Excerpt 1. David 2nd grade

1	I	Vet du vad det här är?	Do you know what this is?
2	David	En bok	A book
3	I	Och vad ska det här föreställa?	And what is this supposed to be?
4	David	En jordglob	A globe
5	I	En jordglob, känner du igen några länder?	A globe, do you recognize any countries?

Excerpt 2. Anton 1st grade

25	I	Men nu Anton ska jag ställa lite frågor till dig. Då vet du förstås vad det här är?	But now Anton I'm going to ask you some questions. Then, of course, you know what this is?
26	Anton	En karta	A map
27	I	Vad föreställer den?	What does it represent?
28	Anton	Hela jorden	The whole earth
29	I	Hela jorden. Känner igen några platser eller länder eller någonting som du ... Det går ju att läsa om man vill	The whole earth. Do you recognize any places or countries or something you ... you can read if you want to

Excerpt 3. Anna 2nd grade

1	I	Vad är det här?	What is this?
2	Anna	Det är jorden	It's the earth

3	I	Varför är den ritad så här? [Pekar på hörnen]	Why is it drawn like this? [Points at the corners of the map]
4	Anna	Den är rund	It's round

Excerpt 4. Paul 2nd grade

3	I	Vet du vad det här är?	Do you know what this is?
4	Paul	Nähä	Nope
5	I	Det här?	This?
6	Paul	Jordklot ... nähä	A globe ... noo
7	I	Är det det?	Is it that?
8	Paul	Jaha	Yes
9	I	Om vi nu säger att det här är ett jordklot, varför är det ritat så här runt?	If we assume that this is a globe, why is it drawn round like this?
10	Paul	Jordklotet är runt	The globe is round

Excerpt 5. Carl 3rd grade

5	I	Det är svårt att veta. Du jag har en fråga till dig. Vad är det här för något?	It's difficult to know. Well I have a question for you. What is this?
6	Carl	Jorden	The earth
7	I	Ser jorden ut så här?	Does the earth look like this?
8	Carl	Ja, kanske	Yes, perhaps
9	I	Kanske, det gör den. Hur ser jorden ut egentligen?	Perhaps, it does. What does the earth look like in reality?
10	Carl	Rund	Round
11	I	Rund som en boll	Round like a ball
12	Carl	Mn	Mm
13	I	Men om man ska göra den som en karta så måste man göra den så här va	But if you're going to make it like a map you have to do it like this right

14	Carl	Mn	Mm
15	I	Och då måste man göra lite böjar så här. Varför ser den tillplattad ut? Varför ritar man den som ett ägg tror du?	And then you have to make some bends like this. Why does it look flattened? Why does one draw it like an egg do you think?
16	Carl	Man kan ju se på hela runt	You can look at the whole around
17	I	Nähä, just det man kan inte se baksidan annars. Men tänka sig att man tar klotet och klipper upp det	No, that's right you can't see the backside otherwise. You can imagine taking the ball and cutting it open

Excerpt 6. Tim 3rd grade

3	I	Jag skulle vilja fråga dig om det här. Vad är det här för något?	I would like to ask you about this. What is this?
4	Tim	En karta, jordklotet	A map, the globe
5	I	Varför ser det ut så här? [elliptisk]	Why does it look like this? [Elliptical]
6	Tim	Där för att den är rund	Because it's round
7	I	Ser jorden ut så här?	Does the earth look like this?
8	Tim	Jaha	Yees
9	I	Det gör den	So it does
10	Tim	Fast den är rundare	But it's more round
11	I	Och sen då?	And then?
12	Tim	Den är jämnare, inte så här lång	It's more even, not long like this
13	I	Nähä, varför tror du att man ritar den så här och inte ritar den rundare? Varför går inte det?	No, why do you think you draw it like that and not rounder? Why can't you do that?

14	Tim	För att man kan inte rita baksidan	Because you can’t draw the backside

Excerpt 7. Eric 2nd grade

43	I	Kan det bo folk här nere då?	Can people live down here, then?
44	Eric	Nähä	Nope
45	I	Varför det?	Why not?
46	Eric	För det är längst ner	Because it’s so far down
47	I	Varför går inte det då?	Why isn’t that possible, then?
48	Eric	Mn man kanske får öroninflammtion	Mm perhaps you get an inflammation of the ear
49	I	Varför skulle dom få öroninflammation här nere då?	Why would they get an inflammation of the ear down here, then?
50	Eric	Det kanske är kallt	Perhaps it’s cold

Excerpt 8. Jakob 3rd grade

37	I	Mn, kan det bo folk överallt på jorden? Vad tror du?	Mm, can people live all over the earth? What do you think?
38	Jakob	Nähä	Nope
39	I	Var kan det inte bo folk?	Where can people not live?
40	Jakob	Där det är kallt	Where it’s cold
41	I	Någon annanstans?	Anywhere else?
42	Jakob	Där det är varmt	Where it’s hot

Excerpt 9. John 1st grade

124	I	Javisst man kan bo i Sydafrika, man kan bo i Sydamerika. Ramlar man inte av jorden då här nere?	Of course one can live in South Africa, one can live in South America. Don’t you fall off the earth down here then?
125	John	Nej	No
126	I	Det gör man inte	You don’t
127	John	Om man kommer så här utanför så ramlar man inte av om man går utanför jordklotet	If you come like this outside you don’t fall off if you walk outside the earth
128	I	Men om man går långt här nere i söder då. Du tycker inte det är konstigt att man kan bo här nere? Tänk om dom bara halkar och ramlar bort från jorden	But if you walk far down here in the south, then? Don’t you think it’s strange that you can live down here? What if they just slip and fall off the earth?
129	John	Nej, det gör dom ju inte.	No, they won’t do that
130	I	Varför gör dom inte det då?	Why won’t they do that then?
132	John	Dom tycker att dom går på sitt sätt. Dom är vanare att gå så eller så.	They think they’re walking in their way. They’re more used to walking like that or something
132	I	Jaha	Oh, I see
133	John	Men egentligen så går man ... känns det som man går rakt och då går man runt jordklotet om man åker för långt	But actually you walk ... it feels as if you walk straight ahead and then you walk around the earth if you go too far

134	I	Så man kan inte ramla av jordklotet?	So you can't fall off the earth?
135	John	Nej det är nästan hur stort som helst	No, it's almost as big as anything

EXCERPTS FROM STUDY II

Excerpts 1 to 7 as one continous sequence

JONAS	om man skulle lägga in den här (0.1) programmet ((pekar på prog A)) (0.7) längst sist där	if one were to put this (0.1) program ((points at prog A)) (0.1) at the end there
	(0.5)	(0.5)
isaac	här	here
	(0.6)	(0.6)
michael	där	there
	(1.2)	(1.2)
JONAS	°där ja°	°there that's right°
	(1.8)	(1.8)
PATRIK	[((ohörbart))	[((inaudible))
JONAS	[va tror ni kommer å hända då?	[what do you think will happen then?
	(0.7)	(0.7)
michael	[den kör väl-	[well it will run-
isaac	[kör den en gång till=	[it will run once more=
JONAS	=då kör den en gång till ja	=then it will run once more yes
	(0.5)	(0.5)
PATRIK	[va händer s-	[what happens th-
JONAS	[men-	[but-
PATRIK	kommer den å [stann-	will it ever [stop-
JONNAS	[då kommer den å komma till samma ställe=	[but then it will come to the same place=
isaac	=där den sluta	=where it stopped
	(1.2)	(1.2)

michael	[kommer den gå runt	[going to go round
helen	[kommer den gå så hela jävla tiden ju	[going to go like that the whole bloody time, then
	(0.5)	(0.5)
JONAS	just de	that's right
	(0.7)	(0.7)
michael	va häftigt	cool
	(1.5)	(1.5)
isaac	fall man tar en sån då?	if you take one of those then? ((places the cursor on the icon with an open switch))
	(0.6)	(0.6)
helen	nej men [°skärp dej°	no [°get real°
JONAS	[mm kan man göra de?	[mm would that be possible?
isaac	nej kan man in-	no you can no-
helen	nej	no
michael	[jo: där efter	[ye:s after there
helen	[nä men vi k- ne:je	[no but we c- no:
PATRIK	kommer den nånsin å- kommer den nånsin å komma till steget efter där?	will it ever c- will it ever come to the step after that one?
isaac	m:	m:
michael	ja:	ye:s
isaac	ne:j	no:
michael	ne:j	no:
helen	varför skulle den inte göra de?	why would it not do that?
	(1.0)	(1.0)
PATRIK	för att om du tänker dig när- om den går igenom hela programmet=	'cause if you think when it- if it goes through the whole program=
helen	=ja	=yes
PATRIK	å sen så: säger den att den ska köra programmet igen liksom då går den in i programmet igen=	then it will tell it to run the program again kind of and then it will enter the program again=

michael	=då sätter vi ett [stopp högst upp	=then we'll put a [stop at the top
helen	[m *jaha*	[m: *y:es*
PATRIK	då kommer den aldrig till	then it will never reach the
	[steget efter där	[step after that one
michael	[eller *det går inte*	[or *it can't be done*
helen	[*a:ha*	[*a:ha*
michael	[jo i början	[oh yes at the beginning
	(1.0)	(1.0)
michael	ett stopp allra högst upp i början	a stop at the very beginning
isaac	jaha?	well?
JONAS	va kommer å hända då?	what will happen then?
helen	a men då stannar ju programmet	but then the program will stop
	[du får ju tänka	[you have to think
michael	[a men men-	[but-
	(0.2)	(0.2)
michael	sen han säger ju till efter där att den den ska starta. (2.0) om man sätter den före a:t. (1.8) så:↑	he's telling it after there to start. (2.0) if you put it before the A:. (1.8) like that
PATRIK	testa å se va som händer	try it out and see what happens
helen	[tror inte att de går du	[don't think it will work though
isaac	[då måste du ta- ta dän den här	[then you have to re- remove this one
michael	nej	no
isaac	sätta dit den här	place this one here
michael	[a ta bort den	[remove it
helen	[ta bara- aj	[just take- ouch
isaac	bort?	remove?
helen	[ta bara Isaac	[just take Isaac
michael	[testa nu	[try it now
	(2.6)	(2.6)
isaac	eh ja. (1.0) nu ska ja trycka på (0.4) den?	eh yes. (1.0) now I should press (0.4) this one?

helen	m:	m:
PATRIK	titta nu på stegen vad den gör för nånting	now look at the steps to see what it’s doing
michael	((ohörbart)) ((programmet kör i 20 sekunder))	((inaudible)) ((the program runs for 20 seconds))
isaac	den kört hela tiden igen	it’s doing it all over again
PATRIK	[va var de-	[what was it-
JONAS	[den stannade nog där förut men så satte ni på den direkt	[it did stop there but then you turned it on again
PATRIK	va va de- va va de som stoppade där. när du satte dit stoppet. den stängde bara av strömmen där va. den gjorde inget den st- den stoppade aldrig programmet va	what was it- what was it that stopped there. when you added the stop. it just shut off the current there, then. it didn’t st- it never stopped the program right
isaac	m:	m:
michael	nej	no

EXCERPTS FROM STUDY III

Excerpt 2. Group 1

Alice:	Å den kan inte stanna kva:r så där uppe	m:: [it can’t sta:y up there like that
Jens:	aså detta är ju, det här är en konstant (3.6)	so this is, this is a constant (3.6)
Betty:	då får- man får gå lite åt sidan (0.7) från sidled om man går som man inte ska gå [precis så här då *hahaha*	you have to- you should move to the side (0.7) sideways a little bit [*like this*

Alice:	[nä men du kan inte gå i sidled för då försvinner du ur bild	[no but you can't move sideways 'cause then you disappear out of the picture

Excerpt 3. Group 7

Hannah:	de här var alltså hastighet (0.9) tid ((ohörbart))	so this was velocity (0.9) time ((inaudible))
	(1.9)	(1.9)
Inez:	ja ve- vad var det första vi gjorde?	I kno- what was the first one we did?
Hannah:	de var ju-	well it was-
	(0.7)	(0.7)
Inez:	de va bara rörelse	it was only motion
Hannah:	lä:ge och tid	posi:tion and time

Excerpt 4. Group 5

Emily:	bakåt (0.3) å::	backwards (0.3) a::nd
Felicia:	*oj*	*oops*
Emily:	*men va gö:r den* (0.7) ja men de e [ju	*but what's it doing* (0.7) yeah but it [is
Felicia:	[ja:	[yea:h
Emily:	=för att man står stilla här	='cause you stand still here
Felicia:	Ne:j	no::
Emily:	då blir de ju [att den går ner på noll	then it [goes down to zero
Felicia:	[ja hallå man ska ju inte stå stilla	[yes you shouldn't stand still
Gina:	=Ne:j	=no:
Felicia:	=det är ju hastigheten som ska vara [konstant	=no it's the velocity that should be [constant
Gina:	[kons- ja::	[cons- yea:h

Excerpt 5. Group 8

Julia:	så först står vi still (0.2) >precis här< sen backar vi (0.8) sen står vi still (0.2) sen går vi mot. (0.4) man får inte gå (1.8) känns som då borde man komma ut- på- (0.5) utgångsläget (1.0) sen ska man stå still sen ska man gå ännu närmare.	so first we stand still (0.2) >right here< then we go backwards (0.8) then we stand still (0.2) then we go towards. (0.4) you can’t go (1.8) it feels like you’ll end up- at- (0.5) the starting-point (1.0) then you should stand still then you move even closer.

Excerpt 6. Group 8

Kylie:	nej. nej de gör man inte eller? (0.6) Nej (0.6) Nej de kan man inte göra, man (0.5) står still, å sen så	no. no you don’t do that or do you? (0.6) no (0.6) no you can’t do that, you (0.5) stand still, and then
Julia:	backar [man	you go [backwards
Kylie:	[backar man, å så (0.8) ökar man hela tiden hastigheten	[you go backwards (0.8) and then you continuously increase your speed
Julia:	m::	m::
Kylie:	Sen går man i samma hastighet	then you walk at the same speed
	(1.2)	(1.2)
Kylie:	i den hastigheten hela tid- eller i ((skrattar)) två sekunder då.	at that velocity the whole ti- or in ((laughs)) two seconds then.
Julia:	ja just de där måste man gå ja. de ja	yeah that’s right you have to walk there. it’s yeah
Kylie:	ja (0.5) å sen så minskar man på hastigheten	yes (0.5) and then you decrease the velocity

Excerpt 7. Group 5

Gina:	de ä ju ganska bra (0.2) men eh::	this is pretty good (0.2) but eh::
Felicia:	vart blir de fel då	where does it go wrong then
	(0.6)	(0.6)
Felicia:	*vart brister de [nånstans*	*where does it [fail*
Gina	[*vart brister de nånstans* (0.2) jag ve:t inte (1.9) den- den går ju för fort nerför	[*where does it fail* (0.2) I don't kno:w (1.9) it's going down too fast

Excerpt 8. Group 5

Gina:	Nu ska jag se exakt (0.2) när jag säger nu:: kollar du var kulan är	now I'm gonna see exactly (0.2) when I say no::w you check where the ball is
Felicia:	m::	m::
	((simuleringen körs))	((the simulation is run))
Gina:	nu	now
Felicia:	nu ä den vid fyra femman	now it's at four five
	(1.2)	(1.2)
Gina:	de är där det är fel	that's where it goes wrong

Excerpt 9. Group 8

Kylie:	Det känns inte som dom räcker till för en	it doesn't feel like they're enough for you
Julia:	nej	no
	(5.6)	(5.6)
Julia:	i och för sig (0.5) eller nä: de va inget	well (0.5) no never mind
Kylie:	visst känns de som den ska åka så rätt länge	sure it feels like it is going like that for quite a while

Julia:	ja: å så ska den upp hä::r å så	ye:s and then it's going up he::re and
Kylie:	a::	ye:ah
	(4.2)	(4.2)
Julia:	fast här eh- (0.8) jag har svårt att tänka ska vi köra en gång får vi se	but here eh- (0.8) I have trouble thinking should we run it once and see

Excerpt 10. Group 3

Carol:	den ska nog ne:r (0.5) lite mera, (1.3) vad händer om den är så här (0.6) oj (1.6) nämen °jag drar ju uppå: t° (5.3) har vi haft sådär?	think it should down (0.5) a little bit (1.3) what happens if it is like this (0.6) oops (1.6) why no °I am pulling upwards° (5.3) did we have it like that?
Diana:	ne::j jag vet inte ((kör simuleringen))	no:: I don't know ((the simulation is run))
Diana:	ja det är ju inte så tokigt	well it's not that bad
Carol:	amen ne:j men den var uppe på fem förut va? (1.2) då var det bättre. (1.2) ska dom här va jämna då?	but no: it was up at five before right? (1.2) then it was better. (1.2) should these be equal then?

EXCERPTS FROM STUDY IV

Excerpt 1. Eric

I:	ser det ut så här om vi flyger här tror du?	Does it look like this if we fly here do you think?
	(1.1)	(1.1)
Eric:	na::↑[ej	No:
I:	[>runt så-<	Round like this-

Eric:	då- då är man- då ser man ju himlen, man ser inte himlen när man är uppe i rymden=	Then- then you are- then you see the sky, you don’t see the sky when you are up in space=
I:	=nehej så man får åka här ungefär kanske	=Oh no so you have to travel about here perhaps
Eric:	m:	M:
I:	ja: (1.2) som vid kanten så	Ye:s (1.2) at the edge like that
Eric:	m:	M:
I:	ja: (4.1) men här då, kan man åka så	Y:es (4.1) but what about here, then? Could one go like this?
Eric:	n:ej för då- för då störtar flygplanet (0.3) ner på marken=	N:o ’cos then- ’cos then the plane falls down on the ground=
I:	=>tror du den störtar ner hit< ner i vattnet då eller?	=>Do you think it falls down here< down into the water or?
	(0.6)	(0.6)
Eric:	[nej	[No
I:	[eller vart skulle det störta då?=	[Or where would it go then?=
Eric:	=a om det skulle ha flugit vatte:↑n	=Well if it would have flown in wate:↑r
I:	a:	Yes
Eric:	å den skulle ha vart uppochne:r skulle den ha störtat rätt ne:r	And it would’ve been upside-do:wn it would’ve fallen straight down
I:	jaha (0.4) ner här	Aha (0.4) down here
Eric:	m:	M:
I:	vad finns det där då?	What’s down there then?
	(1.5)	(1.5)
Eric:	ma:rk!	Grou:nd!
I:	finns det mark där?	Is there ground there?
Eric:	m:	M:

Excerpt 2. Isaac

I:	kan man flyga runt hela jorden	Can one fly around the whole earth

Isaac:	ja=	Yes=
I:	=ja (5.5) så:	=yes
Isaac:	m	m
I:	å här också	and here as well
Isaac:	m:	m:
	(6.9)	(6.9)
I:	skulle man kunna flyga såhär	Would it be possible to fly like this
Isaac:	m:	m:
	(0.5)	(0.5)
I:	[ja	[yes
Isaac:	[men man flyger inte uppochner men man kan flyga runt jorden	[but you don't fly upside-down but you can fly around the earth
I:	ja (2.4) men om- om det är här (0.4) flyger den uppochner då=	Yes (2.4) but if- if it is like this (0.4) does it fly upside-down then=
Isaac:	=>ne:j<	=>No:<
	(1.6)	(1.6)
I:	men som dom är på bilden då?	But the way it is in the picture then?
	(1.4)	(1.4)
Isaac:	där flyger den uppochner men jag tror inte att den gör det på riktigt	there it flies upside-down but I don't think that it would do that for real
I:	nej (8.5) om vi åker här	No (8.5) if we go like this
Isaac:	m:	M:
I:	börjar de vri↑da sig då tror du	Does it start to tu↑rn then do you think
	(2.1)	(2.1)
Isaac:	°nej det tror jag inte°	°No I don't think so°
	(1.4)	(1.4)
I:	det är inte så att flygplanet fö↑ljer jorden här då	Isn't it possible that the plane fo↑llows the earth
	(2.2)	(2.2)
Isaac:	>jag vet inte< jag har aldrig åkt flygplan själv så	>I don't know< I've never travelled in a plane myself so

I:	ne:↓j nej då är det lite svårt att veta (3.1) du tror inte att det skulle kunna <u>ramla</u> här då	No:↓ no then it's a bit hard to know (3.1) but do you think that it could <u>fall</u> <u>off</u> here?
Isaac:	nej det tror jag inte	No I don't

Excerpt 3. Helen

I:	om man åker med ett flygplan så här	If one travels in a plane like this
	(0.6)	(0.6)
Helen:	m	
I:	runt jorden (2.6) skulle man kunna flyga <u>här</u> då?	around the earth (2.6) would it be possible to fly <u>here</u> then?
	(3.1)	(3.1)
Helen:	man kan inte flyga uppochneråt	You can't fly upside-down
	(1.0)	(1.0)
I:	ne:j finns- kan man åka uppochner eller åker den uppochner när den åker så här?	No: can you go upside-down or does it go upside-down when it's going like this?
	(1.5)	(1.5)
Helen:	ne:j	No:
	(1.0)	(1.0)
I:	gör den inte det	So it doesn't?
	(1.0)	(1.0)
Helen:	tror ja inte	I don't think so
I:	ne:j (0.9) varför ser det ut så↑ här då?	No: (0.9) why does it look like this then?
	(1.4)	(1.4)
Helen:	bara för att (0.8) <u>de</u> <u>är</u> <u>ru:nt</u>	Only because (0.8) <u>it's</u> <u>rou:nd</u>
I:	ja just det (0.7) så det ba- det ser bara ut så kanske=	Yes that's right (0.7) so it only looks this way perhaps=
Helen:	=ja	=Yes
	(0.5)	(0.5)
I:	ja	Yes

Helen:	fast den kanske flyger rakt °egentligen°=	But perhaps it really flies straight=
I:	=den åker rakt egentligen ja just det (2.1) så då skulle den inte kunna ramla så här	=It actually travels straight yes that's right (2.1) so then it couldn't fall off like this
Helen:	nej	No
I:	nej	no

Excerpt 4. Oscar

I:	kan man åka flygplan över hela (0.2) jorden	Can one travel with aeroplanes all over (0.2) the earth?
Oscar:	>ja< (1.9)	>Yes< (1.9)
I:	skulle man kunna åka så här då?	Would it be possible to go like this then?
Oscar:	ja: (2.7)	Ye:s (2.7)
I:	här då (0.7) vad händer då? (0.8) blir det så här=	How about here (0.7) what happens then? (0.8) would it be like this?=
Oscar:	=han flyger över vattnet	=He's flying over the water
I:	flyger över vattnet	Flying over the water
Oscar:	°ja° (1.7)	°yes° (1.7)
I:	ska man flyga så här? (0.4) om man är i (1.0) södra afrika (2.5)	are you supposed to fly like this (0.4) when you are in (1.0) southern Africa? (2.5)
Oscar:	a (2.5)	Yes (2.5)
I:	man är inte uppochner där då? (1.2)	One isn't upside-down there then? (1.2)
Oscar:	uppochner? (1.2) ne:j det ser inte jag (3.5)	Upside-down? (1.2) No: I can't see that (3.5)

<table>
<tr><td>I:</td><td>man flyger bara så (4.5) men om jag kommer <u>här</u> (0.2) igen (1.2) man skulle inte kunna <u>ramla</u> <u>hit</u> då?</td><td>You only fly like this (4.5) but if I come <u>here</u> (0.2) again (1.2) you wouldn’t <u>fall</u> <u>here</u> then?</td></tr>
<tr><td></td><td>(0.2)</td><td>(0.2)</td></tr>
<tr><td>Oscar:</td><td>nej</td><td>No</td></tr>
<tr><td></td><td>(1.7)</td><td>(1.7)</td></tr>
<tr><td>I:</td><td>varför skulle man inte det</td><td>Why wouldn’t you do that</td></tr>
<tr><td>Oscar:</td><td>för öh (1.6) a: som ja sa förut att, dom tror att jorden är platt så att man inte kan- ”ramla vi neråt”- trodde dom förr i tiden</td><td>Because eh: (1.6) we:ll as I said before, that they think that the earth is flat so you can’t- “we will fall down”- they thought a long time ago</td></tr>
<tr><td>I:</td><td>ja:</td><td>ye:s</td></tr>
</table>

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