The Development of Expertise in Information Systems Design

Anneli Eteläpelto

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To Markus and Tuomas

ABSTRACT

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The study investigates the nature and development of expertise in information systems design and development. Following a critical discussion of mainstream cognitive science approaches to expertise, the study proceeds to a content-specific analysis of design expertise with functional explanation as its goal. The five separate articles in the thesis analyse expertise in information systems development from slightly different perspectives. Expertise is analysed in terms of metacognition (article I), developmental levels (article II), the domain-specific quality of subjects' knowledge structures (article III) and contextual and strategic knowledge (article IV). Article V discusses the need for a redefinition of design expertise from a contextual-developmental perspective.

In the empirical studies, expertise is analysed as a consequence of domain-specific experience arising out of practical problem-solving in real-life contexts; the experience in question comprises (a) the work experience of experts (professionals) and (b) a practical project-based course for novices (university students). The empirical studies were conducted using cross-sectional expert-novice comparisons and a longitudinal strategy. The latter was used to analyse the role of the practical project-based course in the acquisition of initial levels of design expertise. A new method of Conceptual Model Construction and Reflection (CMCR) was introduced and utilized to elicit subjects' practical domain knowledge. The empirical studies also used a task requiring domain problem-solving, interviews, essay tasks and thinking aloud. Qualitative and quantitative analyses were complementary in the assessment and description of various qualities of design expertise.

A comparison of experts and novices in terms of their metacognitive knowledge and awareness in computer program comprehension showed that experts were superior to novices in these specific components of metacognition, and had better interconnections between the knowledge, awareness and regulation components. A comparison of experts and novices in terms of domain-specific knowledge structures showed that experts tended to perceive information systems development from a more comprehensive perspective, adopting more the perspective of overall work organization. By contrast, novices were more restricted in their scope and often failed to integrate end-user issues into their procedural working models. The analysis of design problem-solving tasks showed that during their project course, novices had acquired strategic competence in using domain-specific tools and methods, but were not able to consider users' constraints comprehensively. The highest level of expertise was characterized by a comprehensive and interactive approach involving a flexible use of both domain-specific strategic knowledge and contextual knowledge of the users. It was concluded that the acquisition of such high-level design expertise, which was found among only a minority of the professional systems analysts, required - in addition to the domain education - not less than 4-5 years of practical experience in a relatively stable work organizational context.

The general discussion addresses how the different kinds of expertise in information systems design and development should be characterized, and how it is related to subjects' differing background experience. On the basis of the empirical results, it is suggested that subjects' background experience should be analysed, starting from their functional roles and what these imply in terms of representations of domain expertise. Although professional design expertise is shown to be highly context-sensitive and normative in its nature, certain developmental continuities in the learning and acquisition of necessary knowledge domains can be discerned. These include the initial focus on strategic domain knowledge which the novices derived from their first practical experience. Later, the focus moved towards the acquisition of contextual knowledge concerning the users. On the basis of the results and the discussion on expertise in ill-defined domain of information systems design and development, a portrait of high-quality expertise is outlined. The methodological and practical implications are derived and suggestions for further research are set out. A theoretical discussion of the cognitive approach leads to suggestions for redefining of design expertise from a contextual-developmental perspective.

Key words: expertise, learning and development, design expertise, information systems, practical experience, project-based instruction

PREFACE

The fascinating question concerning the nature of human expertise, its development, acquisition and background, has interested me since the eighties. From that time originates also my interest in the new qualifications and learning demands on human jobs arising out of the introduction of information technology. As an assistant researcher in an interdisciplinary research project, Man-Computer Interaction, funded by the Finnish Academy of Sciences I had an opportunity to focus on cognitive strategies and competencies in computer program comprehension. For support during this period I am thankful to the leaders of the project, Professors Pertti Järvinen and Juhani Kirjonen. Later, when I was working at the Department of Psychology, University of Jyväskylä, I am grateful to Professors Isto Ruoppila and Heikki Lyytinen who backed me in my undertaking to investigate human competencies and their cognitive basis by using methods, such as thinking-aloud, which had not previously been much applied here.

This thesis addresses the nature and development of expertise in complex computer-based tasks. These tasks were chosen as the focus of the analysis because they were thought to represent qualifications and competencies becoming more common in our future working life. In the domain of computer-based tasks, the main objects of my interest have gradually shifted from programming to design and development.

The human activities of design and development have several characteristics which make them especially challenging both as professional tasks and as subjects of psychological and educational research. Design and development represent complex and active construction of mental contents and artifacts of the kind that is characteristic of genuinely human activity. Involving also the value component, design and development tasks imply the necessity of subjectively defining and specifying the target and purpose of the activity. The normative aspect is thus inherent in such tasks. Due to these characteristics, design and development are unlikely to ever become totally mechanized, and will hence be preserved as the focus of human learning and education.

Analysing the tasks of information systems design and development has involved similar difficulties and challenges as the practical performance of these tasks. The first difficulty entailed redefining the research theme in terms of an adequate conceptual and theoretical framework which would capture the relevant aspects of expertise in complex human activity. The thesis was started using concepts derived from the applied cognitive approach to expertise research, the main focus being on phenomena described in terms of cognitive strategies, metacognition and knowledge structures. These concepts were used in a quite domain-specific way, that is, cognitive phenomena were specified and described in terms of the subject-matter domain to be analysed. Later the cognitive approach was challenged by paradigms which put more emphasis on contextual and situational aspects. In line with these trends, the thesis also began to question certain aspects of the cognitive paradigm. The need for a critical redefinition of the cognitive approach became particularly evident when the study proceeded to elaborate issues involved in learning and the acquisition of professional design expertise.

The critical discussion of the cognitive science approach made it necessary to consider alternative paradigms. A profound influence here was my participation in a task force on Situated Learning and Transfer that was part of an international and interdisciplinary research programme on Learning in Humans and Machines funded by the European Science Foundation for 1994-98. In the context of this programme, I addressed situated approaches to learning and their contribution to the redefinition of professional design expertise.

Despite this situational excursion, my main interest has been in those aspects of human learning and development which manifest themselves in professional competence and expertise acquired as the consequence of higher education and practical work experience. The studies composing the thesis are made in the spirit of an educational policy which emphasizes continuous and lifelong learning. This implies that the scope of the research is not limited to the educational system but that the study also addresses competencies and expertise produced through participation in authentic working life practices, intertwined on many levels with educational practices.

In Finland, the barriers between the practices of education on the one hand and of working life on the other have recently become lower. This is manifested, for example, in an increased flexible overlapping between the theoretical and the practical elements of the curriculum in professional and higher education, in the wide adoption of apprenticeship training and in the introduction of competence-based assessment in vocational and adult education. Recent discussion of the needs of polytechnic (AMK institutions) and higher education to pay more attention to the challenges of working life is another indication of such lowering of barriers between education and working life.

Apart from being common trends in vocational and professional education, such crossing of institutional boundaries and the use of activity-based instructional methods have recently increased also in general education. Activity-based methods, such as project-based learning, collaborative learning and other methods of 'expert pedagogy', have become more popular. As a consequence of this, we need approaches and models appropriate for assessing and evaluating learning outcomes produced in these environments. Advanced models of expertise development could offer new frameworks for the critical evaluation and assessment of learning outcomes generated through such methods.

Paying attention to these practical constraints has been an important background to and a central source of motivation for my studies. All the sub-studies included in the thesis have been closely linked with and derive their motivation from such educational considerations as well as the applied research especially in the field of professional and adult education in which I have been involved at the Institute for Educational Research, University of Jyväskylä. For my years at the Institute for Educational Research I wish to express my profound gratitude to all my colleagues there. When I worked at the Vocational Education Unit, its department head, Raimo Mäkinen, helped me to discover the practical relevance of my interest in research on expertise. Professor Jorma Ekola from the Department of Teacher Education supported me in my application of what is known about expertise and the concept of expertise in the context of AMK institutes. Throughout many years I have found my contacts and collaboration with the personnel of the Jyväskylä Vocational Teacher Education Institute very important and inspiring.

In my home institute, the research team on Learning and Acquisition of Professional Expertise has given much support for my work. Professor Juhani Kirjonen has taken on most of the burden of administrative responsibilities, thus allowing researchers to concentrate on their research work. I thank all the members of the team for the pleasure of many inspiring discussions about learning in higher education and the acquisition of professional expertise in other domains. Later, in the research team CATO, headed by Professor Pirjo Linnakylä, I have been given the freedom that I needed to concentrate on finishing my thesis. At the final stage of my work on the thesis Director Jouni Välijärvi and Professor Linnakylä played a very crucial role by offering me their strong support and the necessary time resources when I was writing the summary of the thesis. I also appreciate their creation of an innovative research atmosphere at the Institute for Educational Research.

Over the course of many years, Professor Sauli Takala has given me invaluable help. He has provided me with many stimulating references and has had the main responsibility for teaching me to write scientific English. He has often been the first colleague to whom I was encouraged to give my first draft to read, and he has always come back with constructive suggestions. Donald Adamson and Hannu Hiilos have helped by polishing my English further.

My special thanks for many kinds of practical collaboration in the gathering and analysis of the research data go to Eero Tourunen from the Department of Computer Science and Information Systems. Eero has helped me in many ways at the data collecting stages and especially in contacting the research subjects. Maija Jurvanen helped me in collecting and evaluating the data. Raili Puranen and Kaija Mannström have transcribed the interviews and the thinking-aloud data, and they have later helped me in many ways. Many thanks belong to all of you.

I also wish to thank my research subjects, students and the staff of the Department of Computer Science and Information Systems at the University of Jyväskylä, and the systems analysts from fifteen different software development organizations in Jyväskylä who took part in the study. It could not have been realized without their generous use of time on my project.

At the most critical stages of writing the thesis, Professor Heikki Lyytinen from the Department of Psychology gave me valuable help and support. I greatly appreciate his way of making insightful questions that focus on essential points of the study.

Professor Pertti Saariluoma, who acted as a thorough and thoughtful pre-reviewer of the thesis, helped me discover and explicate some of its previously tacit presuppositions. I am very grateful for his contribution, which greatly increased my awareness of the methodological aspects of the thesis. Professor Carl Bereiter, who was the other pre-reviewer, opened up the prospects of gaining further understanding of expertise through a reflection on its manifold manifestations in our common professional and non-professional activities.

During the lengthy process of conducting the research involved in the thesis, I have been privileged to receive valuable help, advice and comments from both many internationally recognized scientist and the anonymous reviewers of my papers. I greatly appreciate the contribution especially of the following distinguished scholars: Winfried Hacker, Robert Glaser, Joseph Novak, Wim Nijhof, Stella Vosniadou, Paul Light, Edith Ackerman and Joan Bliss.

The personal management of the complementary roles of my life would have been impossible without the help of many of my friends who have given their support in manifold ways. I wish to express my gratitude for all of them. Special thanks for their patience and sympathy belong to Sirkka and Jukka.

My mother Eeva Eteläpelto has always been available as a helping grandmother, and has thus relieved my guilty conscience about handling the roles of a mother and a researcher. My father Pauli Eteläpelto has always encouraged me to set myself ambitious goals, and backed me in my endeavours to realize them.

My warmest thanks go to my dear sons, Markus and Tuomas, who have so bravely shared with me the whole burden of the time required to complete the thesis. Their increased independence and responsibility for developing their own areas of expertise has given me the opportunity as well as the motivation to do my best in my own areas.

Jyväskylä, November 1998

Anneli Eteläpelto

CONTENTS

GENERAL DISCUSSION

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following articles, which are referred to in the text by their Roman numerals.

I Eteläpelto, A. (1993). *Metacognition and the expertise of computer program comprehension.* Scandinavian Journal of Educational Research, 37, 3, 243-254.

II Eteläpelto, A. (1994). *Learning process in the control theory. Commentary on "Moving from cognition to action: A control theory perspective" by R. G. Lord and P.E. Levy.* Applied Psychology: An International Review, 43, 3, 370-376.

III Eteläpelto, A. (1994). *Work experience and the development of expertise.* In W. J. Nijhof & J. N. Streumer (Eds.), Flexibility and training in vocational education (pp. 319-341). Utrecht: Lemma.

IV Eteläpelto, A. (1997). *Contextual and strategic knowledge in the acquisition of design expertise.* Paper presented at the 7th European Conference for Research on Learning and Instruction (EARLI), August 26-30, 1997, Athens, Greece. Manuscript submitted for publication.

V Eteläpelto, A. & Light, P. (in press). *Contextual knowledge in the development of design expertise.* In J. Bliss, P. Light & R. Säljö (Eds.), Learning sites: Social and technological resources for learning. Elsevier.

Copies of the articles are included in the thesis.

I https://doi.org/10.1080/0031383930370305

II https://doi.org/10.1111/j.1464-0597.1994.tb00830.x

III https://scholar.google.com/scholar?hl=fi&as_sdt=0%2C5&q=Etelapelto+%22Work+experience+and+the+development+of+expertise%22&btnG=

IV https://doi.org/10.1016/S0959-4752(99)00014-6

V https://scholar.google.com/scholar?hl=fi&as_sdt=0,5&cluster=15689736974416393978

GENERAL INTRODUCTION

1 RESEARCH TASK AND AIMS

1.1 Purpose and focus of the thesis

The purpose of this thesis is to examine the nature and development of expertise in tasks of information systems design and development. Following on a critical discussion of early cognitive science approaches, the thesis analyses expertise in terms of domain-specific knowledge structures, strategies of domain problem solving and metacognition. These are understood as essential components determining the nature and quality of expert performance and its development.

This study takes as its starting-point the open and ill-defined nature of design problems, which gives rise to considerable qualitative variation in the nature of expertise. This qualitative variation was assumed to be all the greater in the present study, which analysed expertise in both educational and working life contexts. It seemed that qualitative approaches were required, and the use of a variety of methods to find out the qualitatively differing ways of perceiving domain tasks.

The developmental aspects of expertise are examined by focusing on the relationships between subjects' practical experience and the quality of their expertise. The empirical sub-studies included in the thesis attempt to specify how subjects' domain expertise is related to two main learning and adaptation processes, involving a project learning experience organized for university students and authentic work experience gained in professional contexts. Figure 1 presents the main focus of the thesis.

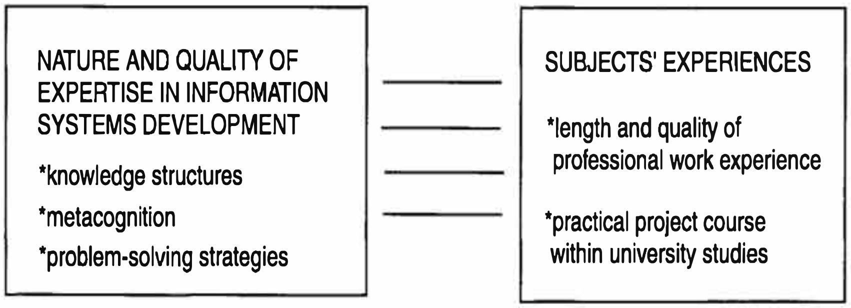

FIGURE 1 Main focus of the present study.

The thesis deals in the main with the nature and development of expertise in complex and ill-defined professional tasks. To analyse the developmental aspect, one has to ask what is involved in this expertise and how this is related to subjects' background experience. One would expect the acquisition of expertise in the complex and ill-defined domain of design and development to be a lengthy process, involving learning in both educational and working life contexts; hence a cross-sectional approach employing professionals with varying backgrounds was chosen as the main research strategy. However, in addition to this, the thesis tries to capture the critical stages of students' transition from the university context to the working life context, using a longitudinal analysis. It was hoped that this would provide a more elaborated understanding of how students integrate their theoretical studies with practical experience of working life at the initial stages of acquiring design expertise.

Until now, most empirical studies have understood experience very simply in terms of the length of subjects' work experience. The qualitative aspect of experience has not been much discussed, with little attention to what makes certain kinds of work experience more developmental than others. In this study, we are interested in two aspects of experience which can be better differentiated in the German language than in English. One aspect of experience, called '*Erfahrung*' in German, usually views experience as a concrete human activity, such as work experience. The other aspect, called '*Erlebnis*', refers to the subjective aspect of experience. In the cognitive science approach the subjective side is often forgotten, especially because it is difficult to grasp as an objectively measurable phenomenon. However, if we are trying to understand those aspects of experience that are important for human learning and the acquisition of expertise, we cannot ignore the subjective aspect. Despite our limited methodological tools for grasping subjective learning histories, this study makes an attempt to tentatively identify some of the main sources of professional design expertise, including those which belong to the consequences of subjective experience.

Like earlier studies applying a cross-sectional expert-novice paradigm, this study is similarly limited in its analysis of the relationships between the nature and quality of expertise and subjects' background experience. However, an attempt was made to avoid some of the most serious limitations of the cross-sectional approach by using as a complementary strategy a longitudinal analysis of university students who participated in a practical project learning course of seven months' duration. Additionally, retrospective data on subjects' domain experiences and their work histories were gathered.

As a consequence of the longitudinal strategy in the analysis of project learning, as well as the aim of understanding the developmental processes involved in professional learning, the thesis was obliged to go beyond the knowledge base of current cognitive science research on expertise. Achieving a better understanding of project learning and the consequences of professional experience implied a need to draw on the concepts and knowledge base of learning research, an area to which debates between cognitive and situative approaches have recently directed discussion. The present thesis is also engaged in such discussion, in that it asks whether the situative approach could contribute to the understanding and redefinition of design expertise.

The participants in the empirical studies included in the thesis consisted of university students and also professional system analysts from various kinds of work organisations. This implied a focus on the work histories of the professional systems analysts, and on their present work organizational contexts, these being assumed to be the sources of their expertise. As regards the university students, the study focused on the expertise which they derived from their practical project course.

Methodological challenges were encountered in the elicitation and description of the expert knowledge included in information systems design and development. In order to respond to these challenges (arising from the goal of eliciting the practical knowledge that subjects have acquired during many years of professional experience), creativity was required in devising new methods of extracting such experience-based practical knowledge. In addition to introducing a method of Conceptual Model Construction and Reflection (CMCR), the empirical studies made use of a task related to domain problem-solving, and also interviews, essay-tasks and thinking-aloud. A largely data-driven approach was adopted in the analysis of data and in the description the different qualities of expertise. Qualitative and quantitative analyses were regarded as complementary rather than as mutually exclusive.

1.2 Structure and contents of the thesis

The thesis is composed of separate articles which focus on different questions involved in the general research task.

The first of the articles (Eteläpelto, 1993a) focuses on the relationships between expertise and metacognition. Metacognition is here conceived as a necessary constituent of expertise development; it is also regarded as a desirable characteristic of a reflective practitioner, and one which may be particularly desirable in design expertise (Rowland, Fixl & Yung, 1992; Schön, 1983,1987).

The second article (Eteläpelto, 1994a), which is theoretical in orientation, summarizes the author's research findings on metacognition and expertise while providing a commentary on Lord and Levy's (1994a, 1994b) control theory. The article seeks to improve the ecological validity of the theory. In addition to emphasizing the importance of previous findings relating to metacognition and expertise, the article suggests that a five-stage-model of expertise development should be considered.

The third article (Eteläpelto, 1994b) focuses on domain-specific knowledge and different qualities of subjects' conceptions of information systems development. Using a novel method of *Conceptual Model Construction and Reflection* (CMCR), the article demonstrates the qualitative variation in conceptual structures that occurs in the domain of information systems development. The study also analyses the backgrounds and origins of different kinds of expertise. In addition to making a comparison between experts with lengthy work experience and novices with little experience, it focuses on the relationship between subjects' qualitatively different backgrounds and their qualitatively different modes of expertise.

The fourth article (Eteläpelto, 1998) addresses learning and the acquisition of design expertise. These phenomena are analysed in terms of contextual knowledge (concerning the end-users) and strategic knowledge of design tools and methods. The purpose of the article is to investigate how these necessary components of design knowledge are acquired during the first practical project-based course taken by university students, and also how they are acquired from professional learning in working life. The article presents results which are based on an analysis of subjects' solutions in a design task. As well as analysing separate dimensions of contextual and strategic knowledge, the study tries to specify the typical solution patterns. These are analysed in relation to subjects' backgrounds: the experience gained during education and working life.

The fifth article summarizes the empirical results of previous studies on the development of design expertise (Eteläpelto & Light, in press). The article also critically discusses the cognitive science approach to design expertise and asks whether a situated approach to learning and cognition would offer a more adequate framework for the redefinition of design expertise.

In international discussion, research on expertise has been seen as having a great deal of practical significance, particularly in educational contexts and as a background for curriculum design (Achtenhagen, 1995; Berliner, 1992; Boshuizen, Smith, Custer & van de Viel, 1995; Calderhead, 1996). Bereiter and Scardamalia (1986, 1993) have aptly remarked that it is very rare for an issue which originally interested behavioral scientists purely as basic research to take on such practical significance as research on expertise has recently done in industrialized societies. It seems that rapid changes in working life and increased demands for professional competencies may be responsible for this upsurge of interest in expertise and how it develops.

Paradoxically, there is a danger that a concept such as expertise, which has been widely adopted outside the scientific community, will lose its scientific and explanatory power. In order to avoid such a danger, the concept should be perceived as embedded within the theoretical framework where it was originally developed. The next chapter describes and critically discusses the theoretical background and mainstream traditions of prior research on expertise. Each separate article in the thesis additionally gives a short description of how expertise is understood and operationalized within its given context.

The first article makes a rough distinction between two of the most common meanings of expertise. Expertise can be exhibited by (a) an excellent, and/or (b) an experienced performance. Understanding expertise as an excellent, good or skilled performance has been the norm in applied cognitive science, in which expertise has mainly been operationalized on the basis of subjects' performance on domain tasks. By contrast, studies in adult education or in professional learning have tended to regard expertise as exhibited by an experienced performance and have thus operationalized it as the length of domain experience.

In the second article, the definition of expertise is further specified in the course of discussing a five-stage-model of expertise development, and utilizing findings on the relationship between expertise and metacognition. The third article summarizes some of the most consistent findings derived from expert-novice comparisons made in semantically rich domains. In this connection critical remarks are made on the use of length of experience as the only criterion for operationalizing expertise.

In the fourth article, expertise is investigated from the point of view of various knowledge components included in design expertise. In this connection, strategic and contextual knowledge are the main types of knowledge analysed as central components of professional design expertise. The fifth article further elaborates on contextual knowledge and inquires what the situated approach of learning and cognition could bring to the redefinition of professional expertise.

The different studies included in the thesis have thus analysed expertise from slightly different perspectives. Although the empirical studies included here have operationalized expertise as having - in addition to domain education - a certain minimum length of practical experience, the studies have all gone further in their elaboration of expertise than merely comparing experienced and non-experienced subjects. The studies have in fact had the goal of specifying what is characteristic of high-level expertise, and how this is distinguished from other kinds of experienced and expert performance.

In all the studies in the thesis, expertise is defined in a domain-specific way. This means that the studies have not tried to discover generic talents or abilities which could distinguish between expert and non-expert subjects. Nor have the studies attempted to define design expertise purely on the basis of previous findings related to general cognitive processes and structures. Instead, the studies have taken as their starting point recent conceptions prevalent in professional discussion of what constitutes a high quality of expertise in information systems design and development. Following on these characterizations, the empirical studies can then try to determine the specific qualities of the knowledge structures and problem solutions that correspond to these characterizations.

In order to clarify the relationships between the various studies it seems proper to mention that the empirical data sets consist of two main data sets, which differ according to the subjects under study. In the first empirical study, the subjects were novices (computer science students) and professional programmers who had experience of a particular programming language. The remaining empirical studies used different subjects (with the exception of one who took part in the first study as a student and as a systems analyst in the second); these subjects were randomly chosen from the register of university students .

The methods used in the various empirical studies are summarized in Tables 1-3 (Appendices 1-3). These methods are classified into three categories according to their role in the study. It will be seen that the first main column presents those methods that are used in knowledge elicitation. The second column describes the methods used in analysing, that is in reducing and summarizing the data; the third column shows the methods that are used in the presentation of data.

In the long term, in order to develop adequate and ecologically valid models of how professional expertise in design and development is acquired, we should try to understand what kind of continuities or discontinuities exist across different institutional contexts of higher education and professional learning, and how these contexts contribute to or set limits to the attainment of high levels of expertise. These questions will be addressed in the general discussion part of the thesis. In this connection, an attempt is made to suggest a portrait of what a high level of expertise in information systems design really consists of, together with the necessary conditions for its development. Arising from this depiction, some practical implications for instructional design will be suggested.

The next chapter addresses how those mainstream approaches which have been most influential in previous research have analysed expertise. In cognitive psychology, expertise has been analysed in terms of cognitive skills, memory processes and knowledge structures. The main strengths as well as limitations of these approaches will be considered. Based on a critical argumentation, there will be an emphasis on the need for a content-specific approach and for functional explanations in research on expertise.

2 PRIOR RESEARCH ON EXPERTISE; THEORETICAL BACKGROUND AND LITERATURE REVIEW

Early studies in cognitive science and research on artificial intelligence addressed primarily the basic information-processing capabilities employed by subjects in problem-solving situations where they lacked specialized knowledge and skill. The information-processing model suggested by Newell and Simon (1972) and the Adaptive Control of Thought (ACT) model developed by Anderson (1983) represent the mainstream approaches which previously predominated in cognitive psychology studies of expertise and the learning of cognitive skills (section 2.1.)

Another main line of research in cognitive psychology which has been linked to expertise involves the study of human memory systems. From this approach has developed the notion of chunking, which has been understood as the basic mechanism for overcoming the restrictions of human short-term memory in the learning of cognitive skills. In studies of semantic memory, the notion of the schema in its different versions has also been a powerful concept in describing the general structures of the knowledge stored in human long-term memory (section 2.2.).

In recent discussion of human memory systems, the concepts of short- and long-term memory have been regarded as inadequate. Research on expertise has given rise to the introduction of an additional memory system called long-term working-memory (LT-WM). This has been considered necessary for the understanding of expert memory functioning and its retrieval (section 2.3.).

These concepts derived from memory research have had an immediate impact on studies of how cognitive skills are learnt. They have also been used in the few influential studies which have investigated expertise in program design. In cognitive science studies on design expertise, most empirical analysis has focused on architectural design. This has also entered the domain of theoretical discussion when examples have been sought for cognitive processes in design.

Those first-generation studies of expertise research have been characterized as sharing a background of information-processing models (Holyoak, 1991). They describe human cognition mainly in terms of information-processing strategies, rules and procedures. The information-processing models developed in cognitive science have been constructed using a strong computational analogy. They have thus provided the formal vocabulary needed, for example, in the modelling of computer-based expert systems which were thought to be destined to replace human activities in many areas. However, the models did not provide adequate tools for the content-specific description of professional knowledge and the activities needed for high-level expert performance.

The computational analogies used in the domain of artificial intelligence often led to very formal and mechanical models of human cognition. These models did not seem to capture the essential characteristics of human expertise. By contrast, some of the most advanced models of expertise development emerged as a by-product of inquiries that were taking place at the crossroads of artificial intelligence and hermeneutically oriented philosophy. A five-stage model of expertise development suggested by Dreyfus and Dreyfus (1986) arose out of an interdisciplinary research endeavour aimed at investigating how far computers can replace human intelligence, and in what way human and artificial intelligences differ. Although the model originally lacked systematic empirical evidence, it has since been verified in professional domains such as nursing and teaching.

In the present chapter, after critically analysing the contributions as well as inadequacies of previous models, we shall discuss the need for a content-specific approach in expertise research. In reviewing the information-processing approach and that of memory research, we shall show that neither of these approaches alone can provide an adequate framework for a genuinely content-specific understanding of human expertise. Recently, these approaches have been severely criticized (Saariluoma, 1997) for not providing an adequate vocabulary or theoretical model for the analysis of expertise in a genuinely domain-specific manner.

Starting with an analysis of mainstream approaches in cognitive psychology, this chapter will then move to various expert-novice comparison studies, which have been carried out in a number of professional domains involving complex problem solving (section 2.4.). These studies have described expertise mainly in terms of the domain-specific characteristics of problem-solving strategies and the general nature of subjects' knowledge representations. It will be shown that these studies can also provide a fruitful basis for constructing hypotheses about the differences between experts and novices in the domain of information systems design. Nevertheless, the limitations of these studies - which arise especially from the use of artificial research tasks and the use of students as research subjects - should be considered when one comes to evaluate their external validity. Additional limitations arise from the use of a cross-sectional design as the only research method. On the basis of a critical discussion, it is suggested that there is a need for approaches which are more realistic and more ecologically valid (section 2.5.).

The lack of ecological validity in expertise research has become more evident as the focus of analysis has gradually shifted from knowledge-lean and novel research tasks to knowledge-rich and more realistic tasks. In accordance with this trend, cognitive psychology has witnessed a transition from analysis of general cognitive skills and heuristics to a focus on domain-specific knowledge structures and complex problem-solving strategies. Those studies which have been carried in semantically rich domains can give a more adequate framework and better starting point for constructing advanced hypotheses regarding professional expertise - at least in those domains where a significant body of research exists.

In the domain of design expertise, no such situation exists. So far, there has not been much research on expertise development in such ill-defined and open-ended tasks as design. Moreover, the few studies which do exist have not used realistic tasks or real professionals as subjects. Neither have they aimed at generalizable results relating to various manifestations of design expertise, or at deriving developmental continuities from them. Although in theoretical and methodological discussion the need for developmental analysis has been recognized, empirical studies on professional development have so far remained few and far between.

This thesis aims to understand the development of design expertise by investigating the relationships between expertise and the subjects' background experience. As a starting point for this inquiry, section 2.6. analyses how experience has been understood and used in prior research on expertise. It will be shown that experience has been mainly analysed as a quantitative issue, as measured by the amount of practice or by the length of experience. The qualitative aspect has been analysed only in studies focusing on excellent performances. In professional domains, the recent emphasis on contextual and situational aspects has not greatly advanced the analysis of how these aspects of experience contribute to the development of professional expertise. Moreover, the emphasis on contextual and situational factors has paradoxically led to a neglect of the subjects' developmental background as a central determinant of their expertise.

In general and cognitive psychology, there is quite a long tradition of modelling human behaviour considering the plan as a central component of human activity (Hacker, 1978; Miller, Galanter & Pribram, 1960). However, this tradition has no more to offer in analysing design expertise than it had in modelling and analysing other types of expertise. Instead of utilizing such general models of human activity, this study specifically characterizes design activity, taking as its starting point (section 2.7.) the cognitive science discussion on the nature of ill-defined and ill-structured tasks. This characterization is used as a basis for the empirical investigations of design and development. In the following section (2.8.), there is a critical summary and a discussion of the need for content-specific analyses and functional explanations. The last section (2.9.) specifies the research questions addressed in the subsequent five articles.

2.1 Production systems in cognitive skill acquisition

The information-processing model of Newell and Simon (1972) has been criticized for failing to incorporate the perspectives of learning within its model of problem solving. Newell (1990) had suggested that when we become familiar with a problem domain, we learn which operator[1] can be applied without having to search among different operators. Newell believed that we transit smoothly into a problem-solving search, and that much of human cognition is a mixture of routine problem solving and problem solving that involves search. (Newell, 1990; Simon, 1979).

Anderson (1993) argued that problem-solving research has been stunted through its inability to deal with variability and change in behaviour, and that problem-solving approaches would do well to incorporate into their analysis some of the ideas from learning theories. This would contribute to the understanding of the variability in behaviour of different individuals as well as the gradual improvements in the distribution of responses with experience.

Based on the information-processing model of Newell and Simon (1972), Anderson (1983) put forward his Adaptive Control of Thought (ACT) model, which attempts to give a process-description of problem solving and cognitive skills acquisition. In his elaboration of this model, Anderson makes a distinction between declarative knowledge, which encodes factual knowledge, and procedural knowledge, which encodes much of cognitive skills including problem-solving skill. Procedural knowledge is encoded in terms of production rules that are condition-action (if-then) pairs. These rules are basically problem-solving operators encoded in an abstract form that can apply across a range of situations. Procedures are represented in the ACT production system that operates as an active part of a semantic network. When knowledge is transformed into the form of production, it can be applied much more rapidly and reliably.

Anderson's (1983) model suggests that declarative knowledge is converted into procedural knowledge through the following mechanism and memory systems:

> Every time a production matches some long-term memory network structure that has to be retrieved into working memory, the proceduralization mechanism creates a new production that has that network structure incorporated into it and that avoids the need for the long-term memory retrieval. The simple mechanism merges semantic net knowledge into the production that uses it. In order for this mechanism to be selective in what memory it merges, we make a distinction between two kinds of declarative memory: a permanent memory and a transient, temporary memory. In ACT the permanent memory is the activated part of its semantic network (LTM) and the temporary memory is network structure that has just been created. Postulates, once committed to memory, are part of permanent memory. The representation of the current problem is a part of temporary memory (Neves & Anderson, 1981, 65).

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[1] An operation is an action that transforms one state into another state.

The ACT model maintains that the two key features of human problem solving are difference reduction and sub-goaling (Anderson, 1993). Difference reduction means the tendency of the problem solver to select operators that produce states more similar to the goal state. This is due to the fact that people are usually very reluctant to pursue paths that temporarily take them in the direction of states less similar to the goal. Sub-goaling means goal-setting where reaching the final goal implies splitting the task into smaller parts. When the problem-solver cannot proceed directly to the final goal, he or she sets sub-goals which are perceived as a means to the ultimate goal.

In the ACT model, the strength of encodings is the critical factor that determines both the accessibility of declarative knowledge and the performance of procedural knowledge. The strength of encodings reflects the amount of practice and thus explains the variability of problem-solving behaviour. Using an analysis of learning in intelligent tutoring systems constructed according to the principles of production rules, Anderson (1987) tried to verify that productions rules are the correct unit of analysis. He further confirmed that the production rules (condition-action loops) serve much the same function as that assigned to the stimulus-response-bond in past theories.

The description of skill in the ACT model is broadly in accordance with the associationist tradition of learning. Anderson (1983) states that the skill appears to be nothing more than the sum of the production rules which are learned independently. Hence, complex cognitive skills reflect the acquisition of many specific pieces of knowledge.

Because of limitations in human processing capacity, complex cognitive skills would thus be learned through the acquisition of large integrated 'chunks' of knowledge. In knowledge compilation, chunks take the form of larger, more detailed conditions and actions of production rules. Larger conditions provide more precise specifications of the circumstances under which the action is appropriate. Larger actions allow more to be accomplished by a single 'rule-firing'. In addition, knowledge compilation involves a reduction in the need to access declarative memory; it also allows speedier rule-firing due to increases in the strengths of rules with each successful application (Andersson, 1993).

Knowledge compilation and the increase of general processing capacity though practice is connected with a distinction between automatic and controlled processing and thus with automatization (Schneider & Shiffrin, 1977; Shiffrin & Dumais, 1981). Controlled processes generally involve consciousness of various components, since these processes require attention: they consist of strategies, decisions, and the like. With practice involving consistent tasks and parts of tasks which stay stable, these processes become automatic processes which do not require conscious attention. However, getting processes to be automatic is not a guarantee that the processes will be properly performed. If automatized performances are to be corrected or changed, it is necessary that subjects become aware of them and that the processes come into the focus of attention (Neves & Anderson, 1981). The subjects' awareness of task accomplishment thus has importance for expertise development, understood in terms of the acquisition of skilled activity.

The ACT theory purports to explain some of the transformations and learning processes that occur as subjects move from novice to expert level.

However, as a first-generation theory of expertise research, it is based on an apparent analogy with computer functioning. It explains learning mainly in terms of proceduralization and it applies to tasks or parts of tasks which remain relatively stable. In such tasks, the theory explains the process of automatization. However, it does not have much to say about tasks which have more unstable task conditions.

In complex tasks such as those in design, where task conditions usually involve much variation, the model described above is far too simple. It is restricted in the same way as other associationistic models which are based on subjects' random actions and the gradual strengthening of adequate associations as a consequence of practice. In the learning of design expertise, subjects do not start with random undertaking and the strengthenings of those condition-action connections which are successfully accomplished. In such a complex activity as design, subjects rather have in mind a formal model or methodology they have learned during their professional education. In design problem solving, subjects evidently try to apply such models. When subjects enter working life, they do not start from random trials or experimentation with some random connections, but rather try to specify the expectations of their social contexts and take these into account.

Nevertheless, there have been attempts to apply Anderson's model of production systems in the domain of design problem solving. Chan (1990) used the model in analysing cognitive processes in architectural design problem solving. Chan tried to verify Anderson's model of production rules while describing cognitive processes in architectural design problem solving. He used as experimental data a thinking-aloud protocol. This was obtained from an expert designer who had been given the task of designing a house for a family. The investigator attempts to demonstrate how the ACT model can be applied to design behaviour, describing it in terms of elementary cognitive processes. Using the problem-solving model of Newell and Simon (1972) and the ACT theory, Chan proposes basic concepts which can be used in the description of problem solving, as follows:

* the knowledge base: schemes
* a control strategy: goal plan, perceptual test
* search:
    -recognition
    -a means-ends analysis
    -generate-and-test
* design constraints (Chan, 1990).

The study confirms the existence of a goal plan and of different methods of search in design problem solving. It also explains how a perceptual test controls the progress of problem solving. The model thus does indeed describe design activity, making use of an information-processing model and schemes. However, it is very much based on a computer analogy, and has little to say about the content-specific nature and the developmental aspects of design expertise. Among the practical implications drawn from the analysis, there is a suggestion that novices should be explicitly instructed in constraint management since that is the main activity in design.

Jeffries, Turner, Polson and Atwood (1981) applied the model of production system in an analysis of cognitive processes in program design. However, they defined program design as a very limited process of translating a set of task requirements into a structured description of a computer program. These studies had the verification of Anderson's model as their main goal and thus they mainly functioned as demonstrations, applying to the design domain a canonic concept of problem solving. They did not in fact contribute greatly to the understanding of the overall nature and development of design expertise.

Saariluoma (1997) claims that production systems can provide us with knowledge about mental contents, because the conditions and actions in productions constitute information contents. However, production systems cannot be used to ask genuinely content-specific questions, and they provide no answers to the question of why one mental content is related to another, or why the elements make sense together. Production systems thus do not model mental content in a strict sense, and this means that they do not provide us with knowledge about the contents.

In explaining mental contents as being of central importance for human expertise in semantically rich domains, the concept of schema has been considered more promising. From the 1970s on, an increasing number of investigations have emphasized the importance of the schematic knowledge stored in long-term memory and available to people in complex problem solving. Section 2.2. of this study will address the notion of the schema and how the notion has been used in the description of human semantic memory. This semantic memory includes the general knowledge of concepts, principles, and meanings that is used in the process of encoding or comprehending particular inputs. Schema theories describe the organization of that knowledge.

2.2 Schema theories in the description of general knowledge structures

In cognitive psychology, the concept of the schema has been used to describe general structures of knowledge stored in long-term memory. A schema has been understood as a higher-order knowledge structure representing the generic concepts stored in memory. Schemata are thought to cover behaviour in a particular domain or activity, and they are regarded as specifying the principal elements of a given domain, providing an abstract structure onto which examples can be mapped. They are also postulated as including mechanisms which drive a generation process that leads to certain outcomes; these outcomes are themselves structured according to the conventions shared by expert members in a discipline (Rumelhart & Ortony, 1977).

A schema is thus theorized as incorporating both declarative and procedural knowledge. Other characteristics of schemata include:

* schemata have variables, and associated knowledge concerning the variables and their interrelationships
* schemata can be embedded one inside another; a schema is a network of sub-schemata
* schemata represent knowledge at all levels of abstraction
* schemata represent knowledge rather than definitions.

A schema is thus a net consisting of variables, the value of a variable and knowledge of how to use it. All the pieces of knowledge associated in a certain domain are hierarchically organized, and the whole structure is called the knowledge base (Chan, 1990; Rumelhart, 1975, 1980).

A schema can be used to organize complex material into constituents. The same structures guide the comprehension process by arranging incoming information so that it is structured according to the underlying abstract schemata. A general schema may include references to various sub-schemata. For example, the schema for 'face' makes reference to the sub-schemata of eyes, ears, and nose. Absence of an appropriate schema can interfere with both the initial comprehension and subsequent recall of a text (Rumelhart, 1980).

The schema concept derives from the work of such theorists as Kant (1787/1963), Selz (1913), Bartlett (1932), and Piaget (e.g., Piaget & Inhelder, 1969) and more recent theorists have attempted to characterize schemata in a much more precise manner than previously. Not all schema theorists use the term 'schema'. Kintsch (1977) and Rumelhart and Ortony (1977) use the term, but others refer to frames (Minsky, 1975) and scripts (e.g. Schank and Abelson, 1977). Although there are some differences in the attributes of these terms, they all attempt to characterize human knowledge of the world. Norman and Rumelhart (1975) and Rumelhart and Ortony (1977) describe schemata as the structures of data representing generic concepts stored in human memory. One of the goals of schema theories is to characterize the process by which conceptual structures are assigned (Bransford, 1979).

Story schemata represent an excellent example, used to describe story comprehension. It is suggested that through experience of various stories, children develop schemata that help them to comprehend and master stories that they hear and read. Schema theorists assume that the comprehension of a story consists in (1) finding a schema that fits a particular input, (2) discovering those entities that correspond to particular roles required in the schema, (3) making inferences that fill in the gaps in the story. Most stories and tasks involve a large number of schemata and these again include a reference to its sub-schemata (Bransford, 1979). In a similar manner, people may develop schemata that guide their understanding of scientific articles (Kintsch, 1977; Rumelhart, 1975)

While Rumelhart's (1980) usage of schema is directed at problems of memory and comprehension, Neisser (1976) used the concept in analysing mainly perceptual processes. For Neisser, the concept of the schema was important in explaining the interaction of the human perceiver and the environment. As regards the role of perceiving for the perceiver, he states that although the perceiver does not change the world, it (the world) does change the perceiver (as of course does the action). The schema undergoes what Piaget calls 'accommodation', and so does the perceiver. He has become what he is by virtue of what he has perceived (and done) in the past; he further creates and changes himself by what he perceives and does in the present (Neisser, 1976, 213).

In terms of schema theory, the skilled activity at each moment depends on the existing state of affairs, on what has gone before, and on the plans and expectations of the performer. This cyclic process fits the paradigm of the perceptual cycle where the schema directs exploration and the exploration further focuses on objects and their available information, which again modifies the schema (Neisser, 1976).

As an analogy for a schema, Neisser (1976) suggests a format in a computer programming language. The format specifies that information must be of a certain kind if it is to be interpreted coherently. Other information will be ignored or it will lead to meaningless results. However, a schema is not merely like a format; it also functions as a plan of the sort described by Miller, Galanter and Pribram (1960). Perceptual schemata are plans for finding out about objects and events, for obtaining more information to fill in the format. The schema determines what is perceived, because information can be picked up only if there is a developing format ready to accept it. Information that does not fit such a format goes unused. In this way, perception is selective. Thus, in addition to being a plan operating in perception, Neisser (1976) regards the schema also as the executor of the plan, and as a pattern of action.

Soloway, Adelson and Ehrlich (1988) used schema theories to investigate the knowledge and programming strategies employed by expert programmers in attempting to understand computer programs. The investigators started with the question of what is it that expert programmers know but novice programmers do not know. They suggested that there are two types of knowledge, the first of which is the knowledge of programming plans; this consists of program fragments representing stereotypical action sequences. The second type of knowledge is knowledge of the rules of programming discourse, consisting of rules that specify conventions in programming. Modelling an experiment following the Chase and Simon (1973) chess study, Soloway and his colleagues presented both plan-like and unplan-like programs to experts and novices. The results replicated the chess experiment, in that the performance of advanced programmers was reduced to that of novices on the unplan-like material.

Jeffries, Turner, Polson and Atwood (1981) used the schema theory in analysing problem solving in software design. The authors supposed that experts have schematic knowledge concerning the overall structure of a good design and the process of generating one. Using this knowledge, they direct their actions during software design. The authors thus suggest that the design schema is used in both the generation and the comprehension of designs. The design schema is not tied to any specific problem domain but rather consists of abstract knowledge of the structure of a completed design, and the processes involved in the generation of that design. The assumption is that although the design schema may differ from expert to expert because of differences in background experience, the overall structure of the schema will be similar in most cases. The design schema develops with increasing experience of software design. The authors thus maintain that a design schema represents the global organization of a designer's professional knowledge. On the basis of this assumption they try to specify it in terms of if-then production rules.

Starting from the first use of the schema concept in cognitive psychology, there has also been discussion of the dangers of using schemata as an explanation for people's performance. Brown (1978) maintains that it is easy to fall into the trap of saying that people failed to understand something because they lacked the schema for it. Bransford (1979) suggests that unless we can independently measure what people know and then see how this affects performance in particular situations, explanations in terms of schemata can become circular. We are then left with pseudo-explanations which lead us into believing that we understand something that is not in fact adequately understood.

Winograd and Flores (1986), who have emphasized the situated nature of human activity, regard the concept of schemata as somewhat vague. These authors further maintain that cognitive schemata are inherently non-representable. By contrast, Patel and Ramoni (1997) who investigated medical expertise in an applied cognitive psychology framework, maintain that the concept of the schema is valid and important as the organizing unit of a memory organization typical of experts, since it captures what cognitive psychology knows about the basic reality of expertise.

Saariluoma (1997) states that schema theories claim to explain the selectivity in perceiving relevant information which is essential for expert performance. Nevertheless, he does not regard schema theories as sufficient in providing a content-specific description of mental contents. He considers the main defect of the schema theory to be that it does not, by and large, analyse the problems of relevance in describing mental contents. It would seem that schema theories are unable to explain why some represenational elements are relevant or why they are related to each other.

To sum up, research on expertise has derived a great deal from cognitive studies of human semantic memory. Conversely, studies on human expertise have contributed greatly to the understanding of memory systems and their functioning. While early studies on skilled performance tried to explain the exceptional memory performance of experts, more recent studies on skilled performance have given rise to a new construct, namely long-term working memory. The next section will try to specify in more detail how memory research has contributed and interacted with the understanding of expertise in complex cognitive domains.

2.3 Expert memory functioning and long-term working memory

The properties of human memory provide information that is relevant to the interpretation of several aspects of expert performance. The phenomena associated with recognition explain how learned information can be used during thinking. The size of the wholes which can be actively manipulated in working memory increases with increasing skill. Experts are better at constructing large working-memory representations than less experienced novices (Saariluoma 1995).

In the traditional model of human memory (Atkinson & Shiffrin, 1968), immediate free recall yields items directly derived from a temporary short-term memory (STM) and items retrieved by retrieval cues from a more durable storage in long-term memory (LTM). STM is assumed to have a limited capacity of around seven chunks (Miller, 1956), with a chunk corresponding to a familiar pattern already stored in LTM. Storage in STM is temporary, and when attention is diverted to another demanding task, information originally stored in STM becomes unavailable in a matter of seconds. In contrast, the storage capacity of LTM is assumed to be vast and much more durable than that of STM. Storage in STM is assumed to be primarily associative, relating different items to one another and relating items to attributes of current situations (current context). The primary bottleneck for retrieval from LTM is the scarcity of retrieval cues that are related through associations to the desired items, stored in LTM (Ericsson & Kintsch, 1995).

Long-term memory has very different functions as compared with working memory. Long-term memory provides a storage medium for a very large task-specific retrieval structure (Ericsson & Kintsch, 1995). The structure is essential for the maintenance of on-going activity. The retrieval structure contains task-relevant information. It is a part of long-term memory and it entails relevant information of very different types; there are pieces of information and their relationships, allowing the pieces to be joined into chunks. The retrieval structure may contain visual as well as verbal elements. It is thus a very complicated hierarchical unit activated for some task-maintenance purposes (Saariluoma, 1995).

When unfamiliar tasks are used, the limitations of working memory are evident. However, the model of STM memory limitations does not provide a plausible explanation in skilled activities where complex tasks are used. On the basis of their analyses of skilled performance, Ericsson and Kintsch (1995) suggest a construct which they call long-term-working memory (LT-WM). They suggest that long-term working memory represents a domain-specific phenomenon in the case of skilled performance. An example of this kind of retrieval structure is found in the construction-integration model of text comprehension (Kintsch, 1988). The investigators go on to provide evidence of the domain-specific superiority of experts' memory performance in such domains as chess and medicine.

The distinctive criterion of medical experts is their superior accuracy in diagnosing medical cases. In a laboratory analogue of the medical diagnosis task, subjects are presented with a text describing a particular patient, and their diagnostic performance on this task is closely related to medical expertise (Patel & Groen, 1991; Schmidt & Boshuizen, 1993). The task of medical diagnosis presents challenges to the short-term working memory, in that symptoms and relevant medical facts have to be maintained in accessible form until the correct diagnosis is identified. Regular engagement in the diagnostic activity would offer opportunities and motivation for improvement in working memory capacity; this could account for its improvement as a function of the greater knowledge and experience of medical specialists as compared with medical students and internists (Ericsson & Kintsch, 1995).

Empirical evidence is consistent with the acquisition of a retrieval structure that allows medical experts to encode basic medical facts about a patient into higher level diagnostic facts; in this way the correct diagnostic category and specific diagnosis can be arrived at. It has been found that medical experts are able to identify and recall important information better than novices (Groen & Patel, 1988). Schmidt & Boshuizen (1993) were able to show that the free recall of experts became more abstract and summary-like as their level of expertise increased. Fact recall was replaced by higher level statements that subsumed the specific facts. After extensive clinical practice, medical experts are able to acquire high-level concepts which can be induced from data on patients. This allows for more effective reasoning, with the possibility of processing information about typical patients in a bottom-up mode, using forward reasoning strategies similar to those in normal text comprehension, as suggested in Kintsch's (1988) construction-integration model (Scmidt & Boshuizen, 1993; Ericsson & Kintsch, 1995).

The best laboratory task for capturing chess skill involves the selection of the next move in an unfamiliar chess position (Charness, 1991; Saariluoma, 1990). The critical demand on working memory in skilled chess playing occurs during the selection of the next move, during which the subject is planning the consequences of long sequences of moves. Charness (1991) found a reliable correlation between the maximum number of chess moves planned ahead and chess skill. Saariluoma (1991) found that chess masters generated potential moves much faster and more fluently than novices in chess. Both Charness (1991) and Saariluoma (1990) have shown that the depth of planning during the selection of a move increases with chess skill, up to the level of an advanced chess expert. It seems that increases in chess skill beyond that level are associated with a more sophisticated focus of evaluation and abstract planning. The representation in working memory of planned chess positions reflects the characteristics of actual chess positions, allowing chess players to uncover the strengths and weaknesses of these positions and to accurately evaluate and analyse them (Ericsson & Kintsch, 1995).

Ericsson and Kintsch (1995) suggest that the construct of long-term working memory (LT-WM) is needed as a domain-specific construct to explain skilled human activities in complex tasks. The research on the planning and memory of chess positions offers some of the most compelling evidence for long-term working memory. The results clearly implicate the existence of long-term working memory in maintaining access to updated chess positions.

Saariluoma (1995) concludes that memory systems offer several functions that are important in experts' selective thinking, but that the vitally important aspect of selectivity seems to go beyond current memory research. There is no adequate explanation of the selection of content-specific information and thus of the content-specific aspects of selective thinking. The attributes of memory research, which rely heavily on capacity, are ineffective in terms of discussing content-specific information selection. According to Saariluoma, the problem with current concepts of expert memory is clear in that these concepts do not have content-specific attributes. Retrieval structures are undoubtedly content-specific structures. However, we have no knowledge about these content-specific aspects of memory structures, except perhaps in the area of semantic memory, and even if we had, it is unclear what the role of memory would be in bringing exactly the right elements together (Saariluoma, 1997).

Although memory research has recently increased its ecological validity in analysing complex expert performances, it still lacks the ecological validity needed for understanding expertise in complex and ill-defined domains. The generalizability of the findings of memory research are limited due to the experimental tasks used. Studies have been carried out in experimental settings where the task demands were at an elementary level, far removed from the demands of real professional tasks.

In the last two decades, however, there has been increasing research on how the transition is made from novel to routine problem solving as one gathers experience within a problem domain. This reflects a shift in interest both towards learning and towards knowledge-rich, real problem-solving domains, such as physics and programming. At the same time studies have moved away from knowledge-lean toy tasks such as Tower of Hanoi (Ericsson & Kintsch, 1995). A great deal of this research has looked at how relative experts compare with relative novices at a problem-solving task. On the basis of these comparisons, inferences have been made about the development of expertise. The next section will focus on the findings of these studies conducted in semantically rich domains.

2.4 Analysing expertise in semantically rich domains: a knowledge-based approach

From the 1980s onwards, expertise research has increasingly focused on knowledge-rich tasks requiring hundreds and thousands of hours of learning and experience. The analysis of expertise in semantically rich domains, such as in physics, algebra, medical diagnosis and programming has shifted interest from general heuristics and the processing mechanism to the domain-specific knowledge necessary to complete the tasks. Studies in semantically rich domains have thus offered insight on the learning and thinking of experts who require a rich structure of domain-specific knowledge.

In several studies of cognitive skill acquisition it has been generally confirmed that experts are usually faster than novices in their domain problem solving, and that they also make fewer errors than novices. The main qualitative differences found in expert-novice comparisons can be summarized as follows (Bereiter & Scardamalia, 1986; Ericsson & Lehman, 1996; Ericsson & Smith, 1991a; Glaser, 1987; Glaser & Chi, 1988; Gruber, 1994; Holyoak, 1991; Mayer, 1988; Saariluoma, 1995; Sonnentag, 1995):

* experts perceive large meaningful patterns in their own domain
* experts focus on the relevant cues in the task
* experts represent their domain problems at a deeper level than novices

* expert knowledge is organized in a way that is relevant for problem solving
* expert subjects use more time in problem analysing and constructing a detailed mental representation of the problem before they enter into the solution
* experts' knowledge structures are hierarchically organized and have more depth in their conceptual levels than those of novices
* experts categorize problems in their own domains according to abstract high-level principles; and their knowledge structures are more coherent than those of novices
* experts have better self-monitoring skills than novices
* high-performing professionals spend more time on problem evaluation.

In the following sections, each of these characterizations will be addressed in more detail.

1. Experts perceive large meaningful patterns in their domain.
This has been shown in various domains. In chess it is well-known that chess masters excel in their recall of those clusters of pieces they see. The superiority of experts in perceiving large meaningful patterns has been replicated in several other domains, including the GO-game (Reitman, 1976), reading circuit diagrams (Egan & Schwarz, 1979), reading architectural plans (Akin, 1978) and interpreting X-ray plates (Lesgold et al, 1988). It has been pointed out that this ability to see meaningful patterns does not reflect a generally superior perceptual ability; rather, it reflects the organization of an expert's knowledge base (Glaser & Chi, 1988). Programmers can recall key programming language words in meaningful clusters (McKeithen, Reitman, Rueter & Hirtle, 1981), expert programmers can also recognize and recall familiar subroutines (Soloway, Adelson & Ehrlich, 1988). Expert subjects also use a higher-level and more abstract representation of the target object (Mayer, 1988).

2. Experts are more selective with respect to relevant information.
Selectivity is manifested in perceiving the problem task as well as in applying strategies based on the information relevant to successful problem solving. In ill-defined tasks that require decision under uncertainty and which involve no single or optimally correct procedure, experts focus on fewer cues than novices. Experts also use different information, and apply different patterns of search which will allow them to take advantage of relevant information. (Chi, Glaser & Farr, 1988; Saariluoma, 1995).

In judicial decision making, Lawrence (1988) has shown that an expert's performance differs from that of a novice in terms of the amount and kind of information, and also in terms of goals that affect the inferences made, based on case details. As compared with the more patterned approach of experts, novices seem to work with single details.

Voss and Post (1988), who analysed problem-solving in the social sciences, found that experts develop a problem representation using a general strategy of problem decomposition to delineate major factors which cause a problem. These factors are then used to convert the problem into one that can be solved. In utilizing this general strategy, experts draw on their knowledge to state a history of previous attempts at a solution, and to build a case by enumerating reasons why their solution might work.

In the field of medical diagnosis, Groen and Patel (1988) have shown that in analysing textually presented clinical cases, experts make inferences from relevant information, whereas novices infer from less relevant material. The selectivity of experts with respect to relevant information can be explained by the development of a problem representation that filters out irrelevant information.

3. Experts see and represent the problems from their own domain at a deeper and more principled level than novices, who tend to represent the problem at a superficial level.

In an expert's representation, the problem is perceived in a way that is optimal for the solving of the problem. This has been demonstrated by getting experts and novices to sort domain problems and thereafter analysing the nature of their groupings. With regard to physics problems, Chi, Feltowich and Glaser (1981) found that experts used the principles of mechanics to construct categories, whereas novices built their problem categories around literal objects stated in the problem description. Similar results have been found in the domain of programming (Weiser & Scherz, 1983). When expert and novice programmers were asked to categorize programming problems, the experts categorized them according to solution algorithms, whereas the novices did it according to areas of application. These results indicate that both novices and experts have conceptual categories, but that the experts' categories are semantically or principle-based, whereas the categories of the novices are syntactically or surface-feature oriented (Glaser & Chi, 1988; Mayer, 1988).

Schmidt and Boshuizen (1993) and Schmidt, Norrman and Boshuizen (1990), who analysed diagnostic problem solving in medicine, found that students and experienced physicians seem to represent clinical cases in different ways, applying functionally different knowledge. In diagnostic problem solving medical students mainly applied biomedical knowledge, whereas experts used clinical information which was based on their prior experiences with clinical cases. Experts seemed to have a multi-faceted layer in their knowledge base and they utilized several levels, depending on the nature of the task; for example, they utilized contextual knowledge of their cases more than novices (Schmidt and Boshuizen, 1993).

Similar results were obtained by Feltowich, Johnson, Moller and Johnson (1984), who conducted expert-novice studies in paediatric cardiology. They concluded that novices' knowledge of disease structure was anchored in the most prototypical (usually the most common) instances of a disease category; it lacked cross-references and connections between the shared features of classes of cases in the memory. By contrast, the experts' memory store of disease models was found to be extensively cross-referenced, with a rich network of connections relating to diseases that can present similar symptoms. Patel and Ramoni (1997) conclude that experts are capable of reasoning at different levels of abstraction, and that methods exist for switching between levels depending on the demands of the task. Among experts the level of representation is thus highly case-specific.

Analysis of the conceptual structures of domain knowledge has shown that the knowledge structures of experts are hierarchically organized and that they have more depth in terms of conceptual levels than those of novices (Roehler et al, 1988; Ropo, 1991; Strahan, 1989). From comparisons of intermediates with experts, Patel and Groen (1991) and Patel, Arocha and Kaufman (1994) concluded that intermediates have acquired an extensive body of knowledge, but have not yet re-organized this knowledge in a functional manner to perform various tasks. Thus, an intermediate's knowledge has a heterarchical or flat structure which necessitates considerable searching; this also makes it difficult for intermediates to set up structures for rapid encodings and the selective retrieval of information (Patel, Kaufman & Magdar, 1997; Patel & Ramoni, 1997). Experts can screen out irrelevant information using their hierarchically organized schemata. The difference is reflected both in the structured organization of knowledge and the extent to which it is proceduralized to perform different tasks.

In time-restricted conditions, intermediates have difficulties. Smith and Boshuizen (1993), who used short exposure times in the representation of clinical cases, concluded that intermediates process a great deal of irrelevant information, unlike experts. Novices, on the other hand, do not conduct irrelevant searches, simply because they lack a knowledge base rich enough to support such a search. While a novice's knowledge base is likely to be limited and an expert's knowledge intrically interconnected, an intermediate may have a lot of pieces of knowledge in place, but it lacks the extensive connectedness of an expert. Until this knowledge becomes further consolidated, the intermediate is more likely to engage in an unnecessary and sometimes counterproductive search (Patel & Ramoni, 1997).

4. Experts spend a great deal of time in analysing the problem qualitatively. Protocol studies show that at the beginning of a problem-solving episode, experts typically try to 'understand' the problem, whereas novices fall immediately into attempting to apply equations and to solve an unknown. This would suggest that when experts qualitatively analyse a problem, they basically make an attempt to build a mental representation from which they can infer relations that could define the situation; they also bring in constraints to the problem (Voss & Post, 1988).

Expert programmers used more time in constructing an initial representation of the programming problem before they went on to write the code (Sonnentag, 1995; Vessey, 1985). Adelson and Soloway (1988), who analysed the software design process using protocol analysis, found that experts initially construct an abstract mental representation of the task and that this becomes more concrete as the design progresses. In addition, they found that in constructing representations, expert designers make memory notes of constraints, partial solutions, or potential inconsistencies, which eventually they will have to deal with.

In a comparison of experts and novices in software design, Jeffries, Turner, Polson and Attwood (1981) found that novices first understand that the problem has to be broken into smaller parts. Next, they add the idea that the problem should be approached iteratively, involving several cycles. At the next level, they carry out the decomposition in terms of meaningful sub-problems. Experts, on the other hand, devote a great deal of effort to understanding a problem before they attempt to break it down into sub-problems. They clarify constraints on the problem, derive their implications, explore potential interactions, and relate this information to real-world knowledge about the task. By contrast, novices show little inclination to explore aspects of a sub-problem before proposing a solution.

5. Experts have strong self-monitoring skills and they seem to make more precise evaluations of their way of dealing with the problem.
Experts seem to be more aware than novices of when they make errors, why they fail to comprehend, and when they need to check their solutions. For example, the expert physics-problem solver would often check his answer (Simon & Simon, 1978). The self-knowledge of physics experts is also manifested in their being more accurate than novices in judging the difficulty of a physics problem (Chi, Glaser & Rees, 1982). Expert chess players are more accurate than novice players at predicting how many times they will need to see a given board position before they can reproduce it correctly (Chi, 1987). Experts ask more questions, particularly when the texts from which they have to learn are difficult (Miyake & Norman, 1979). Novice learners, on the other hand, ask more questions on lower-level texts (Glaser & Chi, 1988).

Glaser and Chi (1988) argue that the superior monitoring skills and self-knowledge of experts reflects their greater domain knowledge and a different representation of that knowledge. They illustrate this dependence on domain knowledge with an example from their own work on physics. They found that expert physicists were more accurate than novices in predicting which physics problems will prove difficult to solve. When they elaborated the basis on which experts made such judgements, they found that experts relied on the same knowledge of principles as they used to sort problems into categories. By contrast, novices used more non-problem related judgements (such as 'I've never done problems like this before') (Chi, 1987). The ability of experts to predict accurately which problems were difficult and which were easy enabled them to monitor accurately how they should allocate their time for solving the problems. Glaser and Chi (1988) thus conclude that the monitoring skills of experts appear to reflect their greater underlying knowledge of the domain, which allowed them to predict problem difficulty on the basis of physics principles rather than less relevant surface features.

Metacognitive knowledge has been here analysed mainly indirectly, focusing on subjects' evaluations of task difficulty. However, there has been little analysis of subjects' metacognitive knowledge of advantageous strategies and their relation to expertise.

6. Results have been less consistent where strategies are concerned.
Studies comparing the strategies used in computer-based tasks have indicated that experienced subjects prefer a top-down strategy. Experienced subjects also seem to make greater use of external aids such as drawings and notes (Vihmalo, 1987). Case studies of highly competent software professionals have, however, given more inconsistent results. Adelson and Soloway (1985) found that experts

used a top-down strategy when working on design. Guindon (1990) and Visser and Hoc (1990) found that expert strategy was mainly opportunistic. Experts also modified their strategies more often while performing the task than did low-performing professionals (Mayer, 1988; Sonnentag, 1995).

Vessey (1985), who examined strategies in program designing, debugging, comprehension and modification, found that high performers spent more time in evaluating information and engaged in more disciplined problem solving than did low performers. In program comprehension, high performers used a cross-reference strategy which implied thinking about both the application domain and the program (Pennington, 1987). High performers thus had the same kind of characteristics in design as in other domains, in the sense that they spent more time in analysing problem requirements and evaluating the solution than low performers.

In their summary of expert-novice differences in semantically rich domains, Glaser and Chi (1988) conclude that the investigations contrasting novice and expert performances in knowledge-rich domains show a strong interaction between structures of knowledge and processes of reasoning and problem solving; in their view, the results force us to think of high-level competence in terms of an interplay between knowledge structure and processing abilities.

Although these authors emphasize the importance of interaction between domain knowledge and more general processing abilities, they place their main emphasis on domain knowledge in their interpretations of expert-novice differences. In addition to the knowledge component, however, they refer to those aspects of metacognition which manifest themselves in self-evaluation and the regulation of one's own activity. Their overall position is that the differences between less and more skilled performers in particular domains primarily reflect the experts' possession of an organized body of conceptual and procedural knowledge that can be readily accessed and used with superior monitoring and self-regulation skills.

The interpretation of findings regarding expert-novice differences in semantically rich domains has mainly followed the trends of knowledge-based approaches to expertise (Greeno, Collins & Resnick, 1996). The superiority of experts in their problem solving domain is believed to depend on the expert's possession of an extremely rich knowledge base, acquired through extensive experience. Such a knowledge-based approach has also appeared to offer a fruitful theoretical framework in analysing expertise in computer-based tasks.

With this approach, however, findings are often presented as a list of separate attributes whose relationships are not clearly specified. For example, it has not been specified how selectivity would be related to the perception of large meaningful patterns. The lack of the relationship between different attributes has meant that findings have not really been used as a basis for constructing more coherent theoretical models of expertise development. When one merely lists expert-novice differences, one tends to include findings derived from descriptions at very different levels of human activity. There is also a tendency to describe very general aspects of expertise, such as selectivity in perceiving relevant information, though other characteristics may be mentioned, such as the use of time for different task components.

For future research on expertise Glaser and Chi (1988) suggest that we must better understand the properties of domain structure and integrated knowledge. To do so, we should investigate the forms of reasoning and problem-solving strategies that structured knowledge facilitates. They further suggest that we need to understand how expertise is acquired, how it can be taught, and how beginning learners can be presented with appropriate experience.

In a summary of expert-novice studies in computer-based tasks, Mayer (1988) suggests that a lot of theoretical work is needed for the development of precise models corresponding to the knowledge of expert and novice computer users. He further suggests that future expert-novice comparisons should use a wider battery of effective measures in expert knowledge elicitation. In addition to the commonly used tasks involving problem recall, problem sorting and problem solving with thinking aloud protocol analysis, Mayer maintains that novel methods are needed to capture different kinds of expert knowledge.

In general, a knowledge-based approach to expertise research can been considered fruitful and capable of contributing to a more realistic understanding of the nature of human expertise and its learning conditions. In a recent summary, Feltowitch, Ford and Hoffman (1997b) take the view that it has established many new findings so that many aspects of cognition of expertise can now be characterized fairly well. However, the limitations of a knowledge-based approach should be considered when the generalizations of findings derived from it are evaluated.

2.5 Limitations in the knowledge-based approach, and the importance of context

The limitations of cognitive science approaches and the knowledge-based approach to expertise research have recently been discussed in various connections (Bereiter & Scardamalia, 1993; Engeström, 1992; Eraut, 1994; Gruber, 1994; Rambow & Bromme, 1995). Expert-novice comparisons which operationalize expertise mainly as a certain length of experience have been criticized, in that they tend to overestimate the role of practice as the main source of expertise. It is well known from daily life that despite having worked at something for many years, some people are still not very skilful.

Cross-sectional expert-novice comparisons have also been criticized for giving a static and uniform picture of professional expertise. Indeed, studies in knowledge-rich domains have shown that there is a lot of qualitative variety in the nature of subjects' solutions, and that such variety can tell us a great deal about the nature and quality of learning which produced the expertise. Studies addressing open and ill-defined tasks have shown that the nature and variety of subjects' experience explains experts' high performance better than the length of their work experience (Sonnentag, 1995; Waltz, Elam & Curtis, 1993) After a certain minimum length of experience, the scope and versatility of experience seem to be more important than the length of it[2].

In professional learning, the need for a redefinition of expertise has emerged from the rapid changes in working life and social conditions which have taken place in the industrialized world. As a consequence of these changes, people less often work at the same task for long periods. This has brought with it a constant need to learn the use of new tools, methods and technical facilities; this in turn involves a continuous challenge to professionals' prior knowledge and competencies.

In this context, there have recently been definitions of expertise which emphasize the need for continuous learning. Bereiter and Scardamalia (1993), who approach expertise from the perspective of a career, suggest as the central determinant of high-level expertise the subject's continuous surpassing of his or her previous level of knowledge and competence. This kind of 'surpassing oneself' means that subjects are continuously working on the limits or developing edge of their competence.

Other recent definitions of expertise also emphasize its contextual and social aspects (Engeström, 1992; Eraut, 1994; Lave, 1988; Lave & Wenger, 1991). Although different schools of thought have understood these contextual aspects differently, discussion on the role of context in the determination of expertise has gradually led to the adoption of a wider perspective; this involves the organizational, cultural and social aspects of the working and learning environment. The increased emphasis on social aspects of professional expertise has also led to the increased use of colleague or peer-evaluation in operationalizing expertise (Mutka, 1998; Sonnentag, 1995).

Indeed, the recognition of the social group[3] has been considered as the primary determinant of expertise in these definitions[4]. In the domain of service production, where customer and client perspectives are important, these perspectives can in fact be used in the definition of high-level expertise. The emphasis on contextual aspects in expertise research has also led to the substitution of laboratory environments for field studies and authentic study settings (e.g. Symon, 1998).

Despite the limitations of expert-novice comparisons made within the framework of a knowledge-based approach, these studies have significantly contributed to our understanding of how to differentiate between beginners and more advanced performers; they have also helped us to understand better the kind of changes that take place as the consequence of learning from practical

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[2] The question will be discussed at greater length in section 2.6.

[3] The social recognition of expertise has also provided an important criterion of expertise in the legitimization and licensing of professional expertise, involving competence-based evaluations (Mäkinen & Taalas, 1993) which have recently covered a number of complex professional domains

[4] In public discussion, there is considerable ambivalence and misunderstanding in relation to the concept of expertise. One misconception lies in the assumption that experts are merely specialists. Another issue in which there is ambivalence involves the power that experts possess in modern societies. Questions of power, and of the role of experts in relation to the 'ordinary' citizen, are surely an important theme for expertise research (Kirjonen, 1997); however, as sociological issues, they go beyond the focus of this study.

experience.

Nevertheless, it is clear that there has been much confusion through a failure to distinguish between experienced and high-performing subjects. Bereiter and Scardamalia (1993) have suggested that we should make a distinction among experienced subjects by differentiating between experienced experts and experienced non-experts. According to this differentiation, experts are high-performers; the non-experts could be experienced subjects, but their performance would be relatively poor.

In studies focusing on top-performances, expertise is operationalized as high-performance (Ericsson, 1996; Ericsson & Lehman, 1996). These studies have usually started with the selection of research subjects in a way that reflects their position on a ranked scale. In most domains of professional activity, however, this kind of ranking is hard to obtain, due to the contextual and normative character of professional expertise.

Previous studies of expertise in information systems design can be criticized for focusing mainly on programming tasks. Moreover, the research tasks have often been rather narrowly defined and artificial textbook tasks, and this has limited the external validity of the findings. In addition, most studies of software design have been conducted as individual sessions, although design and development usually involve interaction and dialogue between different designers and with users. Research tasks have often been formulated in such a way that the interaction and dialogue aspect is disregarded (Sonnentag, 1995).

In previous studies, the external validity of the findings has also been limited by the selection of research subjects. In many expert-novice comparisons, research subjects have been chosen in such a way that the novices are students at the initial stages of their studies, and the experts are students who have studied considerably longer. Professional subjects have not always been used, even if the findings are supposed to be generalizable to professional expertise.

The limitations of research tasks and study settings have not allowed subjects to use their various knowledge domains, especially those connected with contextual and situational knowledge. It is thus understandable that these knowledge domains, even if they would have had central importance for professional problem solving, have not been manifested as expert knowledge. This is one important reason why we should redefine expertise in a way that incorporates contextual and strategic aspects. And indeed, following on criticism of previous expert-novice studies, much recent research has attempted to use approaches which would capture human expertise in its authentic contexts.

Professional expertise and contextual knowledge. The need for a redefinition of professional expertise has been increasingly discussed during the 90s. The central theme in this discussion has been that the role of context should be seriously considered when expertise is addressed. Many researchers now take the position that the analysis of expertise should not separate itself from the context of the expertise, context being seen an essential component of the expertise. The general theme of emphasizing the role of context has been common to different theoretical approaches (Brown & Duguid, 1994a, 1994b; Gruber, Law, Mandl & Renkl, 1995; Hoffman, Feltovich & Kenneth, 1997;

Moran, 1994, Norman, 1993). However, there are also considerable differences between schools concerning what is to be understood by the concept of context. Thus, anthropologically oriented approaches have defined context as socially and culturally conditioned aspects of practical communities, whereas cognitive science approaches have seen the context as constituted by environmental circumstances and also by the characteristics of artifacts which determine the nature of human activities.

Although there has been active theoretical discussion on the role of context, there is not much empirical research on how the context becomes present as subjects reason on problems within their domains. Those few studies which deal with this issue have supported the suggestion that contextual issues have different roles at different stages of acquiring expertise. Expert-novice comparisons made in knowledge-rich domains have shown that the role of context is more important for experts' decision-making than for that of novices. Among novices, context has a minor role and is thus more or less separated from decision-making activities. Schmith and Boshuizen (1993) found that in a recall task, expert physicians were able to recall more of their patients' contexts than novices; moreover, in diagnostic tasks, expert physicians made more use of their contextual knowledge of their patients than novices. A lack of such knowledge also seemed to have a greater effect on the quality of the diagnosis among experts than among novices.

Beyond these studies, there has so far been relatively little research on the role of context and how it is connected with subjects' development of expertise. At present it is true to say that the issue of context has generated more theoretical interest than empirical investigation. One of the most influential theoretical models describing the different roles of context is the model suggested by Dreyfus and Dreyfus (1986). In the domain of human-machine interaction, Suchman (1987) has also presented an influential discussion from the perspective of situated action. These models will be dealt with in the later sections of the thesis.

The next section will summarize previous research, and look at how previous studies have understood and operationalized the role of experience in learning and expertise.

2.6 Experience in explanations of expertise

From the very beginning, psychological research has addressed the relationship between human memory and individual experience. When Ebbinghaus (1885/1964) introduced the experimental approach to studies of memory, he was keenly aware that the most important factor in memory is the subject's individual experience. Ericsson and Kintsch (1995) maintain that this was why Ebbinghaus used nonsense syllables as test material: to eliminate or minimize the effects of individual's relevant experience, since this was regarded as a source of error when one was attempting to extract generalizable laws of pertaining to human memory systems.

In first generation theories of expertise research (which include the ACT model of cognitive skill acquisition) the relationship between expertise and experience is understood, quite simply, as a matter of length of experience or amount of practice. Approaches based on the associationist tradition explain the learning and acquisition of cognitive skills in terms of a selective strengthening of those encodings which are most used and practiced. The defect of such models is that they do not really explain why certain connections do in fact strengthen. An explanation based merely on the selection of connections is not sufficient as an explanation of complex cognitive skills acquired under changing conditions.

Practice was emphasized more in the associationist models of learning than in the schema-based approaches. In the latter, it was supposed that the schema includes something more general than merely connections arising from selective reinforcement. The schema as a concept represents a construct that is the outcome of subjects' prior experience. As such it has the function of focusing on the subject's perception and information intake and thus acting as an intermediary between the subject's background experience and present way of perceiving the world.

However, the relationships between past experiences and schemata are very complex, since a schema represents a kind of generalization from experiences. Schema theories do not have much to say about how these generalizations emerge, and how they change as a consequence of experience. In the case of story schemata, for example, it is commonly asserted that as a consequence of having experience with stories, children develop for themselves a story schema. The story schema thus represents a generalization from different stories. However, schema theories do not provide us with explanations of how this is taking place. We are not told whether some experiences have a more crucial impact on the construction of the schema than others; or how additional information might alter the schema; or how the schema is modified when contradictory or conflicting information is presented. Although schema theories have recognized the importance of the subject's prior knowledge for the selectivity of information intake, they do not in themselves specify the nature of this relationship. And thus they cannot specify the relationships between prior experience and expertise in general.

In research on semantic memory, the relationship between experience and expertise can be addressed in the distinction made between semantic and episodic memory. This distinction, and the interaction of these memory systems, has importance when we try to understand how the personal experiences gained during subjects' personal histories interact, or how they have an impact on subjects' conceptions and knowledge of a domain.

The distinction between semantic and episodic memory was first made by Tulving (1972). While semantic memory consists of conceptual knowledge and knowledge of meaningful contents of the surrounding world, episodic memory is closely tied to subjects' own experiences and thus the specific features of time, place and situations (Bransford, 1979). Semantic memory was originally considered to consist mainly of verbal meanings, but later it was thought to involve all our knowledge of the world around us. Episodic memory was supposed to contain personal memories of subjects' life events and being thus dependent on situations. By contrast, semantic memory has been described as relatively independent of situations, in the sense that information stored in the semantic memory does not necessarily contain memories of particular episodes or subjective experiences of where and when the information was originally coded or acquired.

Although the interaction of episodic and semantic memory is little discussed in the literature, we can suggest that these memory systems interact. Semantic memory is enriched when we generalize from the experiences we have gathered into our episodic memory. For the development of expertise as a consequence of subject's domain experience, it would seem that an interaction between semantic and episodic memory is necessary. Furthermore, we may assume that such interaction is also necessary for the construction of functional relationships between a metacognitive knowledge of advantageous working strategies and the use of such strategies in problem solving.

Considered from a wider point of view, the interaction between semantic and episodic memory systems would indeed seem a necessary condition for the existence of any kind of relationship between domain experience and expertise. If human episodic memory - consisting of personal experiences - did not interact with semantic memory, one would almost be obliged to exclude a connection between subjects' experiences and their conceptions of the world. The connections between subjects' immediate perceptions and their conceptions have been confirmed by number of studies. Some of these have addressed, for example, children's conceptions of the physical world: Vosniadou (1992) showed that there is a close correspondence between children's early concepts of planetary systems and what they have observed during their early experiences.

However, the question of mutual enrichment and interaction between conceptual representations and subjects' prior experiences becomes far more complicated when we focus on knowledge-rich domains of expertise. In such domains, subjects have to acquire a great deal of factual and conceptual knowledge before they can start to acquire relevant personal experiences. During their education, subjects acquire the conceptual knowledge which it is thought they will later call upon in their various domain activities. Memory research does not tell us how this conceptual knowledge is used and transformed in the course of acquiring practical experience within the domain; this is despite the fact that in the literature on professional learning one finds plenty of discussion concerning inadequate or non-existent interaction between conceptual knowledge and practical experience. Mandl, Gruber and Renkl (1994), for example, refer in their discussion to 'inert' knowledge; by this they mean the knowledge that subjects have acquired but not applied in problem solving.

Expert-novice comparisons made in knowledge-rich domains have addressed the relationships between expertise and experience from two main perspectives. In the first place, these studies have frequently operationalized expertise as a certain length of professional work experience; thus novices are those who have the domain education but little or no work experience, whereas experts are subjects who have in addition to their domain education a considerable amount of work experience. In determining the limit of minimum experience, there is variation depending on the domain. Two years is the minimum length most often adopted, since this is usually the time during which subjects are became familiar with their work organization and working conditions. Some professional associations demand a certain minimum length of experience before professionals can apply for membership of the association. For example, in legal profession, this minimum length is usually four years.

The minimum length of necessary work experience will naturally vary, depending on the task domain and, for example, on the amount of practical experience which has been built into the student curriculum. In systems design as well as in other design tasks, it is considered important that subjects should have had a minimum period of training during which they will have completed at least one authentic project, including feedback from clients and users. The working conditions of designers do not always allow them to get proper feedback from their work (Rambow & Bromme, 1995); this is often the case, for example, with architects. Nevertheless, the length of projects would normally be considered when setting minimum requirements for the length of experience.

With regard to professional tasks, there are few studies which have analysed the qualitative aspects of experience. Wang and Horng (1992) compared educational-based and experience-based experts in business management. They found that experience-based expertise, observed from managers and novices, was characterized by a solution-focused and heuristic cognitive strategy. By contrast, education-based expertise, observed from students with higher levels of education, was characterized by a systematic and knowledge-based cognitive strategy.

Schmith and Boshuizen (1993) compared two kinds of medical experts in their use of medical knowledge: those with clinical experience and those with research experience. The authors found that those physicians who had experience as researchers were similar to students in their use of biomedical knowledge. By contrast, those experts who had had actual clinical experience used their clinical knowledge: this clinical knowledge is regarded by the authors as an encapsulated form of biomedical knowledge (see also Van de Wiel, 1997).

Other studies referring to the quality of subjects' background experience are mainly case-studies or demonstrations from single subjects. These studies have usually specified the nature and quality of the subject's education and work experience in content-specific terms (Chan, 1990; Jeffries, Turner, Polson & Atwood, 1981). However, these studies have not aimed at generalizable results concerning the quality of experience.

When we turn to studies of top-performances, for example those in sports and music, we find a more systematic focus on the background conditions under which the skill is practised. These studies have provided valuable knowledge of the circumstances which were present during the top-performers' life history. Although the studies may be limited in their domains of analysis, they can provide valuable knowledge of some of the general conditions under which expertise develops.

Given that the length of experience within a domain is generally a weak predictor of performance, recent research has tried to identify the most effective training activities for improving performance within the domain (Ericsson, Krampe & Tesch-Römer, 1993). According to biographies of and interviews with elite chess players, the best practice activity that they can engage in by themselves for extended periods is the study of previous chess games between chess masters. During the study of such a game, the chess player would try to predict each move made by the chess masters. In case of failure to predict a move, the chess player would then study the associated chess position more carefully and plan out move sequences to a greater depth in order to uncover the reasons for the chess masters' actual move. Studies have found a high correlation between the estimated amount of this type of chess study and the chess rating of a large group of tournament players (Ericsson & Charness, 1994).

Studies on exceptional performance have revealed how beginners acquire complex cognitive structures and skills that circumvent the basic limits confronting them (Ericsson & Chase, 1982). However, researchers have not uncovered any simple strategies that would allow non-experts to acquire expert performance rapidly. Analyses of exceptional performance involving for example exceptional memory or absolute pitch, have shown how it differs from the performance of beginners, and how beginners can acquire skill through instruction in the correct general strategy, with corresponding training procedures. However, to attain exceptional levels of performance, subjects must in addition undergo a very long period of active learning during which they refine and improve their skill, ideally under a supervision of a teacher or coach. Ericsson, Krampe and Tesch-Römer (1993) use the term 'deliberate practice' to refer to these individually planned programs of training activities which appear to be necessary to attain high-level performance.

One of the significant observations derived from the studies on top-performance is that nobody achieves a high level of performance in any domain without a great investment of time. Biographical studies have confirmed that in a number of domains, the minimum period of practice needed to attain excellence seems to be about ten years of intense preparation (Ericsson & Charness, 1994; Ericsson & Lehman, 1996). Hayes (1987) has also estimated that it takes ten years to achieve a master´s levels of performance in most professional domains. The 'ten years' rule' has usually been thought to indicate that problem-solving expertise does not come from a superior problem-solving ability, but rather from successful domain learning.

In various domains of human everyday and working life as well as in educational contexts, people acquire skills under less structured conditions - conditions that lack strict and generalizable criteria for evaluation. The conditions also vary from one individual to another, depending on the particular circumstances of their lives. By contrast, stable expert performance is typically restricted to standardized situations in a limited domain, where the criteria for top-performance can be precisely specified. These criteria also provide a shared goal for individuals, one which directs and constrains their often life-long efforts to attain their maximal performance.

Ericsson, Krampe and Tesch-Römer (1993) suggest that the study of expert performers and their teachers offers an almost untapped reservoir of knowledge about optimal training and training methods. This knowledge has been accumulated in many domains over a long period. Ericsson, Krampe and Tesch-Römer have, for example, found evidence for an intriguing invariance in the duration and daily scheduling of practice activities. They suggest that further efforts are needed to investigate training and the development of training methods, and to derive principles that generalize across different domains. Above all, we should seek a better understanding of the social and other factors that motivate and sustain performers at an optimal level of deliberate practice. Such an understanding would have direct relevance to motivational problems in education.

Research on professional learning and expertise - which has traditionally been separated from the analysis of exceptional performance - could benefit from top-performance studies, since the latter have had better study designs and contained more intensive analyses of cases. However, longitudinal studies are needed to elaborate whether similar conclusions could truly be applied to the development of expertise in working life. So far, most studies of top-performances have been carried out on activities such as sports and music where the emphasis is on senso-motor performances. There have been fewer studies on complex problem-solving domains where the solution criteria are difficult to define. The generalizablity of findings derived from prior studies is clearly limited when we come to ill-defined problem domains such as we find in information systems design.

From their analysis of top-performance in various domains, Ericsson and Smith (1991b) suggest that future research on expert performance would gain most from a taxonomy of the various mechanisms acquired through various learning and adaptation processes - and not by restricting the definition of expertise to a specific type of acquisition through learning. This would imply a strong content-specific approach which would first of all aim to understand the specific characteristics of the activity in question. Since design activity is the main focus of this thesis, the next section will address the nature and structure of this activity.

2.7 The nature of design

2.7.1 Design and development as an area of ill-defined problems

The pursuit of a science of design, which has existed as a goal within cognitive science since the 1970s, has produced a description of design activity as an ill-structured, ill-defined and open problem domain, with much the same characteristics irrespective of the actual design content (Simon, 1973). Thus, architectural and engineering design has been perceived from the same perspective as instructional and information systems design.

Although the borderline between well- and ill-defined problem domains is vague, and dependent on the level of analysis adopted, it has been agreed that the work of a designer involves tasks near the ill-structured end of the problem continuum. In so far as the designer is trying to be creative, design tasks can be considered as ill-defined and ill-structured in a number of respects (Simon, 1973). First of all, there is initially no definite criterion to test the proposed solution. Secondly, the problem space is not defined in any meaningful way, for a definition would have to encompass all the kinds of structures which the designer might at some point consider. Even if we were to argue that the problem spaces can in principle be defined, some of this information shows up only in the final stages of the design process, after a great deal of searching.

Nevertheless, in any design process there are conditions and circumstances that in some way limit or constrain the process. The term 'constraints' was initially used rather broadly to refer to any or all of the elements that enter into the definition of a problem (Reitman, 1965). In design problem solving, the designer usually starts by deriving some global specifications from the initial goals and constraints. Later, the task itself, such as designing a house, evokes from the designer's long-term memory a list of other attributes that will have to specified at an early stage of the design. These include the characteristics of the ground on which the house is to be built, its general style, whether it is to be multi- or single-storied, etc., together with some system for organizing the design work, methods of drawing sketches, etc. All these issues can be considered as constraints which are not always set out in the design assignment but which must be taken into account by the designer.

Voss and Post (1988), who studied problem solving in social sciences, describe ill-structured problems as problems in which there is little consensus regarding the appropriate solutions; the problems include open constraints that are resolved in the course of finding a solution. However, as the solution proceeds, the problem may become at some point well-defined. This takes place, for example, when the initial task is broken up into a set of well-structured problems which are then solved. Voss and Post found that in order to be able to do this, experts must have a relatively large amount of information in their memory so that they can utilize appropriate components of knowledge to reach a solution. Ill-defined problems are also typically found in the social sciences and in judicial decision-making.

Of course, the same task domain may include both ill- and well-defined problems. Simon (1973) argues that many kinds of problems which are often treated as well-structured are better regarded as ill-structured. For example, the ill-structuredness of chess playing becomes fully evident when we consider the course of an entire game, and do not confine our view to just a single move (Simon, 1973). The same is true of software design. If software design is analysed at the level of writing a piece of program code using a specific programming language, it can be perceived as a well-structured task. By contrast, if a systems analyst is asked, for example, to design a virtual learning environment which promotes students' understanding of science concepts, this represents a very ill-defined task.

The difference between ill- and well-defined problems has been illustrated by Rowland (1993) who considers the respective task of an architect and a mathematics student. When an architect is asked to design a new building, he or she has an idea of how to proceed, but cannot be certain that this will lead to an effective design. An architect attempts to create a design that satisfies the requirements of the owner and user of the house, but he or she can never be entirely sure that all the requirements have been identified, which variations in the design components best accommodate the constraints of the situation, and how stable the requirements will be over time. The process and criteria were not clear at the beginning, and the adequacy of the solution is not entirely clear at the end.

By contrast, a mathematics student who is presented with a problem searches the problem statement for the variables that are involved, and for which values are given and which must be found. The student tries to understand what the problem is, identifies the problem as being of a certain type, obtains an appropriate formula, applies it and derives the solution. The instructor reviews the student's solution and marks it correct, meaning that only one single correct solution is known to the instructor.

Both examples involve problem solving, but only the architect's task can be regarded as ill-defined. The mathematics problem is well-defined because it has a single correct solution that the instructor or anyone else with the appropriate knowledge can obtain, given the problem statement. The initial conditions, and appropriate and efficient paths to the solution can be identified up front. This is not the case with the building problem. An almost infinite number of solutions to the same problem are possible, and one can never say with certainty which solution is best. One can only hope for a satisfactory solution that meets most or all of the requirements. Neither the initial conditions nor the most appropriate and efficient process by which to obtain a satisfactory solution are entirely clear. Moreover, the complexity of the problem is not the key distinction. A mathematics problem can be very complex, but the initial conditions of the problem, a single solution, and a limited number of paths to that solution are generally agreed upon.

Because design-problems are ill-defined, the designer never has all the information; design problems are not susceptible to exhaustive analysis (Cross, 1982). Rowland (1993) suggests that this is the main reason why designers tend to be solution-focused rather than problem-focused.

In design problem solving, the problems must thus be both found and solved. Since we can suppose that individuals interpret and understand problems differently, it can be argued that each individual solves a different problem rather than just generating a different solution to the same problem (Lawson, 1980; Rowland, 1993).

In designing, the process of problem understanding and problem solving may be simultaneous or sequential. Systems engineering models, which are presented in the literature as prescriptive models, typically call for complete understanding of the problem prior to efforts at a solution. Problem understanding and problem solving are to be carried out sequentially, and preconceptions are to be avoided. The solution concept is sought only after all necessary data have been obtained (Rowland, 1993). Such models suggest that a designer is engaged in a series of formal steps or stages, one after the other, and that a description of the problem and definition of the goals are completed at the end of the problem definition phase.

The use of sequential models in design can be seen as severely restricting the designer's ability to understand the problem, since in design problems, understanding is developed through efforts to solve the problem (Robinson, 1986). The two processes of understanding and solving the problem can thus be regarded as interdependent and simultaneous or cyclical, with goals being gradually uncovered in the context of attempts at a solution. Lawson (1980) has argued that in design problem-solving the solving and the solution emerge together; one does not follow logically from the other, and this makes the process of design dynamic and unpredictable.

Looking at different conceptions of design, Robinson (1986) found empirical support for the exploratory nature of design. In design as exploration, preconditions applying to the design assignment are sought and then subsequently challenged. Rather than attempting to withhold judgments, the designer makes preconceptions explicit then subjects them to analysis, evaluation, and criticism.

Designing has also been understood as a process of converting information originally presented in the form of requirements into the form of specifications (Hubka & Eder, 1987). When the need for some new product is recognized, the designer's job is to identify what the new product must do and to create something that will satisfy the requirements.

In order to make the transformation from requirements to specifications, the designer needs to have learned a language or system of codes. To the information obtained from the situation the designer adds an 'ordering principle' through which the abstract patterns of user requirements are turned into the concrete patterns of an actual object (Cross, 1982).

Although designing can be seen as an exploratory process, designers often employ systematic methods, i.e. they follow a series of general steps or stages, such as problem definition, analysis, design, development, and evaluation. These methods typically involve solving problems by breaking them down into sub-problems which can be understood and solved separately, then recombined. The designer continues to balance resources and organize the design process according to the relationships between the sub-problems, and a series of problem-solving cycles is implied (Carroll, Thomas & Malthora, 1980; Rowland, 1992, 1993; Thomas & Carrol, 1979).

Breaking down problems in this way has been criticized, in that it may lead to costly, unduly large and poorly integrated designs in which the parts rather than the whole are optimized (Järvinen, 1980; Järvinen, Kirjonen, Tyllilä & Vihmalo, 1982). As an alternative to a systematic decomposition and specification of sub-problems made at the initial stage of the solution, the designer may await the emergence of sub-problems during preliminary solution attempts, and, by focusing on sub-problems as they arise, find a more elegant solution to the whole. Thomas and Carrol (1979) have suggested that this is a much more dynamic way of approaching design problems. Cycles of problem solving are derived dynamically during the design process, these may vary in duration and extent, and sub-problems can be addressed when and in whatever form they present themselves.

In the development of a systems approach to instructional design, Rowland (1992) emphasizes that thinking of design problems and solutions as elements of prospective systems is important in generating elegant and effective designs. As Kerr (1983) points out, designing ultimately involves personal choices based on a sense of what is right. A systematic approach or method is not in itself a mechanism for making these decisions and may provide only a framework in which the decisions can be made (Rowland, 1993).

The design process has been also considered as a learning process. More traditional approaches perceive only one learning subject, namely the designer, whereas more recent approaches involve also the user in a collaborative process of learning. Jones (1979) has suggested that by engaging in design, the designer discovers what he or she knows and does not know about a problem and its solution. Filling the gap is a learning process. In a sense, each action generates an answer to the question that enables the next question to be posed. Robinson (1986) perceives design as a knowledge-building cycle in which the designer makes hypotheses (predictions relating the anticipated outcomes of each action to features of the design product), challenges them, and develops arguments to support them. Jones (1979) sees the design process as one of devising and experiencing a process of rapid learning about something that does not yet exist, by exploring the interdependence of problem and solution, the new and the old.

In the domain of information systems design, Lyytinen (1987) has classified some models over two dimensions, namely the target and the nature of the system being developed. The target may include the technical or the social system; the nature refers to whether the system operates at the individual or the group level. If the target system includes a technical system and the system is perceived from an individual perspective, the models are typical engineering models, such as the traditional life-cycle model. Models focusing mainly on technical systems and having mainly a group-level perspective include prototyping. If the target of the development is perceived as the social system and the nature of the development covers the individual perspective, these are typical learning models. If models cover only the social system, they are models which address organizational change. Models which include also the technical system are called models of evolutionary design. Group-level models focusing on social systems include dialogue models, which focus on negotiations between different parties or the process of discourse.

Traditional conceptions and models of design can be criticized for their viewing design as a solitary individual activity; the interaction between designers and their organizational context is simply not there. Traditional models have also described design problem-solving as a very professional-centred activity. The users of the prospective system are not admitted within the process of designing. Neither are the users considered as collaborators who would work interactively with the designer. More recent conceptions of design have, however, emphasized that the users should be involved in a process of collaborative design (Schuler & Namioka, 1993). Thus, the design process has been perceived as teamwork rather than the activity of a single professional.

2.7.2 Design as reflective and situated action

Schön (1987) conceives designing from a very broad perspective. He criticizes Herbert Simon's (1981) narrow understanding of design as instrumental problem solving, which in its purest form is merely a process of optimization. Schön claims that the cognitive science view ignores the most important functions of designing in situations of uncertainty, uniqueness, and conflict, where instrumental problem solving and optimization have a minor role.

Schön (1987) perceives designing as a kind of making which involves complexity and synthesis. This means that unlike analysts or critics, designers put things together and bring new things into being; in so doing they deal with many variables and constraints, some initially known and some discovered through the design process. Almost always, the moves of designers have consequences other than those intended. Designers juggle variables, reconcile conflicting values, and manoeuvre around constraints - a process in which, although some design products may be superior to others, there are no unique right answers (Schön, 1987).

If design activity is perceived from such broad perspective, design expertise can be perceived as a competence for managing complexity, for imaging an ideal to be realized in practice or for conducting a search within a field of constraints. Starting from situations that are at least in part uncertain, ill-defined, complex, and incoherent, designers must construct and impose a coherence of their own. Subsequently they should discover the consequences and implications of their constructions, some of which will be unintended. Evaluation and criticism play critical roles within the larger process. Designing becomes a web of projected moves and discovered consequences and implications, sometimes leading to reconstruction of the initial coherence - a reflective conversation with the materials of a situation (Rowland, 1993; Schön, 1987).

This conception suggested by Schön (1987) involves a very general understanding of design. Schön even goes so far as to perceive all human constructive and creative activity as design. Thus, he perceives all professional practitioners (as well as artists) as makers of artifacts and in this sense, designers. Artists are clearly designers since they make things such as poems, pictures, and narratives. But lawyers also build cases, arguments, agreements, and pieces of legislation. Physicians construct diagnoses and regimens of testing and treatment. Planners construct spatial plans, policies, regulatory arrangements, and systems for the orchestration of contending interests (Schön, 1987).

Schön (1987) also perceives professional practitioners as designers in a more general constructionist sense. In his view, whenever professionals conceptualize and frame problems and situations and match them with their professional understanding and the methods they have available, they are in his sense makers of artifacts (see also Filander, 1997; Heiskanen, 1996). Hence, Schön perceives all practitioners as design professionals. However, as the prototype of designing he focuses on architectural design.

Schön's (1987) conception of professional practitioners undoubtedly represents a very advanced model of the modern professional. His definition of the reflective practitioner was originally constructed as an antithesis to the view of professional problem solving as mere technical reasoning. His model of the reflective practitioner has since had significant influence in promoting innovative practices in professional education. The main defect of the model, however, is its isolation from concrete empirical research on, for example, metacognition. Thus the definition of the reflective practitioner has remained an idealized conception of an advanced professional.

A different conception of design has been suggested by Suchman (1987) who perceives designing from the perspective of situated activity. Suchman looks especially at the way designing is determined as a socially and culturally conditioned activity. She distinguishes between different ways of planning, contrasting situated action with plans. Situated designing is characterized as an activity which recognizes that the unexpected things in the path of designing are not only obstacles to be overcome, but also opportunities for new views on the problem. These can produce new elements for the designer to utilize in performing the new action.

Suchman (1987) perceives situated action as action in response to a situation which is being encountered. Its function is not, however, merely to respond to a stimulus. It serves to shape the situation for subsequent decisions, and it does so in ways that are not entirely predictable. Thus, the environment or situation is dynamic, not static, and each action is performed in terms of the effects of previous actions (Suchman, 1987).

This is what distinguishes a situated action from a plan. A plan is fashioned prior to, rather than during, a series of actions. Those who rely heavily on plans assume that the path that needs to be taken is predictable. Plans are therefore more consistent with the rational view of designing, one that sees problems as well-defined, while the notion of situated designing is more consistent with a creative view, one that sees problems as ill-defined (Rowland, 1993).

Suchman (1987), who has a background in ethnography, has analysed design as a culturally conditioned phenomenon. She illustrates different conceptions of design by showing differences in the way a western and a Turkese navigator proceed while trying to keep their orientation. Ways of planning do seem to vary in different cultures depending on the historical traditions they adhere to.

2.7.3 Competence and expertise in design

Just as there have been conceptions of what design is, so there have been many conceptions of the skills and abilities required of a designer. Jones (1970) presents three possibilities via a series of metaphors (possibilities which themselves correspond to actual historical trends). Thus, the field has moved from the concept of the designer as magician, where the process depends on creativity, to the concept of the designer as computer, where logic is paramount. More recently, a concept of the designer as a self-organizing system has become popular.

Schön (1987) has emphasized that design expertise does not lie only in knowledge and skill, but in the designer's ability to reflect on his or her own actions. This is strongly based on his conception that the design process is carried out as a reflective conversation with the situation. The designer is perceived as a self-organizing system which has to reflect on its own actions. This means that the designer must be capable of monitoring and controlling both the rationale and the creative processes, knowing when to apply varying strategies and tactics.

Howard (1985) classifies the knowledge needed by information systems designers. He sees designers' reasoning as concerning the interaction between four knowledge classes as follows:

* The environment, which is the physical and social context of information systems
* The user, which is a generic term for human agents using the system
* The software, which includes the user interface, programs, and supporting applications
* The hardware, which includes computers and interactive devices.

Further distinctions are made in each category. The model tries to capture the diversity of knowledge drawn on during design.

In a field study, Curtis, Krasner and Iscoe (1988) analysed 17 professional software development projects to identify the characteristics of those professionals who were considered exceptional designers. The authors found three main characteristics of high performers. Firstly, they knew the application domain of the software extremely well and were able to integrate their knowledge of the application domain with their computer knowledge. Their knowledge of the application domain was mainly acquired through experience, not by training. Secondly, exceptional designers showed exceptional communication skills. They educated other team members about the application domain and its relationships with computational knowledge. Thirdly, they had a high degree of identification with the project and its success. The study thus demonstrated in addition to cognitive aspects the importance of motivation, social skills and communication skills for professional designers (Sonnentag, 1995; see also Feldt & Ruoppila, 1993).

When the competencies required of a designer have been discussed, designing is seen as involving both technical skills and creativity, both rational and intuitive thought processes. Rowland (1993) suggests that a certain balance between technique and creativity seems to be necessary. For example, technical skills and rationality are required to analyse the situation and to identify requirements, while creativity is important in coming up with ideas for a new product. Furthermore, the competencies of designers is thought to lie not only in having knowledge and skill but in their ability to reflect their own actions.

2.7.4 Design, development and comprehension as human activities

Design and development are activities which involve the goal-setting and constructive aspects of distinctively human mind. In designing and developing a new product, designers set themselves original goals and novel ideas as guides for the future; in so doing they engage in an intentional activity which can affect our environment and social conditions. This implies that designers have to integrate a normative component into their activity when they define the goals and objectives entailed by their task.

Such a normative component implies that design problems will always require subjective interpretation, and this will involve problem finding, delineation (discovering) problem constraints and suggesting a solution. Although a design problem is presented in terms of an unambiguous statement, these statements are never so complete as to exclude uncertainties and encounters with new problems as the design process goes forward. Because the design and developmental activity constitutes an endless process of finding as well as solving problems, it actually represents a mode of thinking where problems and solutions emerge together rather than following logically upon each other.

Because of the ill-defined nature of design problem-solving we cannot determine one single optimal solution to a design problem. In principle, there could be countless different solutions. Furthermore, we can be quite sure that even if we have a substantial number of subjects in our study, we will not end up with an exhaustive collection of all imaginable solutions. In view of this general characteristic of design activities, they can be regarded as creative and heuristic rather than as algorithmic processes. The creative nature of design tasks is similar to that of writing tasks. Bereiter and Scardamalia (1993) state that the results of such tasks can be explicated only after they have been materialized in an end-product.

At first glance, as a form of human cognitive activity, comprehension seems a very different kind of endeavour from design and development. Yet a closer look reveals that comprehension shares features with design tasks. At a basic level, comprehension is an essential component in tasks like design and development and is, like them, open and ill-defined in nature. Of course, there are differences too: comprehension is 'inwardly' directed, whereas design is oriented to producing an external products. In real-life contexts, however, the inward/outward aspects of comprehension and design are intimately intertwined with each other. The construction of a high-quality artifact presupposes that the designer adequately understands the task assignment and the constraints. Such an understanding is crucial for the successful accomplishment of the task. On the other hand, when we look at the phenomenon of comprehension, we see that we cannot capture the inner process of comprehension without the notion of an external representation. A valid external representation of the comprehension process could be an initial memory sketch of the target object. Any kind of modification of the target object could also be used as an indication of a person's understanding of it. In the present author's own study of subjects' comprehension of computer programs, such externalizations were used as indicators of comprehension. Furthermore, the analysis of the comprehension process showed that some experts tended to make a drawing of the target program as they sought to understand it (Vihmalo, 1987). They thus used externalization as a tool for making a visible representation of their understanding.

The empirical analysis of design expertise has repeatedly shown that there is great variability in subjects' solutions, as much within expertise levels as across them. The solutions produced will vary whether we have replications of the problem with different individuals or the same individual on different occasions. In well-defined tasks this variability has traditionally been described in terms of subjects' taking different paths to solve a problem and also in terms of occasional errors in their solutions. Yet although this may be appropriate for well-defined tasks which have strict solution constraints, explicitly set out in the task assignment, and a single correct solution, the situation is quite different in tasks which have an open goal-state - 'open' in the sense that many solutions are possible and the task constraints are not precisely stated in advance.

One basic way of approaching such variability within the canonical framework has been to attribute the differences in solutions to differences between the cognitive models of different people, or between the cognitive models of the same person at different times. However, this leads to a style of theorizing in which separate models are proposed for each subject. Anderson (1993) states that this creates a frustrating problem of generality in the claims that can be made. Brown and van Lehn (1980) have also looked at variability attempting to account for errors in terms of 'bugs', meaning misconceptions about the problem domain. The term 'bugs' comes from an analogy with programming where a program can have an error that leads to a systematic mistake. It was hoped that one could come up with a theory of the origins of these bugs in terms of the learning history of the students. An account of variability based on learning would be a way to achieve generality. Unfortunately, subsequent research has cast doubt on the systematicity of these errors. Students are found to be unsystematic in the errors they make (Anderson & Jeffries, 1985; van Lehn, 1996).

Previous research on design expertise as well as on expertise in other complex domains of problem solving has suggested that there is great qualitative variety in subjects' solutions (Christiaans, 1992; Seitamaa-Hakkarainen, 1997; von der Weth & Frankenberg, 1995). Alternative ways of studying such domains have been sought since cognitive science began to concern itself with design science. These methodological alternatives have been discussed in the framework of a canonical conception of problem solving which has aimed at causal explanations. Yet the goal of causal explanations, (which has been dominant in experimental and cognitive psychology), is not really applicable if one aims to understand the qualitative nature of design expertise and its developmental background.

2.8 Functional explanations in research on design expertise

Saariluoma (1997) has shown that cognitive psychology has so far been oriented to causal or teleological explanation, which is inadequate when content-specific aspects of information processing are to be investigated. Since functionality seems to be a very basic characteristic of the human mind, the functionality of representations would itself seem to provide an explanation of why certain elements or pieces of information have relevance, or why they belong together (or make sense in connection with each other). Saariluoma thus claims that functional rather than causal explanations are required when we explore the characteristics of human mental representations.

Saariluoma (1997) argues that the functionality of artificial and man-made things follows the functionality of the human mind. He further claims that cognitive psychologists' belief in a general causal model of explanation has been unfortunate, since it has unnecessarily turned attention away from important content-specific connections towards a pseudocausal formalism when explanations of mental contents are being constructed. He suggests that instead of causal or teleological explanations, functional explanations should be sought when the contents of mind are considered[5].

By functional explanation is meant explanation in which a part of a system is explained in terms of its function within this particular system. The goal of functional explanation is to explicate what kind of functions the elements of the system serve in the whole. The function of a move in chess may be, for example, to block the attacker's path of attack. This simple function explains why the move is included in the representation. The function of a handle on a cup is to allow drinkers the possibility of keeping it firmly in their hands[6].

Saariluoma (1997) further makes a distinction between functional explanation and functional analysis. By functional analysis is meant the definition of the roles of the parts within a functional system; a functional explanation attempts to use the functional roles as explanations. Functional explanations are necessary in explaining the representational selection processes and structures of representations. General causal laws for their part cannot explain meaningful structures, as there is no way to incorporate the necessary selectivity within causal schemata.

One might wonder whether functional explanations make generalizations about representational contents impossible. Saariluoma (1997) states that there are in fact ways to generalize about such contents. One can investigate how common certain representations are in a given population. One can also develop theoretical concepts for one task environment and use the same or similar concepts to resolve problems in other task environments. Thus, the use of functional explanations in investigating mental contents in no way excludes the pursuit of general explanations.

In analysing the nature and development of expertise in IS design, this thesis will address subjects' mental contexts with regard to the nature and organization of their domain knowledge, problem solving and metacognition. In examining these mental contents, the present study aims at a functional explanation. This means that the study aims to explicate why the mental representations of central topics within a domain have a particular quality: why certain elements are in these representations, and what kind of functions the elements in the system serve within the whole. However, in addressing the

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[5] As evidence of the functionality of human mind, Saariluoma (1997) argues that man-made objects or social systems all seem to have very similar structural properties as representations of minds. As an example he takes the components of houses which are not random, but serve certain functions. The walls protect against cold and wind. The roof protects against rain and sun. The windows, which serve to provide light and allow us to look outside, are made of glass for this purpose. The materials of the different components have been selected so that they best serve the functions these elements have within the whole. A house is thus an example of a functional whole, as each of its elements has a function within the whole.

[6] At least this is primary explanation of the handle, although strong causalists might regard the manufacuring process as the immediate explanation (Saariluoma, 1997).

relationships between different kinds of representations (in expertise) and different aspects of experience, the study will not be looking for causal relationships in the strict sense. This is because such causal relationships require certain time relations, i.e. the occurrence of a reason/cause before an effect. Although the thesis will mainly refer to subjects' prior experiences when discussing the effects of experience on the quality of expertise, this is not always the case. Experiences may also be present in subject's representations in a way which reflects, for example, his or her present work and organizational context. On the other hand, experiences may also include a future dimension, in reflecting the subject's career plans or the anticipation of learning demands (such as new methods of IS development). Thus, we cannot be sure that the reasons why certain elements are included in the representations are to be found only in the past.

2.9 Specification of research questions

In the present study, the nature of design expertise will be investigated in relation to three main components. These include first, an explication of domain knowledge, its structure and organization. Secondly, the study will address different components of metacognition, including activity regulation, self-awareness, and metacognitive knowledge in relation to experience-based domain expertise. Thirdly, it will analyse domain problem-solving, asking how different components of contextual and strategic knowledge are manifested in subjects' solutions, and how these components are related to the subjects' educational background and work experience.

The goal of functional explanation implies content-specific descriptions of subjects' representations of their domain knowledge. The specific components and their relationships will be qualitatively specified in such a way that the hierarchy and relationships of the components are described. There will be an examination of how subjects with different backgrounds construct subjectively meaningful conceptional models and problem solutions within their domain. The functional relationship of the parts within constructs will be specified. This will include a description of what were perceived as the defining characteristics, and principle concepts, and how these are related to each other.

Content specificity is taken as the methodological guideline of the present study. This is realized in such a way that the thesis will start with a definition of design expertise, focusing on domain-specific conceptions of what is regarded as high-quality expertise. Based on this, there will be consideration of how far these elements (for example, user constraints) are included in subjects' conceptual models and problem solutions. In the description of the nature and quality of expertise in information systems design, the content-specific elements will include, in addition to user constraints, the methods, procedures and work organizations where the systems are developed. Domain expertise will be seen as manifested in the way subjects select relevant items and issues for their solutions.

The research questions and their backgrounds, addressed in the five articles (Chapters 3-7) are as follows:

(Article I) In program comprehension, a content-specific functional explanation involves analysing how subjects' explicated conceptions of ideal methods of program comprehension are related to their awareness of the strategies they use in comprehension, and to their monitoring and controlling functions. Since there were obvious inconsistencies, it will be asked why subjects acted in the way they did. Thus, an attempt will be made to discover preconditions for consistency in subjects' metacognitive knowledge of an ideal strategy, and in their means of using such a strategy.

In the models of the learning and acquisition of cognitive skills (section 2.1.), the changing role of subjects' awareness was described. However, in investigations of the relationship between metacognitive knowledge and activity regulation, the role of awareness has not been much scrutinized. In the first article of this thesis, the concept of awareness is used as a hypothesis, with a view to specifying the relationship between knowledge and activity. From this it proceeds to the question of why metacognitive monitoring and regulation of one's own activity seems to improve subjects' understanding among experts, but not among novices. This question has arisen from our earlier studies on cognitive strategies and competence in program comprehension (Eteläpelto, 1991). Our prior results (on the use of a compensatory strategy in a situation of missing background knowledge) pointed to the importance of subjects' metacognitive knowledge of task demands and of their awareness in choosing an adequate strategy (Vihmalo & Vihmalo, 1988).

The first study of this thesis frames the hypothesis that in order to strengthen relationships between knowledge and activity components, subjects must have an adequate awareness of the strategies they actually use. Without an adequate awareness of these (and thus the nature of their own experience) subjects cannot compare the strategies used with those they regard as advantageous.

In the first article, an attempt is made to specify the functional relationships between the domain-specific components of metacognition in program comprehension. These components include three elements of cognitive processes, namely knowledge, awareness and action regulation. The knowledge component is manifested as the subject's conception of an ideal and desirable strategy of program comprehension. Awareness is understood as a subject's domain-specific conception of the strategy that he or she is actually employing in program comprehension. The regulation component is understood as the subject's own active monitoring and regulation during comprehension, as manifested in thinking-aloud protocols.

(Article 2) Models of human cognition and activity have tended to construct very general descriptions (Lord & Levy, 1994a, 1994b). The models have remained very static in the sense that they have not included aspects of human learning and development. By contrast, research on expertise has aimed at developmental models. Although most expertise research has used cross-sectional expert-novice comparisons, these have nevertheless tried to capture the developmental transitions which take place through the learning and acquisition of expertise. Expert-novice comparisons made in semantically rich domains have so far produced a substantial body of consistent descriptions of the differences between experts and novices, and they could thus substantially contribute to general models of cognition. Findings from expert-novice comparisons could be useful in specifying the general dimensions of learning and development. In addition, the components of metacognitive knowledge and regulation could be specified. The second article of the thesis aims to incorporate learning dimensions within an activity-theory model.

(Article 3) In traditional cognitive psychology, and also in knowledge-based approaches to analysing expertise, the research tasks and methods have often been too narrow to take into account the professionals' functional role and the contextual knowledge they gain from it. It is suggested that relatively open task formulations, which allow subjects to define their conceptions, beliefs and common ways of solving problems, are an excellent means of determining the nature and quality of their expertise. If the methods used in analysing the expertise additionally allow subjects to reflect on their expertise (bearing in mind that reflection has been regarded as an important aspect of design expertise) it can be expected that essential components of design expertise will be captured.

Prior studies concerning design problems and design problem-solving indicate great qualitative variability in subjects' perception of information systems and their development. It is assumed that subjects' conceptions can be revealed through their construction of semantic networks of the meaningful concepts within their domain. This thesis will ask what kind of subjective representations can be found, what is included in these representations, how the elements are related to each other in terms of priority, the main organizing structure (principle) and the relationships between the elements. Additionally, it will be asked how the qualitative variety revealed is connected to subjects' educational backgrounds and work experience.

Process definitions of expertise have emphasized that the key to an expert career includes continuous surpassing of one's prior level of expertise. However, methods aiming to achieve this have so far proved inadequate. CMCR has been constructed as a method which starts with the conceptualizing of domain issues and then relates the components of the constructed model to the subjects' background and recent situation, the aim is to find those aspects of representation which are susceptible to change and challenges.

The CMCR method was used in the study reported in the third article of the thesis, with the goal of achieving a functional explanation. The study involved asking the research subjects to specify how the different components of their representation made sense in the context of the conceptual model they had constructed. In the analysis of the conceptual models, subjects were interviewed about the origins of their models. After the subjects had constructed their conceptual models of information systems development, they were asked why they started from a certain concept, why certain concepts were included in their model, and why they proceeded in their model construction in they way they did. Additionally, subjects were asked the global question of where their models originated from. We hypothesized two main origins, involving the subjects' practical domain experience (whether recently or previously gained) and the subjects' functional roles in their work organizations.

(Article 4) The question of knowledge transformation as a consequence of practical experience has been a central focus in various studies of expertise development and cognitive skill acquisition. Anderson's (1983) ACT model attempts to give a description of knowledge proceduralization. Furthermore, knowledge-based approaches to expertise have shown that through experience, the subjects' domain knowledge may be transformed into a form which is more appropriate for problem solving. It has been shown, for example, that in medical diagnosis this means the encapsulation of previous biomedical knowledge within the form of clinical knowledge.

Previous research on expert-novice comparisons indicates that different knowledge components dominate subjects' representations of their domain problem solving at different stages of expertise development. Using a research task that allows the utilization of different kinds of prior knowledge components, the question will be empirically analysed in the fourth article of the thesis. Two main components of design knowledge are, first of all the strategic knowledge of domain tools, methods and general solution models, and secondly knowledge concerning prospective users and their organizational contexts. The fourth article tries to determine the developmental continuities that might be found in the learning and acquisition of these knowledge components, and the typical solution patterns occurring among subjects with different backgrounds. This study attempts to specify typical patterns and to analyse why certain elements are included in these functional wholes. The study also analyses how common these qualitatively different wholes are among novices and experts.

(Article 5) The analysis of ill-defined tasks has shown the subjective nature of task definition. It has also led to an understanding of the role of contextual and situational knowledge as a determinant of qualitative variety. Recent characterizations of professional knowledge have emphasized that task redefinition does not merely involve a cognitive component; the individual's beliefs, conceptions, values and wishes are also intertwined within task redefinition. The fifth article attempts to specify the implications of empirical findings for the redefinition of design expertise, and to discuss this in relation to the notions of situated learning and cognition.

GENERAL DISCUSSION

8 GENERAL DISCUSSION AND CONCLUSIONS

This section discusses the main constituents of the nature and development of expertise in information systems development. It further addresses the relationships between different kinds of expertise and the nature of subjects' background experience. Bearing in mind the goal of functional explanation, the discussion considers why a subject has a certain kind of representation and how the different parts of that representation make sense in relation to each other. This implies looking at the functional meanings of the different aspects of subjects' representations, how these are related to each other and in what way they constitute expertise. The five separate studies that form the basis of this thesis and corresponding articles have discussed specific aspects of expertise. By contrast, this chapter derives findings from separate studies while drawing conclusions across and beyond them. In discussing findings from separate studies, this chapter also makes use of ideas from recent theoretical discussion on learning and expertise.

In the first section (8.1.) of this chapter, the following questions are addressed:

* How is the nature and quality of expertise in information systems design and development to be characterized?
* How are the different kinds of expertise related to subjects' differing background experience?
* What kind of developmental continuities or stages of development can be discerned in the learning and acquisition of design expertise?
* To what extent did the practical project learning course (involving initial work experience for novices) contribute to the learning and acquisition of professional design expertise?
* In what way can a high quality of expertise in information systems design and development be characterized?
* What is the role of metacognition in relation to the nature and quality of expertise?

In addressing these questions, this chapter will also discuss what the results tell us about the main questions raised in this thesis. It will discuss especially what the findings tell us about expertise, and what kind of theoretical notions of learning they support. This includes findings which may correct the common presuppositions of prior research, and which could help us to redefine design expertise. The methodological (section 8.2.) and practical implications (sections 8.3. and 8.4.) are also discussed, and further research is outlined (section 8.5.).

8.1 Main results and conclusions

8.1.1 The nature and quality of expertise in information systems design and development

The ill-defined and constructive nature of design tasks had led us to postulate a considerable qualitative variation in subjects' understanding of design expertise. This was confirmed by the variety of subjects' conceptual models and by the variety of solutions suggested to the domain problem. The qualitative variety was found to be especially great among the professional subjects. This was interpreted as due to the greater variety of professionals' background contexts as compared to the more homogenous context of students. The most common conceptions presented in the domain literature were also found in the representations of the participants in the present study.

The examples given in articles III and IV demonstrate the wide variety in subjects' orientations. Information systems development might be perceived as a dialogue between two participants representing the user and the professional community. It might also be perceived as an organization level endeavour involving different levels and perspectives of analysis. The results further showed that novices tended to perceive information systems development as a series of successive stages of professional activities. This kind of description might include some aspects of an individual user, such as a user interface. However, although the novices recognized the importance of the prospective user or client, they usually could not integrate the client's perspective within the professionals' work phase description.

In the design problem solutions, the qualitative variety of solutions was also great; once again, however, the students were more homogenous in their solutions than the professional subjects. The qualitative variety of subjects' solutions was manifested in various ways. Problem solutions varied in the way the task was interpreted and what kind of professional role was adopted. For example, the task of designing an information system could be perceived either as a construction task or as a purchasing task. Qualitative differences were also found in the way subjects tried to grasp the user- or client-perspective. Alternative ways included entering into collaborative and interactive prototyping with the clients, or adopting the client's standpoint.

The characterization of design activity as an ill-defined and open task (as presented in existing literature) was confirmed by the present study. In fact, the subjective nature of design tasks was clearly evident from the findings. The subjective nature of task redefinition was also evident, to the extent that it concerned not simply design problem-solving but rather the definition and understanding of the whole task. It seems that design expertise should not be perceived merely from the perspective of problem-solving, but rather from the perspective of problem finding. This means that design problem analysis should start with how subjects redefine the problem. The analysis of decomposition and the analysis of problem-solving strategies should be subordinated to this[7].

This kind of understanding of a design task is in accordance with, for example, Lawson's (1980) view of defining design task accomplishment (and design problem solution) as a process where problem finding and problem solving emerge as an intertwined process. Since the problem finding is such an essential part of design problem solving it would be misleading to describe design expertise merely as expertise in design problem solving. Even if solving the problem is always a part of the design task and thus design expertise, it is determined by the more primary process of problem finding and task redefinition. Consequently, these aspects should be taken as a starting point of analyses. Since task redefinition and problem finding appear to interact closely with subjects' skills and competencies, we may hypothesize that they are closely related to subjects' expertise and thus affect the content of this expertise.

If one understands professional design expertise essentially as expertise in problem finding, this has methodological implications for the analysis of research tasks. Most studies in the cognitive science tradition have used limited and artificial text-book tasks which do not require subjects to engage in the task of problem finding. With such tasks, essential aspects of design expertise are not captured, and the problem-finding aspect does not receive proper attention. Such results also have low ecological validity for real-life conditions. However, as research on human expertise gradually moves from laboratory settings to more authentic environments (Symon, 1998), the problem finding aspect will undoubtedly gain the attention it deserves. The results of such studies will also have more relevance for the understanding of professional expertise and learning in authentic work contexts.

Since previous studies have not properly addressed the problem finding aspect, they have not given sufficient attention to the relationship between task redefinition and background experience. Yet the nature of professional expertise in open and ill-defined tasks of design and development seems to be largely determined by how the task is perceived and redefined. There are a great many different alternatives in redefining such tasks, and there is also much variety in the expertise manifested in such them. Subjects are likely to define the task in

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[7] The introductory chapter of article IV gave a summary of three main approaches used in cognitive science analysis of design activity. These included sub-goaling, task redefinition and constraint management. All these aspects seem to have relevance for further studies on design expertise. However, when these aspects of design problem solving are analysed, they should be prioritized in such a way that a subjects's redefinition of the design task is taken as the starting point and primary concern of the analysis. The way of perceiving the design task should first be specified in a content-specific fashion. This may include the definition of problem constraints, which is much involved in task redefinition. In any case, analysing problem decomposition or sub-goaling does not make sense until we know how the subject has redefined the task, i.e. precisely what phenomenon is to be decomposed.

a way that is in accordance with their expertise, and consequently task redefinition and expertise are intimately related.

The ways in which one deals with the variation in task definition are, of course, influenced by the aims of the study in question. If the study aims, for example, to demonstrate the content-specific nature of individual variety, or to create starting points for individuals' professional development, it seems sensible to stick to subjects' individualized conceptualizations of their models. These can provide fruitful starting points for subjects' self-evaluation, and in the search for developmental gaps or challenges based on subjects' prevailing conceptions. By contrast, if the aim is to analyse subjects' solution models as a manifestation of their overall expertise, and to make, for example, a comparison between different models with a view to some generalized conclusions, the variety must somehow be reduced. Subjective models must then be described in more general terms, involving a more general system of analysis.

In the fourth article of the thesis, a description system was chosen which tries to set out a reasonable number of more general types into which the majority of cases can be classified. The effort to preserve content-specific and qualitative description in this case conflicts with the aim of finding more general types of expertise. However, the construction of the types was here done in a way that clearly recognized the qualitative differences in aspects of problem solutions. Based on a mainly qualitative categorization of separate solution characteristics, solution types were constructed in such way as to emphasize different solution characteristics. The goal was to find the most general combinations of solution characteristics, in order to describe them as they are manifested in subjects' solutions. Each type was additionally characterized by giving a particular example of it. Such a compromise between the extremes of individualized and generalized description seemed sensible at this stage of the research.

8.1.2 The nature of expertise and the quality of experience

Regarding the relationship between different qualities of expertise and subjects' different background experiences, the present studies suggest that experience is not only related to or having an effect on expertise, but is actually an essential component of expertise. Thus, instead of speaking about the connections or causal relationships between the nature and quality of expertise and the nature of subjects' experience, we should perceive experience as an essential constituent of expertise.

What does this mean and how do our findings bear on this argument? If we try to understand - according to our goal of functional explanation - why subjects' representations have a certain kind of quality, why certain elements are included, how they are related to each other and what purpose they serve, it seems evident that the nature of subjects' experience is much involved in expertise. And if expertise is described (as in this study) in terms of domain representations such as conceptual models or problem solutions, one becomes inclined to the conclusion that essential parts of these representations derive from subjects' individual experiences.

The findings derived from the contents of conceptual models demonstrated that subjects did not, on the whole, actively use concepts or constructions which were not familiar to them from their own working life or project learning experience. For example, the concept of work organization was used by about half of the experts whereas it was present among only a small minority of novices. Further elaboration of the backgrounds of these novices revealed that most of them had an unusual student background, having had many years' experience of working in a company[8]. By contrast, most novices were typical university students with a high school background, who had not yet got concrete experience of a work organization. Even during their project work, novices had not acquired much experience of a work organization, although they had been in contact with individual users.

The results showed that in most of the novices' representations, individual users were involved. However, this involvement tended to remain separate from the novices' professional activities. This was illustrated by a novice student's conceptual model which consisted of two separate parts: one describing the user interface, and the other the successive stages of information systems development. When the student was interviewed about her model, she said that the interface-part was there because she had perceived it as important during her work as a bank teller during the summer. The other part of her model - the part describing a professional's work phases - originated from her project studies. The student complained that she could not yet put these parts together although she knew that they both were central issues in IS development. Both parts were thus based on the student's conceptualizations of her practical domain experience. What was missing was the experience of how these components could be integrated with each other.

The design problem solutions suggested by the professional subjects gave further evidence for the more specific conclusion concerning the relationships between expertise and experience. Based on our findings, we can conclude that the professionals' functional role, which represents a contextualized form of professional experience, will largely determine the nature and quality of subjects' expertise. The conclusion can be derived both from the subjects' conceptual models and their design problem solutions.

A clear illustration of how the functional role is manifested in a problem solution is given by an expert subject (article IV, Appendix VI) who elaborates on the clients' ability to pay for the product (the information system). The subject starts his solution by questioning the rationality of the system from the perspective of its cost-benefit ratio. He further addresses the problems of families' ability to pay, supposing that the system has to be specially constructed and not purchased as an off-the-self-package. This kind of strong focusing on the client's purchasing capacity, which was present only in a minority of solutions, becomes understandable from the perspective of the professional's background. Since the professional is working as an individual consultant whose work consists of contract work, his job requires awareness of the purchasing capacity of clients. A systems analyst working as an individual consultant has to specify financial aspects in the agreement between the

[8] not as a systems analyst, but, for example, as an office worker.

supplier and the customer. These issues thus arise from the system analyst's functional role in relation to his clients. Since the systems analyst usually gets his salary directly from his clients, the productivity of his work is much dependent on how far the clients add on extra tasks requiring updating and corrections to the software. The consultant must avoid agreements that are too broad in relation to the reasonable resources he or she can employ in such projects.

Another example illustrating the relationship between the subjects' functional role and their expertise is that of an expert system analyst who had worked for nine years in a big software production company (article III, Figures 15.4. and 15.5.). The systems analyst perceived the development of information systems as a dialogue and interaction between the users and the system deliverer. This conception was actually a generalization from her personal experience of working as a representative of the system deliverer, in a firm producing software products. Because much of the work of the systems analyst consisted of negotiations with users, giving advice, and maintaining the software by making corrections and updating, refining the interface, etc., she perceived the developmental work as a dialogue, with the users and herself as participants. Moreover, from this conception of systems development as a dialogue, she considered the process of exchange and interaction as the organizing principle of her model.

In addition to these individual cases, which demonstrated how subjects' concrete experience and especially their functional roles were present in their problem solutions and conceptual models, the systematic comparison within the larger group of subjects further confirmed the relationship. The results presented in article IV showed that those who in their own organization had the role of purchasing and tailoring software suggested this as a solution to the design task. By contrast, those who had the role of constructing software de novo tended to suggest this as a solution to the problem. Subjects thus seemed to transfer not only the strategies or models of solutions to their problem solving, but they also their functional roles as professionals.

These findings thus seem to suggest that if subjects' experience is understood in terms of their functional roles, that experience is very much present in their expertise. One could say that the functional roles are involved or embedded in the nature and quality of the expertise. The significance of functional roles is seen particularly in the type of interaction or collaboration subjects prefer to have with their clients, and in how broadly subjects concern themselves with their clients' constraints.

Since subjects' experiences can thus be considered as functional reasons for their particular representations of the target domain, we can claim that the nature and quality of subjects' background experience - and especially their functional roles - can largely explain the nature and quality of their expertise in open and ill-defined tasks such as information systems design and development. Experience can thus be regarded as an essential constituent of the nature and quality of expertise.

As a methodological implication arising from this conclusion, it is suggested that expertise cannot be characterized without characterizing the nature and quality of subject's background experience, which may involve, for example, his or her discourse of that experience[9]. This is due to the fact that we cannot understand why a subject has a certain kind of representation, or how the components of this representation make sense in relation to each other, without reference to the subject's experience[10]. In the empirical findings of this study, the integral nature of subjects' experiences was manifested to the extent that the nature of their experience was present in all their conceptual models and problem solutions[11].

In recent discussion of learning and instruction, cognitive and knowledge-based approaches to expertise research have been criticized for their basic belief that knowledge and expertise are located in the heads of individual subjects. The situated learning approach, which has challenged cognitive science assumptions, suggests that knowledge and expertise are primarily present in the discursive interaction of practical communities (Lave, 1988; Lave & Wenger, 1991). In these approaches, which use the participation metaphor (Sfard, 1998), knowledge is understood, not as static schematic structures, but rather as ways of relating to and participating in the world (Ackerman, 1996).

The discussion between the cognitive and situative paradigms has led to the conclusion that both paradigms can offer useful starting points in researching different kind of problems, and can also promote educational practices of various kinds. Sfard (1998) has emphasized that cognitive and situative paradigms seem not so much to be in contradiction, but rather to focus on different aspects of human life and activity.

On the basis of the present study, professional knowledge and expertise can be understood as 'related', in the sense that professional knowledge and expertise are first and foremost determined and imbued by subjects' functional roles in their work communities. These may consist of traditional work organizations with their working cultures, power relationships, divisions of responsibilities, and so on. Moreover, in tasks producing services such as information technology artifacts for clients, the clients can be regarded as important determinants of the professionals' functional roles. In addition to these, the market supply of software tools and hardware facilities has an influence on the nature of professional activities needed for systems design. Thus, the professional's work organization, market supply and clients together constitute the important social context for the expertise and professional knowledge applied when he or she perceives a domain task and solves this

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[9] Schank and Abelson (1995) have recently asserted (with regard to the social functions of knowledge) that virtually all human knowledge is based on stories constructed around past experiences (see also Kihlström and Klein, 1997).

[10] More specific questions relating to experience as a part of expertise would touch on the precise aspects of experience to be described and taken into account when experience is described. These aspects might include such issues as the length of experience in different kind of tasks, the subject's functional role in work organization and the subject's personal learning history in terms of his or her conceptions of domain issues (e.g. the primary factors in the selection of relevant tools and methods of working), together with how these factors have changed during the subject's work history. One might also consider the subject's recent work tasks and personally adopted challenges for the near future.

[11] The correspondence between subject's expertise and their experience can also be regarded as an indicator of the ecological validity of the method used. This is discussed in detail in section 8.2.

task. In this sense we can argue that professional expertise has a context-sensitive nature - this is manifested in professionals' socially conditioned functional roles.

However, in the case of professional expertise this is only part of the truth. Despite being influenced by their functional roles in their work organizations, professional subjects also seem to be affected by their developmental backgrounds, which involve their domain learning. The findings of the present study showed that professionals' expertise does not seem to be determined only by their context, but rather that they seem to utilize their subjective experiences[12] in making conclusions derived from these contexts. These conclusions strongly guide subjects' conceptual constructions and their conceptions of the domain. The issue will be discussed further in the next section.

8.1.3 Developmental continuities and initial work experience in the learning and acquisition of design expertise

Despite the great qualitative variety in subjects' representations and the importance of functional roles in the determination of expertise, the findings of the present study also suggest certain developmental continuities in the acquisition of design expertise.

In the fourth article, developmental continuities were derived from subjects' problem solutions mainly in terms of strategic and contextual knowledge. In the first and third article they were analysed in terms of metacognition and domain knowledge representations. In all these empirical studies, the length of subjects' practical experience was the main criterion used to differentiate between novices and experts.

It can be suggested that length of practice as a determinant of expertise is much more important in tasks containing stable and constant elements than in tasks such as design and development which have continuously varying conditions. In ill-defined tasks, such as we find in design and development, relatively few elements remain constant from task to task. Additionally, if there are any constant elements, these are often fairly abstract and thus more difficult to discern from subjects' activities. If design is analysed as a real practical endeavour, and not merely as an application of a prescriptive model, the constant elements are correspondingly vague and difficult to extract.

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[12] If experience is understood as immediate subjective experience, it has been recently addressed in a phenomenologically-based critical discussion of cognitive science approaches. Varela, Thompson and Rosch (1991) have claimed that 'cognitivism' - and indeed the whole of western philosophy - has largely ignored the analysis of immediate human experience as well as reflection on that experience. Because of this, an essential part of the human mind is ignored. The authors claim that instead of focusing on human functional mind, cognitive science has rather focused on the computational mind. In analysing experience, cognitivism has mainly limited itself to sub-conscious mental processes which are perceived as detached from human self-consciousness. Drawing on the French philosopher Merleau-Ponty (1962, 1963), Varela, Thompson and Rosch have critically addressed the detachment of cognitive processes from the conscious human mind.

Nevertheless, it does appear that a certain length of practical experience is a necessary but not sufficient condition for the acquisition of a competent level of expertise. This conclusion is supported by the analysis of subjects' background in articles III and IV.

In specifying the minimum length of experience needed for the acquisition of a competent level of expertise, it was suggested in article IV that the two-years' minimum period should be replaced by a four or five years minimum. The suggestion is based on the findings for subjects with less experience. From the findings reported in the third and fourth article, it appeared that two years of domain experience (the period used in the studies for the operationalizing of expertise and thus as the criterion for selecting our expert subjects) is by no means a guarantee that a certain level of expertise has been achieved. Furthermore, the more detailed analysis (article IV) implied that in addition to a certain quantitative minimum, certain qualitative criteria are necessary for the achievement of a high-level of expertise. These qualitative criteria are particularly connected with professionals' work roles, which must have stability, and sufficient breadth to allow successful professional development.

How did the practical project course (which was analysed as the initial work experience of the novices) contribute to the learning and acquisition of professional design expertise? From the analysis of the learning outcomes of subjects' first practical domain experience and a comparison with the solution models of experts who had lengthy professional experience, some developmental invariances could be derived. The comparison of subjects' problem solutions showed that at the initial stage of acquiring domain experience, students focus on the strategic knowledge of domain tools, methods and models of working. At this initial stage, the novices paid little attention to the perspective of their prospective users and clients, in the sense of considering their contextual constraints. Although the project course was largely aimed at demonstrating the users' perspective, and the main goal of the course involved taking into account that perspective, novice students tended rather to concentrate on learning professional tools and methods.

Since technical competence through the adoption of strategic models, tools and domain methodologies seems to be the main objective in early practical experience, the methods students initially employ are of great importance. The methods students apply determine their opportunities to acquire relevant expertise. For example, if students use methods that allow them to work interactively with their clients, they evidently acquire concrete tools for taking the perspective of the client into account. By contrast, if they start using heavily professionally-centred tools and methods, they will tend to adopt these methods in the future, even if their theoretical studies included client-centred notions. Students are in fact highly dependent on the methodology they used in their initial practical courses.

Since the initial acquisition of a professional role and identity seems to be so much involved with the acquisition of professional working methods, it is extremely important to consider whether the methods used are in accordance with prevalent theoretical notions as well as current practices in working life. In the project course analysed in this study, the methods are almost certainly those which are prevalent in working life since the course is organized in collaboration with relevant outside organizations. The products made in the course are constructed for the purposes of these outside organizations, and the students must use methods regarded as feasible by those organizations.

As mentioned above, it is also important that the strategic methods and tools used in practical courses should be in accordance with recent theoretical notions and the ideas presented in lectures and textbooks. However, if students are, for example, given theoretical instruction on client-centred notions of systems design, but get no practice in using such methods, we cannot assume that they will readily put the notion of client-centred design into practice. Since we can expect that the methods which are practised during initial work experience will be especially well-assimilated, the nature and quality of these methods is vitally important.

With regard to the relationship between the content-specific nature of subjects' developmental continuities and the theoretical notions prevalent during the short history of information systems development, it was concluded in article IV that these were congruent with each other. These developmental trends include a trend from professional-centred to more interactive approaches, from context-free to more individualized solution models, from limited technical competence to user-centred and user-involving approaches, from individual performance to teamwork. The trends seem to correspond largely to those trends which can be found in the evolution of theoretical notions of information systems development (see Baeker, Grudin, Burton, & Greenberg, 1995).

The results of this study do seem to imply that the theoretical notions taught during basic university education have relatively little significance for subjects' problem solving as compared with the approaches they adopt later from their practical working life experience. During their basic studies, different age cohorts may learn very different kinds of theoretical notions. When the oldest professionals in the present study had their basic education, restricted notions of professionally-centred technical rationality were much more common than today. However, these kinds of restricted technical orientations did not usually appear in the professionals' problem solution. In fact, the restricted approaches were found among certain students who might have been expected to adopt the modern paradigm of client-centred approaches during their basic education. This seems to show the strength of learning through practical problem solving, and emphasizes the importance of learning in the course of one's working life.

The data and methods used in the present studies do not allow us to generalize in any detailed way to other developmental mechanisms or processes (involving, for example, the process of integration between strategic and contextual knowledge). Further studies using the methods of protocol analysis are needed to elaborate the processes of knowledge integration in expertise development. Further studies are also needed to outline how the different stages of professional development are related to or intertwined with adult development analysed in terms of more general phases of cognitive development (Kitchener, 1983; Kitchener & King, 1981) or in terms of contextual constraints which could act as a challenging facilitator of professional development (Järvinen, 1997).

An extreme domain-specific definition of expertise - as well as an extreme emphasis on contextual and normative aspects of professional expertise - would tend to neglect the general characterization of high quality in expertise. If an extreme domain-specific approach is taken as the starting point, we could come to the conclusion that a high level of expertise is identical with the most recent conceptions and models prevalent in domain literature. By contrast, an extreme emphasis on mere contextual and normative aspects would suggest that a high level of expertise is to be characterized in terms of performance in working life and work organizational demands, and is in fact identical with them.

Although both these aspects are necessarily involved in the characterization of a high quality of expertise, they are not sufficient as such. At their extremes, both domain-specific and working-life-based definitions share the defect that they do not recognize the autonomous role of the subject and his or her development. Nevertheless, in creative work - which consists of ill-defined and open tasks - there is an increasing emphasis on the individual subject's skills and competencies and thus on his or her expertise. In tasks of an open and constructive nature, professional subjects have a great deal of freedom in defining their tasks as well as their functions and positions in organizations. As a consequence of this, subjects' expertise and competencies may even play a part in determining the profile of organizations. In this situation, it seems legitimate to ask what a high level of expertise at an individual level consists of.

8.1.4 How a high quality of expertise in information systems design and development is to be characterized

From the findings of the present study, it is suggested that the central constituent of design expertise consists of constraint management. The empirical findings presented in the third and fourth articles indicate that high-level expertise in design and development is primarily characterized by the consideration and management of a multitude of high-level constraints relating to (product) users. In our subjects' perception of information systems development, high-level constraints were described in terms of the work organizations where the information systems were developed. In design solutions, a high-level solution was characterized in terms of multiple and comprehensive client constraints. In the design of information system for household finances, these high level constraints included, for example, the economic and social conditions of the families. They might further include a questioning of the second-order rationale of the design task in terms of the meaningfulness of the entire task assignment.

This characterization of high-level design expertise in terms of a consideration of comprehensive client constraints is in accordance with the conclusion drawn by Chan (1990). In analysing architectural design Chan suggested (on the basis of one expert subject) that the consideration and management of manifold constraints should be taught to novices, since it seems to represent a typical approach in expert problem-solving.

The main explanation for the experts' focus on high-level constraints may presumably be found in their complex and high-level mental representation of the target domain. Schraagen (1993), who analysed problem solving expertise in experimental design, found that design experts preferred to keep an overall picture of the entire paradigm in their working memory during the design process. They went back to the same paradigm again and again, leaving details open at first, but gradually filling them in. Thus the experts worked out their solutions using higher-level representations. Such complex high-level representations are also found in expert reasoning in other domains, such as in guessing the horse that will win in a horse race (Cesi & Liker, 1986). This has been verified also in the domain of programming. Koubeck and Salvendy (1991) found evidence that exceptionally competent programmers used a more general and abstract representation of the program than conventional experts.

The rationale of experts' questioning of the entire task has not been addressed in the cognitive science literature on expertise. However, the topic has been dealt with in discussions of adult development and the progression of epistemic beliefs (Kitchener & King, 1981; Pirttilä-Backman, 1993). It is also addressed in the literature on wisdom (Kramer, 1990; Sternberg, 1990). Although wisdom was originally considered in the context of professional tasks involving person-to-person interaction, such as teaching, social work and management, the issue seems also to have relevance also for systems analysts if their work is considered in relation to their clients. It should be noted too that the work of the systems analysts involves teamwork or collaborative design, so that the quality of the interaction and the ability to perceive the perspective of others becomes a central determinant of high-level performance (Häkkinen, 1996; Vehviläinen, 1997). The professional tasks of a systems analyst thus seem to demand wisdom in the same way as those of a manager or a teacher. This view is also taken in a recent discussion of collaborative design, where mutual perspective taking is seen as an important aspect of successful collaboration (Design Studies, 1998).

Another characteristic typical of high-level design expertise manifested itself in the ability to perceive alternative strategic ways of solving the problem. While lower-level solutions were characterised by perceiving only one strategy or method of problem-solving, the highest-level solutions typically included more than one way of solving the problem. Different kinds of strategies were seen as alternatives whose advantages and defects were considered. They were critically evaluated, considering for example the client's economic situation and the professional's role. In discussion concerning reflective professionals, this kind of competence has been characterized as the ability to make comparisons of different alternative solutions (Pirttilä-Backman, 1997). A similar characteristic was typical of the high-level solution pattern in design problem-solving.

In previous literature on metacognition, the evaluation, monitoring and controlling of one's own working strategies has been regarded as a higher-level strategy, responsible for the introduction of appropriate lower-level strategies. The successful employment of metacognitive monitoring and controlling has seemed to require that subjects have the knowledge and competence to use alternative strategies. This knowledge and competence would in fact represent a necessary condition for the successful employment of metacognitive monitoring and controlling. The relationships between expertise and different aspects of metacognition are discussed in more detail in the next section.

8.1.5 Metacognition and expertise

The relationship between expertise and metacognition has not been properly clarified by general characterizations of the reflective professional; nor have the process definitions of expertise which have emphasized continuous surpassing of oneself and working on the limits of one's competencies shed sufficient light on this relationship. Definitions based on these notions, separated from other elements of expertise, have remained more or less as idealized descriptions, providing a normative characterization of expertise. They have not specified how, for example, the different components of metacognition are related to subjects' prior domain knowledge and their background experience.

Previous studies carried out in the framework of a knowledge-based approach showed that experts and novices are different in such components of metacognition as the monitoring and controlling of one's own activities, the evaluation of errors made in problem-solving and the appraisal of task difficulty (Baker, 1989; Brown, 1987; Chi, 1987). However, the nature of the connections between the different components of metacognition and the relationships of these to the level of expertise was never clearly specified (Garner & Alexander, 1989). These matters are undoubtedly important for an understanding of developmental aspects of expertise.

The first study analysed various components of metacognition, which were specified as a) metacognitive knowledge of the program task and domain strategies, b) subjects' awareness of their strategies, and c) metacognitive monitoring and controlling of one's own activity. These components were analysed in relation to subjects' background experience. In addition, the connections of these components were analysed, looking further at subjects' background experience in order to understand why metacognitive monitoring seemed to contribute to program understanding among experts whereas among novices it did not seem to have such an effect.

The results suggested that defects in any of the knowledge or self-awareness components of metacognition - and also a fragile relationship between the various components - might explain the scant contribution of metacognitive monitoring to the outcome of understanding among novices. When a person had adequate metacognitive knowledge and additionally an accurate awareness of his or her activity (both of which were shown by experts), this provided the potential for successful monitoring and regulation of the activity.

Quite possibly, novices might have an adequate metacognitive knowledge of the program task or of ideal strategies to be used in program understanding. They might also have strong tendencies towards monitoring and controlling their own activity. However, our novices' awareness of their own activity seemed to be weak, and the relationships between the different components of metacognition were not firm. The novices thus lacked one of the necessary links in the chain whose overall strength is a condition for the effectiveness of the activity.

From the perspective of a developmental inquiry it would be useful to know how (in what order and sequence) those components should be acquired in order to provide optimal conditions for the acquisition of a high level of expertise. In traditional sequencing within a curriculum, subjects are first given knowledge of ideal strategies of working. After this they are, it is hoped, able to apply this knowledge in their problem-solving activities in their working lives. Failure is, however, common at this later stage; yet the reason is seldom seen as deriving from a lack of awareness of one's own activities.

From the findings of the first study, it appears that if subjects have an adequate awareness of their strategies, and if they possess metacognitive knowledge of good strategies, metacognitive monitoring contributes to a high-level of understanding in computer program comprehension. The results further showed that these abilities and faculties did not seem to develop until a certain amount of practice had been gained in the tasks.

Length of practice, which was much addressed in first-generation theories of expertise research and which mainly explains the process of automatization, thus seems to have relevance for the development of the awareness component. It seems that subjects must have a certain amount of practice in order to establish the skill of perceiving the program code as chunks big enough to allow perception of the program as a whole.

In previous literature discussing capacity-based explanations, subjects' awareness of their task performance has been thought to arise spontaneously when a certain level of expertise has been achieved, and when cognitive capacity has been freed through automatization of the task. These kinds of explanations may help us to understand the mental processes taking place in the course of skill acquisition. However, they do not specify the contents of awareness and knowledge.

The canonic way of explaining the spontaneous growth of awareness as a consequence of practice is based on the limited capacity of the subject's working memory. At the novice level, the subject's working memory is mainly occupied by the conscious attention needed to understand the lower level details of the program code, and by the conscious control and monitoring of this endeavour. Moreover, at the novice level, subjects have had little practice in the use of different kind of strategies, and their metacognitive knowledge of these strategies is limited. This can be seen as the main reason why metacognitive monitoring has a positive effect on program understanding among experts but not among novices.

These findings might serve to correct definitions of expertise which rely on a general characterization, involving for example reflective expertise. If such characterizations are detached from the actual contents of the reflection, they cannot be regarded as sufficient in themselves: although valid up to a point, they will remain vague and misleading if they are isolated from content-specific knowledge. The findings of the first study appear to confirm that the knowledge, awareness and monitoring aspects of metacognition are closely related to each other, and that they should therefore be analysed in relation to each other.

To sum up, in previous studies of cognitive strategies, metacognitive control and monitoring have been understood as constituting a high-level strategy, with the role of regulating the introduction of specific strategies. The findings of this study imply that metacognitive monitoring and control of lower-level strategies will be successful only if the relevant content-specific knowledge has already been acquired and an adequate awareness of subjects' own strategies has already been achieved. Practical conclusions derived from the analysis of the relationship between expertise and metacognition are presented in section 8.4.

* * *

The thesis started with a questioning of the relationships between expertise and experience. From the analysis carried out, the author inclines to the view that these relationships should be redefined, so that we regard experience as not basically a separate entity from expertise, but rather as a part of it. Taking up the German terms used at the beginning, the argument would be that instead of analysing 'Erfahrungen' and trying to find how these are related to subject's expertise, we should rather focus on 'Erlebnisse' which we should acknowledge as the central phenomenon of expertise. This claim is based on the author's conviction that what is important in constructive and creative expertise (such as we find in design and development) is Erlebnisse, i.e. subjects' mental constructions of Erfahrungen - what they have gone through. One way to characterize this conception is to say that people are, in a deep sense, embodied by their experiences. This means that experiences are not a separate entity which could simply be added into the repertoire made up by the contents of one´s mind.Neither does it mean that one's mind is surrounded, contextualized or embedded inside one's experience. Rather, it means that people substantially are what their experiences are.

8.2 Methodological reflections

8.2.1 Research strategy and selection of research subjects

As a consequence of the criticism against cross-sectional expert-novice comparisons in the analysis of professional expertise (see section 2.5.), longitudinal strategies have been suggested. So far, they have been, however, mainly used for analysing the learning and acquisition of expertise in educational contexts (Boshuizen, Smith, Custer & van de Viel, 1995; Järvinen, 1990). By contrast, a longitudinal study of the critical period of moving from schooling to working life and its relation to later professional development is relatively scarce.

In this study, the longitudinal strategy was used in analysing practical project-based learning and its role in the acquisition of design expertise. A comparison of students at the beginning and at the end of a course with professionals coming from working life gave a favourable setting for analysing the different components of professional knowledge. It showed how professionals differed from students and from each other because of their different work organizational settings. Indeed, our results showed that differences among professional designers mainly originated from their different work organizational contexts as well as from the professionals' roles in these contexts.

If we had used advanced students as experts, which has been very common in studies of expertise, we would not have got hold of the contextual knowledge essential in experts' problem solving. If we were thus restricted to students, we could probably capture only the general and context-free (strategic) knowledge which is the starting point for acquiring professional expertise, but in no way is all there is to it.

Without using real professionals as subjects, we would not have realized the role of the contextual knowledge in experts' thinking. Accordingly, it does not seem legitimate to draw conclusions about professional knowledge and expertise without using real professionals as subjects. Further, since professional expertise seems to be strongly determined by professionals' work organizational context, it does not seem legitimate to generalize the results to professionals of a certain domain without having participants from several and very different kinds of work organizations.

The used research strategy as well as the sampling method used in the selection of subjects are naturally connected with the definition and understanding of expertise discussed later (section 8.3.) in this chapter.

8.2.2 Data analysis and the validity of the measurements

Because this study tried to describe the nature and variety of design expertise, quite an elaborated data-driven approach of analysis was considered most promising for this purpose. Such an approach allows keeping close to the original data and the use of the data in the characterization of different types and qualities of expertise. A disadvantage of this kind of approach is a very laborious and time-consuming stage of analysis, especially if generalizable results are pursued using a considerable number of subjects. Laboriousness is evident particularly at the first stage of data analysis, when an attempt is made to cover the whole range of variety in creating descriptive categories (Chi, in press). For the future, new tools are needed to alleviate the burden of this initial stage of analysis where a researcher discusses with the original data.[13]

Summaries of different methods used in our empirical studies are given in appendices 1-3. Table 1 (Appendix 1) presents methods which were used in this study for the analysis and description of different components of metacognition. Table 2 (Appendix 2) presents methods used in the analysis of the content and organization of subjects' knowledge structures and domain knowledge. Table 3 (Appendix 3) summarizes methods used in analysing design problem solving and the strategic knowledge of this process. In all tables, a distinction is made between (i) methods used in deriving and elicitation of the information, (ii) methods used in the subsequent analyses, in reducing,

[13] In our recent studies (Häkkinen, Eteläpelto & Rasku-Puttonen, 1997 August; Linnakylä, 1997), neural networks, which have shown promise in the reduction and visualization of big data sets (Koikkalainen, 1996), will be tried for the initial analysis and description of data (see also Kivi, Grönfors & Koponen, 1998).

assessing and summarizing the data, and (iii) methods used in the final description and illustration of the information. (Hoffman, 1987; Olson & Biolsi, 1991).

Methods are evaluated in relation to the aspects of validity and reliability recognized to be critical in the targeted domain of analysis. Despite the traditional distinction between aspects of validity inquiry involving the construct, criterion, and content validity connected with the operational definition of the addressed phenomenon, validity is here perceived as a unitary concept requiring multiple types of evidence to support specific inferences made from the data (Cronbach, 1988, 1989). Generalization of the results is discussed in terms of ecological validity. Additionally, some functional consequences (Moss, 1992) of the measurement will be discussed. These are especially considered in relation to the method developed for the purpose of promoting subjects' metacognitive awareness and critical reflection of his or her own expertise.

Accordingly, it will be discussed how this goal was reached with reference to the method of Conceptual Model Construction and Reflection (CMCR) used in this study for this purpose. Because we used the method of conceptual model construction and reflection for understanding the nature of subjects' practical domain knowledge (Chapagne & Klopfer, 1981; Hacker, 1992; Roehler et al., 1988), it is important to know how it was eliciting the knowledge and how it corresponds to the ways people perceive the tasks of information systems development in their authentic work contexts. The validity inquiry (Eteläpelto, 1992 July, 1993 July) focused mainly on questions of ecological validity which have the role of evaluating how the artifacts produced in the research context, here the conceptual models and problem solutions, correspond to subjects' real-life work-contexts. Our main questions therefore focused on the issues concerning the origins of the artifacts produced in the research context. From the following three questions of our validity inquiry, the first two concern the issues of ecological validity and the third addresses functional validity.

(i) What are the origins of the constructed models of information systems development?
(ii) What are the origins of the solutions in the simulated planning tasks?
(iii) What are the possibilities of the methods to promote subjects' awareness of their own expertise?

During the stimulated recall of their model construction, subjects were interviewed in many ways as to where their models originated. Such stimulated recall was made during the shared watching and listening of the subject's own model construction which also included his or her thinking-aloud. This offered favourable material to link the interview with the replayed and delayed progression of subject's own reasoning process during the model construction. While subjects were watching the construction process on the monitor and giving answers to the interview questions, they were also encouraged to give complementary comments on their ideas arising at different stages of the working process. Free commenting was aimed to increase reflective confrontation of the construction process and it actually produced a lot of valuable information which could be utilized as complementary data for thinking-aloud. Particularly in the cases of scanty verbalization, the complementary information emerging from the stimulated recall (reflective confronting) produced an important source of additional information.

Those interview[14] questions which were focused on testing the origins of the constructed models were actually used to test the relationship of the used method to the reality where expertise occurs. Based on the analysis of the interview results, the following conclusions were made (Eteläpelto, 1992 July, 1993 July):

(i) Conceptual models, which subjects constructed to describe information systems development, mostly originated from subjects' practical domain knowledge acquired during their work history and during the practical project-based course as well as their actual work situations. However, the strategy used in model construction has an effect on the validity of the model. In the case of subjects applying a concept-driven strategy, where they are primarily driven by the given concept-labels, the resulting model is a less valid indicator of subjects' practical knowledge than in the case of a schema-driven strategy which implies the use of subject's own conception as the central guiding principle.

In the further development of the method, different ways to encourage the use of the schema-driven strategy should be promoted. For example, as compared to the number of 35 ready-made concepts offered in the present study, a smaller sample of carefully chosen concepts should be given. The method could also be used as a collaborative method for constructing a shared model.

(i & ii) As compared to the simulated planning task, the conceptual model construction tended to indicate more validity in the elicitation of subjects' practical knowledge developed during their work history. The most serious shortcomings of the conceptual model construction concerned the elicitation of contextual knowledge, such as the knowledge of economic constraints and issues concerning the division of functions between a professional and a customer. The simulated planning task, by contrast, seemed to function quite well as a complementary method in eliciting the contextual aspects of practical knowledge.

After subjects had solved a simulated planning task they were interviewed about the problem solving strategies and the knowledge they had used. The

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[14] In the systematic interview which was made during the simulated recall subjects were asked how they started the model construction, whether they considered other alternatives and what their reasons were for choosing between different alternatives. Furthermore, they were interviewed about their main strategies in constructing the model, whether they proceeded by first examining the given concepts and then based their model primarily on these (a concept-driven strategy), or whether they first had an idea of the entire model and its main organizing principles which would then direct search for certain concepts (a schema-driven strategy). In these cases subjects might also produce a new concept-label if the targeted concept was missing in the selection of the given concepts. During the simulated recall subjects were also interviewed about the origins of the constructed model. Concerning this theme, subjects were asked whether they had in their minds a prior domain outline, structure or content given in textbooks, lectures or articles which influenced their working. Additionally, subjects were asked if they had in mind a concrete application field or an earlier task accomplishment which had an influence on their working.

retrospective interview, however, seemed quite inadequate in eliciting such expert knowledge. Rather than focusing on the strategies and knowledge utilized in problem solving, the retrospective interview just gave an oral reproduction of the written problem solution. Instead of using retrospective interview, we would in the future prefer the thinking-aloud method for the elicitation of information on subjects' problem-solving strategies.

(iii) A tentative analysis (Eteläpelto, 1993 July) of the central issues that were reflected at the different levels of expertise showed that the method of conceptual model construction and reflection can give an indication, not only of the subject's practical knowledge, but also of his or her current developmental tasks. It can thus be assumed that the central issues of reflection involve the topics of the subject's central developmental challenges[15].

Concerning the validity inquiry in cases where qualitative data is used, Cronbach (1988) suggests that a test interpretation that honestly reports facts is open to validity challenges whenever adverse consequences arise. In this study, the original illustrations of subjects' statements and abundant use of examples taken from subjects' conceptual models and from their solutions had the aim of showing original facts being used as foundations of interpretations and inferences made from the data.

In prior literature, there has been an active discussion on the methods of eliciting experts' knowledge. Particularly, in the domain of artificial intelligence where knowledge-based expert systems are built, several methods have been developed. Cooke (1994) analyses varieties of knowledge elicitation techniques and summarizes for each technique its strengths and weaknesses and gives recommended applications for the use of these. Hoffman (1987) suggests that the method of 'familiar task' implying tasks that experts usually perform is a valid method for the elicitation of expert knowledge. In this study, the design of household finance was regarded as such a familiar task because it was derived from a field of application which is familiar for all subjects.

Ericsson and Simon (1984) have discussed in detail verbal data as an evidence of subjects' knowledge structures. In our analysis of the relationships between metacognition and expertise, we concluded that verbal reports of subjects' cognitive strategies are more reliable among experts than among novices because of experts' better awareness of their strategies.

In our transformation and description of data on knowledge representations, the data of verbal protocols was put into another form of representation. The method of concept-map suggested by Novak and Gowin (1984) was used for this purpose. Typical cases and the rationale of their understanding for the development of information systems development were described. Concept maps, which were used to illustrate individual subjects' knowledge structures and conceptions of the target domain, proved to be very adequate tools in the simultaneous representation of the verbal-pictorial information derived from several sources, such as the thinking-aloud protocols,

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15 Interestingly, the method of Conceptual Model Construction and Reflection (CMCR) was remembered in some detail by the novices after seven months when they participated in the end-of-course tests. We can thus conclude that the method also proved to be a powerful learning task.

videotaped model construction process as well as from subjects' answers to an essay-task and the resulting models.

Concept maps proved adequate for the description and illustration of the qualitatively different kinds of expertise in IS development for several reasons. First, the hierarchy of the maps illustrates subjects' priorities and functional relationships between relevant issues, showing thus an essential characteristic of expertise. The highest level of the hierarchical map showed what were the most important issues and the main principle or dimension used to organize the target domain. Correspondingly, at the lowest level of the maps there were issues that were perceived as having minor importance. Secondly, as compared to the original models which subjects had constructed on the blackboard and which are also presented in the article, the concept maps suggested by Novak and Govin (1984) were more specific in the sense that they included a verbal description on the specific nature of the relationships between concepts. The specification of the exact meanings for the relationships depicts subjects' conception of the phenomenon in a meaningful way. The concept map further offers to the reader an understandable (simultaneous) picture of the nature and organization of the subject's domain knowledge and, thus, the nature of his or her expertise in the domain.

As an alternative to our qualitative and intensive approach to analysis we could have chosen, for instance, to conduct a correlational analysis arising from a coding system based on the analysis of some developmental indicators and the characteristics of subjects' work histories. We could have aspired to find the most important aspects of a developmental career, which would mostly explain the high-level design expertise. However, because we had the purpose of understanding the qualitative nature of expertise in terms of cognitive strategies, subjects' knowledge structures and their metacognitive processes, this kind of correlational analysis of separate dimensions of experience and expertise would hardly have yielded conclusive results (Ericsson & Smith, 1991a).

8.2.3 Generalization of the findings

In the analysis of cognitive structures and processes, the issue of ecological validity has been much discussed in cognitive psychology (Cronbach, 1988, 1989; Messick, 1989; Moss, 1992; Patry, 1997). Authors usually assert the importance of considering context in validity inquiry. This includes asking about the generalizability of assessment-based interpretations and validity conclusions. It also stresses the importance of interpreting the information in the light of other information on context, experience and behaviours of the individuals involved. Cronbach (1988) argues that the best strategy of asking about the local validation vs. extrapolation to other times and places is a form of contextualization where one offers a generalization and then tries to locate the boundaries within which it holds. As that structure ultimately becomes more clumsy, someone will integrate most of the information into a more graceful one. The emphasis on context is also reflected in theoretical discussion on the situated nature of learning and cognition.

The most compelling question of generalizability in this study refers to the work organizational context as an important determinant of professional design expertise. Accordingly, this study can be criticized for not addressing expertise in the contexts of authentic work organizations. Instead of doing this, we chose individual professionals as the participants of the study. We selected the subjects from the university register and contacted them individually. As a consequence of such a sampling procedure, we caught subjects who had their positions in very varying organizational contexts.

This was actually a very conscious selection of participants, because it was attempted to capture and display the variation arising from different kinds of organizational contexts. If our participants has been chosen only from one organization, we would not have been able to discover the role of the contextual knowledge of subjects' work organization and its manifestation in subjects' knowledge structures. By comparing such professionals with students, we obtained a framework for the estimation of the role of subjects' work organizational contexts in their domain knowledge. It was assumed that this kind of research strategy would benefit educational research by contributing to the evaluation and assessment of expertise acquired in higher education, as compared to a study focusing only on one or two organizations.

In this study, we thus chose the experts in such a way that they represented professionals coming from several work organizations. Instead, our novices consisted of students from the same university department who took part in the same project-based course. Novices thus represented quite a homogenous group in the sense of having a similar background of university studies.

Also the professionals had a similar background of having had their basic education at the same university department. However, at the time when they were university students, different notions and methodologies as well as tools and methods of software development and hardware facilities were predominant. This brings about the problem of cohort effect. When expert-novice comparison is used as the research strategy, and when we are trying to make generalizations from our results to the nature and development of professional expertise in a domain in question, the cohort effect arising from these differences cannot be ignored.

In the early research on expertise, there has been surprisingly little discussion on the cohort effect and its influence on the nature and definition on how expertise is defined. At least the cohort effect is not discussed in canonic reviews. One reason for this situation comes from the nature of activities mostly analysed. So far, the most popular tasks analysed in expertise research have had very definite rules such as chess, authorized and legitimated practices (physics problem solving) or established strategies (legal case analysis). In such domains, the cohort effect has not played a crucial role.

A very opposite situation is common in the domain of information technology where a continuous change of tools and methodologies is the rule (Lee & Pennington, 1994; Tillema, 1995). When professional expertise is discussed in terms of textbook knowledge, it is manifested in prevailing concepts, methods and methodologies. In information technology, a lot of 'current jargon' is embedded in software tools and artifacts. Accordingly, these are also connected with the conceptions of what is considered a high quality of expertise.

From the perspective of trendy approaches in organization research, which often totally deny the significance and thus even the existence of human individual development, this study can be criticized for the lack of not collecting data on the discourses of work organizations. The reasons for concentrating in this study on the analysis of expertise development at the level of a human individual, rather than at the level of work organization, come from the author's view that individual development is not reducible into current organizational discourses and the continuities found in these. This does not, however, mean that situative and contextual factors should not be recognized as important conditions or as important determinants of the nature and quality of professional expertise. Based on our critical analysis of cognitive studies on design expertise and the contributions of situated approaches, we suggested (Eteläpelto & Light, in press) the need for a redefinition of design expertise from the perspective of contextual and situational knowledge in order to strive towards a better integration of individual and situational factors.

It is maintained that despite the continuous changes in students' and professionals' circumstances as well as continuous learning demands imposed by modern production life and workplace, this does not imply that subjects' prior experiences would not produce any accumulation of skills, knowledge structures, conceptions, or beliefs which will then influence the nature of their subsequent performance. The author thus maintains that human individuals tend to transfer the learning outcomes of their prior experiences and the consequences of these to their expertise, e.g., from schooling contexts to working life contexts, and vice versa.

By contrast, recent international discussion on learning transfer in a complex cognitive domain (Andersson, Reder & Simon, 1996, 1997; Greeno, 1997) has expressed very negative opinions about the possibilities of automatic transfer of high-level structures or abstract principles. Studies on intentional learning have also often failed to attain positive transfer of learning outcomes from one situation to another. Furthermore, instructional efforts have demonstrated particular difficulties to transfer general cognitive skills such as metacognitive monitoring and regulation of task performance (Cross & Paris, 1988; DeCorte, 1995; Gruber, Law, Mandl & Renkl, 1995). Such results have been used as arguments for the situative nature of human learning and cognition.

Also the findings of science concept learning have demonstrated the laboriousness and slowness of the learning process (Chi, Slotta & de Leeuw, 1994; Novak & Musonda, 1991; Vosniadou, 1992, 1994). These studies have shown that concept learning is especially difficult if subjects have to change their basic assumptions of a target domain. In these cases, learning seems to require not only the enrichment of subjects' prior knowledge but also the reorganization of the whole knowledge structures. It has also been demonstrated how persistently even the students of higher education tend to keep on to the misconceptions they have once adopted.

To sum up, these findings have clearly implied the existence of developmental entities as well as continuities in the learning and progression in complex cognitive domains and thus in the learning and acquisition of professional expertise. The author agrees with the position taken by some researchers (e.g., Crook, 1994) who support the account of learning that views the acquisition of knowledge as initially situated but which recognizes the existence of some general cognitive skills as well as the possibilities and importance of transfer and, for instance, abstraction as a method of generalizing from subject's prior knowledge (see Ackerman, 1996: Ohlsson & Lehtinen, 1997).

8.3 Normative character of professional expertise

Recent discussion of the normative characterization of professional expertise is influenced by the new requirements of working life that emphasize the needs of changes in education and training arising particularly from the requirements of flexibility and the continuous needs of innovations and increasing productivity (Nijhof & Streumer, 1994). Arising from the lively discussion of actual changes of working life, the required expertise has been characterized with a variety of concepts. Desirable expertise has been characterized, e.g., in terms of adaptive (Hatano & Inacagi, 1992; Smith, Ford & Kozlowski, 1996), reflective (Eteläpelto, 1992a, 1992b, 1993b; Rowland, Fixl & Yung, 1992; Schön, 1983, 1987), creative (Akin, 1980; Christiaans, 1992; Winograd, 1995), innovative (Achtenhagen, 1995) and interactive (Engeström, 1992; Launis, 1997) expertise. These are terms used to characterize the general nature of professional expertise needed in modern production life.

In the discussion of required expertise, one single, particular aspect is usually over-emphasized. As a consequence of this, basic foundations, such as domain-specific strategic and contextual knowledge is often disregarded. For example, in the extreme emphasis of the reflective expertise, the strategic domain knowledge and the need for practical experience has been largely forgotten. This brings about misconceptions leading to very limited or one-sided conceptions of what is involved in advanced expertise. It has also been very common that the normative definitions concerning the desirable expertise that emerge from observations on the working life are soon generalized as such to all levels of schooling and educational contexts. However, our results concerning the relationships of expertise and metacognition have shown, for instance, that the metacognitive monitoring that seems very successful among experts is not successful among novices because they have not yet acquired the necessary preconditions to utilize it. This implies that those procedures and phenomena that seem important for promoting expertise among professionals, are not so simply transferable to another level of expertise. Accordingly, when we are discussing a certain normative definition characterizing a desirable nature of expertise, the limits of its generalization should always be considered.

In cognitive and educational psychology where expertise has usually been understood in terms of domain-specific knowledge structures, strategies and general skills, the normative aspect is manifested in current theories and conceptions presented in textbooks and in current professional jargon. Emergent approaches, which involve the ideal of continuous learning, place more emphasis on developmental processes such as continuous investment of mental resources. The process definition of expertise proposed by Bereiter and Scardamalia (1993) puts the question of how novices become real experts instead of experienced non-experts. As an answer to their question, the authors suggest that experts are different from non-experts in that they just do not know more than the experienced non-experts but because they employ a strategy of working at the growing edge of their competence. Accordingly, expertise is seen as a process that generates expert knowledge through the continual reinvestment of mental resources into addressing problems at a higher level. In terms of learning challenges, the reinvestment of mental resources means a willingness to face continuous learning challenges in the task accomplishment (see e.g., Tynjälä, Nuutinen, Eteläpelto, Kirjonen & Remes, 1997).

In our recent analysis of professional subjects' perceived learning challenges and their relationships to subjects' work contexts, it was found that subjects' personal representations of their developmental challenges were closely connected with their work roles and especially with the scope of their organizational duties (Eteläpelto, 1994 June, 1997 April). With regard to the validity of the perceived challenges for the actual work situation, it was concluded that if the quality of expertise is analysed as a developmental process rather than as static structures, subjectively represented challenges seem to function as valid indicators of subjects' quality of expertise. This applies particularly to open and ill-defined tasks such as planning, designing and management, which include demands for continuous growth and development.

One of the recent notions in the discussion of what is the desirable nature of professional expertise especially in rapidly changing workplaces addresses the definition of adaptive expertise. Smith, Ford and Kozlowski (1996) suggest that adaptive expertise involves high quality and content of knowledge structures and metacognitive components. The differentiation between the knowledge, awareness and regulation components of metacognition and the findings concerning their relationships with expertise, which were demonstrated in the first article, have been used by Smith, Ford and Kozlowski in their specification of what is the adaptive expertise needed in today's working life. The authors suggest that in constructing well-integrated, high-quality knowledge structures and in developing metacognitive awareness and regulatory processes such as skills in planning, the monitoring and evaluation of one's own activity is the prerequisite for adaptive expertise.

If it is asked what is adaptive expertise in design and development in information systems, the present author suggests that the adaptiveness of expertise in these domains is manifested in professionals' adaptiveness in relation to the information system's users and their contexts. If this kind of adaptiveness exists, it means that professionals have an abstract mental representation of the target domain and as a consequence of this they are able to comprehensively consider users and customers as well as their organizational constraints. Furthermore, adaptive design expertise involves professionals' manifold use of the strategic knowledge and the contextual knowledge of users and customers. This means fluency in utilizing the domain-specific strategies and their flexible application considering the specific context of users and customers. The results of this thesis suggest that the development of such expertise is not obvious until after the acquisition of adequate domain-specific strategic knowledge and after a lengthy domain-related work experience.

To sum up, the definition of a good quality of professional expertise is always a normative issue. This was also taken as a starting point in our analysis of expertise in information systems development. Our results further specified the normative aspect of the desirable expertise in the domains analysed in present study. The normative conception of what is the nature of desirable expertise has also important consequences for how such expertise is acquired. The relationships of learning outcomes and learning strategies have recently got well-deserved attention in learning sciences. Especially the notion of the contextual and situative nature of learning suggests that 'what is learned' is determined by the situations 'where it is learned' and 'how it is learned' (Vosniadou, 1996). In expertise research, the question of 'what is learned' can be analysed in terms of what is the normative character of the high quality of expertise.

8.4 Learning and acquiring expertise in practical contexts

8.4.1 Practical project-based course as a learning environment

In the research tradition on analysing excellent performance and its sources, the deliberate practice has been considered very different from working life experience. Ericsson and Smith (1991a), for example, have argued that merely performing a task does not ensure that subsequent performance will be improved, and that learning requires feedback in order to be effective. Hence, in environments with poor or delayed feedback, learning may be slow or even nonexisting. Authors thus regard it as important to distinguish between practice and mere exposure to experience.

The practical project-based course analysed in this study involved a lot of feedback and evaluation which was given by the users as well as teachers and other students (Tourunen, 1992). In this sense, the project course can be considered as deliberate practice, rather than as a mere exposure to experience (Blumenfeld et al, 1991). As a learning environment, the project-based course also involved some elements suggested by the situative learning approach and the cognitive apprenticeship models of learning (Collins, Brown & Newman, 1989; Greeno, 1997; Greeno, Collins & Resnick, 1996). However, differing from the cognitive apprenticeship model, the project-based learning environment analysed in this study also had characteristics similar to real work experience because during the course subjects produced an authentic information system for real users who were from outside the educational contexts. For the project-based course, this implied time and economic constraints as well as the constrains of the real users of the system (Eteläpelto & Tourunen, 1991, 1994 November; Tourunen, 1992). As a consequence of these authentic constraints varying from one project to another, the practical project course involved conditions similar to those real challenges for teachers' prior knowledge, which has been found to be advantageous for learning in environments using cognitive apprenticeship models of learning (Järvelä, 1995).

The practical project-based learning experience investigated in this study was organized in a university context[16] and it was preceded by theoretical courses which modelled the process of information systems development. In the university curriculum of systems analysts, the project-based course had the purpose of promoting practical competence and particularly demonstrating the importance of the customer and user perspective in information systems development.

In our analysis of the learning outcomes attained through the course, we did not use the research strategy of a field-experiment where the project course would have been compared with other kinds of learning arrangements (e.g. Tynjälä, 1997). Instead, we used a 'longitudinal' strategy where we compared students before and after the course with real experts representing working life. Thus, we tried to understand the outcomes of the project learning experience in the framework of professional expertise acquired during the years of experience gained in working life contexts.

Based on our findings concerning the learning outcomes we referred to the problems arising from the fact that university education often tends to neglect the integration of students' practical experiences with the theoretical subject matter. Further, we referred to the lack of work organizational constraints in how students perceive the information systems development. However, to be realistic, we have to admit the limitations of the university context in the sense that it cannot function like the workplace. Differences between the university and working life contexts are inherent due to their nature as institutes that have different goals and missions. While the university, and the education context in general, has the primary goal of bringing about high quality learning outcomes, working life contexts primarily aim to produce economically competitive artifacts and high quality products.

The project learning course which we analysed in this study tried to combine both of these goals although the instructional and students' learning goals had primary importance. Even though the course was quite a successful enterprise in the sense of bringing real motivation and authentic responsibility for the completion of a product, it still suffered from the lack of authenticy on account of the basic differences between the two contexts. During the project learning course students did not obtain a similar experience of a real work organization as they could get, for example, from working as an apprentice.

In the domain of higher and further education, we should ask how to alternate between practical and theoretical courses in an optimal way, and how to establish skills and knowledge structures which produce adaptive expertise. In this sense the differentiation between metacognitive knowledge, awareness and regulation seems important. In establishing high level expertise, all these components should be present and integrated in human activity. How these can

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[16] The course was awarded the distinction as the best course of Jyväskylä university curricula in the year 1997.

be used in the construction of the curriculum and how they can be promoted in different contexts of learning, is a challenging question. Based on the previous discussion of the adaptive expertise we can suggest that the formal domain knowledge is to be acquired in the university context. By contrast, subjects' awareness of their working strategies, which is a necessary condition for the development of subjects' metacognitive knowledge, cannot be attained without practical experience. Along with the experience certain basic elements of the skill are automatized and thus fall below the threshold of subject's awareness. Along with this process of automatization and chunking, subjects' awareness is freed from conscious regulation and monitoring of the activity and thus allow space for meta-level awareness and evaluation of subjects' own strategies. A certain amount of practice can thus be considered a precondition for the attainment of the awareness and conscious control and monitoring of one's own strategies. Additionally, if we are concerned with intentional learning of novel strategies, a variety of practice and training in different kind of environments is needed for a competent deployment of these strategies.

8.4.2 Problems of analysing learning and the acquisition of design expertise

If learning and acquisition of design expertise and the necessary strategic skills are analysed in terms of learning transfer, we have to differentiate between the low- and high-road transfer which differ from each other in what concerns their application to different kind of activities and modes of learning (Mayer & Wittrock, 1996; Salomon & Perkins, 1989). Low-road transfer is characterized as occurring as a consequence of direct repetition of a particular activity. The power law of practice, described by van Lehn (1996) as the most ubiquitous finding characterizing the final phase in the learning of cognitive skills, states that the time needed to do a task decreases in proportion to the number of trials raised to some power. Newell & Rosenblom (1981) have shown in their review that the power law applies to single cognitive skills as well as to perceptual motor skill. Furthermore, several studies (Anderson, 1981; Anderson & Fincham, 1994) have shown that in complex cognitive skills the speed of applying individual components of knowledge increases according to the power law, thus indicating that practice benefits those components rather than the skill as a whole. Accuracy also increases according to the power law, at least on some tasks (van Lehn, 1996; Voss, Wiley & Carretero, 1995).

The power law thus explains the processes of learning described in terms of low-road transfer. With substantial practice, simple skills tend to become automatic. Automatic processing is fast, effortless, autonomous, and unavailable to conscious awareness (Logan, 1988; Schneider & Shiffrin, 1977). However, despite substantial practice, the complex cognitive skills as a whole never became as automatic as, e.g. car-driving. Similar skills thus mainly apply the mechanisms of low-road transfer. However, as Holyoak (1991) notes, the models of skill learning that represent the first generation theory of expertise research are mainly limited in the sense that in these theories expertise is viewed as the result of automatic evocation of specialized actions in response to specialized conditions. Novel theories, instead, are needed to suggest what is the adaptive expertise needed in tasks characterized by rapidly changing conditions.

In design and developmental activities, there exist very broad and diverse possibilities to redefine professionals' tasks and roles. Thus, there should also exist possibilities, at least in the long term, for such a continuous redefinition of task assignments and subjects' work roles that involves potentials for the continuous growth of subjects' expertise. Even though the redefinition of planning tasks and subjects' functional roles is conducted in a short term in a way that it is congruent with the respective task demands as well as subjects' respective level of expertise, for the long term career-planning, subjects' growth and developmental aims should be considered. If subjects' roles thus involve ingredients that promote their personal and professional growth and the acquisition of new qualifications required for the future working life, the subjects can be considered to demonstrate an expert career, characterized by Bereiter and Scardamalia (1993) as operating continuously at the growing edge of their competence.

According to the conceptions derived from expertise research, it is not only the focus of learning that changes while moving from the initial level of expertise to the subsequent levels. Also the mode and ways of learning are different in the acquisition of different levels of expertise. In the acquisition of procedural strategic skills, e.g., the process of proceduralization where declarative knowledge is compiled into a procedural form, seems to represent the central mode of learning. By contrast, a different kind of learning and cognitive processing is occurring in the acquisition of science concepts (Vosniadou, 1992, 1994) or deriving theoretical abstractions (Ohlsson & Lehtinen, 1997). Making generalizations or constructing theoretical abstractions requires the integration of the new knowledge into the prior knowledge base. Without a conceptual reorganization (Vosniadou & Brewer, 1987) it does not seem possible to make a transition, e.g., from initial work phase models to comprehensive and interactive approach described as subjects' solution pattern in article IV.

8.4.3 Instructional principles derived from research on expertise

Based on prior research on expertise development (Benner, 1984; Berliner, 1992; Dreyfus & Dreyfus, 1986) as well as the previous findings on the developmental phases in the expertise of complex cognitive skills, the thesis would suggest that different kinds of materials and instructional methods are feasible and useful at different stages of expertise development (see also Goldman et al, in press).

If the suggestion is limited to the domains where the acquisition of domain-specific formal knowledge is a precondition for real-life problem-solving, in can be expected that at the initial (novice) stage subjects will benefit most from context-free, theoretical and conceptual models. By contrast, students may become frustrated in listening to lectures on general principles if they have recently attained the stage where practical and contextual knowledge is the particular focus of learning and acquisition of expertise.

At this second stage (of advanced beginners), subjects' main developmental task involves considering the situational and contextual effects that have an influence on how the general principle is realized in real-life contexts. At this stage when students try to understand how the context-free models and theoretical principles are functioning in authentic situations, and they additionally try to manage with the manifold contextual and situational factors that modify their influences, analysing worked-out examples representing typical domain solutions seems useful.

At the third stage of expertise, characterized as the stage of a competent performer, learners can probably benefit most from participation in real-life problem-solving where authentic tasks are given to the subjects and they are thus getting the possibility for completing them under the supervision of an expert performer. The practical project working course applied with the participants of the present study represents this kind of learning task where learners are given a personal responsibility for real task completion. A central developmental task of a competent performer arises from the requirement of goal-directed task completion. This has the advantage of requiring the learner to differentiate between relevant and non-relevant issues and thus, e.g. to prioritize among various constraints.

At the next level of expertise, which is not attained without a considerable amount of practical experience, subjects already have in their long-term memory a lot of experience-based knowledge on the solution of domain problems of considerable diversity. At this fourth stage of expertise development, characterized as the stage of a proficient performer, subjects can plausibly get most benefit from the reflective analysis of typical cases. When subjects have a great number of paradigm-cases in their long-term memory, they can easily address and evaluate them e.g. in the light of novel theories and paradigms as well as of new cases. This is a common situation for professional and continuing training. If real cases are given at a very early stage of learning and particularly if they are not linked with any principles, theories or general patterns of proper problem solution, they may only cause confusion. This is largely due to subjects' inability to differentiate between relevant and non-relevant features and details of the task or a case. Accordingly, it is not until at the fourth level of expertise, that of a proficient performer, when subjects probably have acquired a conception of what the relevant features for the previous paradigm cases are and according to which a new case can be categorized, that the evaluation and reflection of complex real-life examples is the most advantageous way as an instructional method.

Ignoring the consideration of subjects' actual level of expertise in the specific domain of learning may be an important reason for failures of getting positive (high-road) transfer from the experimentations realized according to the model of cognitive apprenticeship. Empirical studies of the learning outcomes in these environments have demonstrated that without expert's modelling, scaffolding and guidance, novices are not getting much advantage in these kind of environments (Järvelä, 1996; Radziszewska & Rogoff, 1988, 1991; Rogoff, 1990). Based on the notion of expert pedagogy, these functions necessary for positive learning transfer are not involved in individual's ability to adequately complement the learning process until at the level of a proficient performer.

The fifth level of expertise is characterized by a comprehensive conception of the target domain and an involved relationship with the environment.

Dreyfus and Dreyfus (1986) refer to experts' inclination towards fusing into their environment in a way that they do not always separate themselves from their contexts. At this stage, experts' decision-making is based on rapid similarity recognition and it has largely became automatised. Challenge at this stage arises especially in situations where total restructuring of their knowledge-base is required. In these situations, experts have the burden of unlearning the old solution patterns and this is usually achieved only through becoming fully aware of the old patterns. After that, a new endeavour is needed to construct novel patterns.

To sum up, our main emphasis arising from expert pedagogy concerns the notion that at the different stages of learning and acquisition of expertise, different kinds of instructional methods are desirable. In this sense, when potentially effective instructional methods are discussed, the limits of their generalizations in terms of novice - expert continuum should always be specified.

8.5 Further research

In this final section of the thesis, some proposals concerning further issues of research arising from the present study are presented. Methodological development was already referred to in the section on methodological reflections (8.2.). In the further development of the CMCR method as a group-level method, new challenges are evident. The method could also be utilized as a tool for diagnosing subjects' present level as well as the growing edge of their expertise which could be utilized in constructing personal curricula. In the methods section, the application of neural networks and computer-based methods for the capturing and analysis of information intake were also referred to as methods for promoting data-analysis close to the original data. These are important topics for future studies and development work.

The challenges that research on professional expertise poses to the educational research are extensively discussed in a recent article (Tynjälä, Nuutinen, Eteläpelto, Kirjonen & Remes, 1997). Challenges entail the investigation of activity-based instructional methods and their role in the promotion of expertise. Understanding collaborative problem solving in project learning environments appears challenging because methods of this kind are increasingly adopted at all levels of our educational system. Advanced project-based methods are actually utilizing, as an instructional method, collaborative planning which consists of the process of negotiating meanings in constructing shared knowledge base. It is not very well understood, how project-based planning should be used to establish a powerful learning environment. In further studies, collaborative learning processes will be analysed in technologically enriched learning contexts (Häkkinen, Eteläpelto & Rasku-Puttonen, 1997).

What concerns the qualitatively different ways of understanding what is design and planning and the acquisition of high-level patterns of problem-solution, the five patterns which were differentiated in the present study could be further analysed in relation to their ontological and epistemic presuppositions which have been found to have a central influence on learning (Chi, Slotta & de Leeuw 1994; Vosniadou, 1994).

In the theoretical discussion on design expertise, the thesis has issued a challenge to redefine the design expertise. The new requirements which arise especially from the contextual nature of professional expertise as well as human activity in general will have special importance in the specification of the 'contextual-developmental' paradigm for the future studies. The endeavour of redefining design expertise implies many theoretical, methodological as well as practical sub-problems. In terms of theoretical approaches, we have to start from approaches that consider the contextual constraints much more seriously than is customary so far. Furthermore, the choice of concepts which try to capture the essential nature of design expertise should make a conscious compromise between the general and the domain-specific concepts.

Based on the empirical analyses of this thesis, relevant aspects of design expertise can be discerned at a more specific level, and the role of contextual and strategic knowledge can be better understood. However, the methods used in this study have limitations which did not allow conclusions, for example, about the processes of knowledge transformation through learning and development. Analysis of developmental continuities in the acquisition of strategic and contextual knowledge tentatively pointed to a better integration of these knowledge components among experts. However, additional studies using thinking aloud are needed to analyse how this integration takes place, and how the position of different knowledge components changes through this integration when design expertise develops.

The understanding of design activity and respectively of design expertise as a contextually as well as developmentally determined phenomenon implies that the nature and development of such activity are strongly influenced by different kinds of socio-cultural contexts of subjects' work conditions. The continuous increase of inter- and cross-cultural environments as professional work settings as well as the simultaneous growth of globally networked virtual environments are posing novel challenges for the need of understanding the culturally conditioned differences in design and planning. The aim of gaining understanding how subjects with culturally different background grasp each other's perspective while working and learning in such environments is a huge challenge for future research.

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Appendix 1.

Object of analysis/ Target components of expertise	Methods used in deriving and elicitation of data	Methods used in analysing (reducing, summarizig) the data	Methods used in the presentation of information
Metacognitive knowledge of the - program comprehension strategies - program task	Half-structured interviews after the completion of a comprehension task	Verbalized statements were assessed and categorized according to the level of the knowledge	Three-level quantification & specific nature of the ideal strategy defined by subjects themselves Authentic verbal statements of experts
Metacognitive awareness of the used strategies	Half-structured interviews after the completion of a comprehension task Thinging-aloud during the program comprehension & videotaping of subjects' skimming through the program-text	Subjects' owns verbal statements of the used strategies were compared with the strategies independently determined by two researchers on the basis of transcribed thinking-aloud protocols and observations of subjects' focus of attention during program comprehension	Agreement between subject's own conception and the one determined by the researchers Semantic analysis using the idea as a unit of analysis and segmentation of protocols
On-line monitoring and regulation of the comprehension activity	Thinking-aloud during the program comprehension	Transcribed thinking-aloud protocols were analysed using semantic ideas concerning the goals, strategies and details of working.	Three-level quantification according to the extent of monitoring
Program understanding	Tasks of program understanding (five different tasks measuring program understanding at different levels)	Assessment of the outcomes of understanding tasks; a sum-score based on the outcomes of five tasks	

Table 1. Summary of methods used in the analysis of metacognition

Appendix 2.

Object of analysis/ Target components of expertise	Methods used in deriving and elicitation of data	Methods used in analysing (reducing, summarizing) the data	Methods used in the presentation of information
Quality of subjects' knowledge structures in the domain of information systems development	Conceptual model construction on the theme of "development of information systems" & thinking-aloud during the model construction & videotaping of the construction process Stimulated recall of the videotaped construction process (including interview) An essay task with an open-ended question "What are the most important issues in the development of information systems?"	Iterative reading by two researchers Transcribed thinking-aloud protocols & videotaped model construction & protographs depicting the constructed models Transcribed interview-protocols & in ambiguous cases subjects' answers to an essay task were evaluated using the content analysis of verbal data Segmentation of the protocols was based on their sematic features: First, all thematic issues, ideas and conceptions concerning an organization and end-users were extracted from the protocols and from the concepts used in the final models Secondly, a framework for the categorization was constructed and four categories were established. - The whole variance in subjects' representation of the end-users and organizational issues was taken into account.	Concept maps introduced by Novak (1990) were used to demonstrate the qualitatively different organization of subjects' knowledge Concept maps describing the used concepts, linking words between concepts, hierarchy indicating the priority of concepts. Comparison of experts and novies in how they considered user and organizational issues
Amount and quality of subjects' work experiences	Half-structured interviews of subjects' working and learning histories and their actual work situation		

Table 2. Summary of methods used in the analysis of domain-specific knowledge.

Appendix 3.

Object of analysis, Target components of expertise	Methods used in deriving and elicitation of data	Methods used in analysing (reducing, summarizing) the data	Methods used in the presentation of the information
Contextual and strategic knowledge manifested in design problem solution	A problem-solving task involving the task assignment of constructing a plan for developing a micro-computer- based information system for the purposes of helping families to plan and monitor their domestic finances	Systematic content analysis of problem solution and construction of a categorization system for the assessment of (i) solution scope (three categories) (ii) solutions structures (three categories) (iii) the nature of professional strategies (three categories) (iv) the identifying with clients (three categories)	
	After the task completion an interview about the strategies used in problem-solving, about the difficulties of task completion and about the constraints considered	Tape-recorded interviews were transcribed and used as complementary data in unambiguous interpretations For the construction of the five types of many-dimensional solution patterns, the relationships between the categories of separate dimensions were analysed using cross-tabulations and a chi-square test.	Verbal descriptions of five solution patterns & picture outlines
Amount and quality of subjects' work experiences	Interviews of subjects' work histories, their recent work settings and subjects' functional roles in their work organizations		

Table 3. Summary of methods used in the analysis of contextual and strategic knowledge

YHTEENVETO [1]

Johdanto ja tutkimuksen tarkoitus

Taustaa. Työelämän nopeat muutokset, joihin liittyy asiantuntijatiedon kasvava merkitys yhteiskuntaelämän eri sektoreilla, ovat asettaneet mittavia haasteita asiantuntijakoulutukselle ja työssä tapahtuvalle jatkuvalle oppimiselle. Erityisen merkittäviä jatkuvan oppimisen haasteet ovat olleet uutta informaatio- ja kommunikaatioteknologiaa hyödyntävien, mutta samalla myös näiden järjestelmien kehittämiseen ja suunnitteluun osallistuvien henkilöiden kohdalla. Näiden tietotekniikan ammattilaisten asiantuntemuksen laadusta ja tasosta paljolti määräytyy se, millaisia tietojärjestelmiä käyttäjät saavat työvälineikseen ja millaisia sekä keiden tarpeista lähteviä järjestelmiä ylipäänsä kehitellään. Informaatioteknologiaa kehittävien asiantuntijoiden osaaminen on näin ollen tärkeää siltä kannalta, millaisiksi tietoyhteiskunnan työ- ja oppimisympäristöt muotoutuvat.

Tämän tutkimuksen kohteena on tietojärjestelmien suunnittelu- ja kehittämisasiantuntijuus sekä asiantuntijuuden oppiminen ja kehittyminen korkeakoulutuksen ja työelämän konteksteissa. Kun aiemmassa oppimistutkimuksessa on paljolti keskitytty joko yksinomaan koulutuksen tai työelämän ympäristöihin, tässä tutkimuksessa asiantuntijuuden kehittymistä tarkastellaan jatkuvan ja elinikäisen oppimisen hengessä korkeakoulutuksen ja työkokemuksen muodostamalla jatkumolla. Asiantuntijaksi oppimista tutkitaan analysoimalla rinnakkain korkeakoulutuksen ja työelämän sekä näiden sillaksi rakennetun projektiopiskelun tuottamaa osaamista.

Tietoyhteiskunnassa kriittiseen asemaan nousevat korkeaa koulutusta ja monipuolista osaamista vaativat tehtävät, joihin liittyy avoimia ja huonosti määriteltyjä ongelmia. Tällaisia ongelmia ovat myös tämän tutkimuksen kohteena olevat tietojärjestelmien suunnittelu- ja kehittämistehtävät. Tietotekniikan

[1] Tämä julkaisu koostuu yleisestä johdanto-osasta (luvut 1 ja 2), viidestä artikkelista (luvut 3-7) sekä yleisestä johtopäätös- ja keskusteluosasta (luku 8).

alalla asiantuntijuuden hankkimisen ja ylläpitämisen haasteellisuutta lisää alan työvälineiden ja menetelmien nopea kehitys, mikä edellyttää jatkuvaa uusien menetelmien oppimista ja hallintaa. Viime vuosina on lisäksi entistä voimakkaammin korostettu, että tietojärjestelmän suunnittelijoiden tulisi kyetä ottamaan paremmin huomioon järjestelmän käyttäjien, käyttäjäorganisaatioiden ja yleisemminkin asiakkaiden tarpeet, mikä asettaa uusia haasteita tietojärjestelmien suunnittelu- ja kehittämisasiantuntijuudelle.

Tavoite ja tarkoitus. Tämän tutkimuksen tarkoituksena oli selvittää asiantuntijuuden ja eksperttiyden luonnetta ja sen kehittymistä huonosti määritellyillä ongelma-alueilla, erityisesti tietojärjestelmien suunnittelussa ja kehittämisessä. Soveltavan kognitiivisen psykologian lähtökohdista asiantuntijuuden kehittymistä tutkittiin sekä korkeakoulutuksen että työelämän konteksteissa tapahtuvan oppimisen seurauksena. Tutkimusasetelmana käytettiin pääasiassa ekspertti-noviisi vertailuasetelmaa, jossa alan koulutuksen saaneita, mutta vähäisen tai puuttuvan työkokemuksen omaavia aloittelijoita (noviiseja) verrattiin kohtuullisen työkokemuksen ja alan koulutuksen omaaviin alan ammattilaisiin ja asiantuntijoihin (eksperteihin). Vertailuasetelmaa täydennettiin pitkittäistutkimuksella, jossa analysoitiin korkeakouluopintojen loppuvaiheeseen sijoittuvan ensimmäisen käytännön projektiopintojakson aikana tapahtuvaa asiantuntijuuden kehittymistä. Tavoitteena oli selvittää, millaista oppimista tapahtuu siirryttäessä teoreettisesti painottuvista perusopinnoista ensimmäiseen käytännön suunnitteluprojektiin.

Soveltavan kognitiivisen psykologian lähtökohdista nouseva yleinen kysymyksenasettelu liittyi siihen, miten henkilön kokemustausta on yhteydessä laadullisesti erilaiseen eksperttiyteen. Metodisena tavoitteena oli kehittää asiantuntijatiedon esiin saamista palveleva menetelmä. Teoreettisena pyrkimyksenä oli suunnitteluasiantuntijuuden uudelleen määrittely. Tätä varten arvioidaan kriittisesti kognitiivisen psykologian tuottamaa käsitystä suunnitteluasiantuntijuudesta ja pohditaan toiminnan kontekstuaalisuutta ja tilannekohtaisuutta korostavien lähestymistapojen antia.

Tutkimuksen teoreettinen tausta ja aiempi eksperttiystutkimus. Katsaus soveltavan kognitiivisen psykologian piirissä tehtyyn eksperttiystutkimukseen (luku 2.) osoittaa, että alan tutkimus on viimeisen kahdenkymmenen vuoden aikana huomattavasti lisääntynyt, samalla kun se on laajentunut koskemaan entistä moninaisempia tehtävätyyppejä. Hyvin määritellyistä tehtävätyypeistä, kuten fysiikan ja ohjelmoinnin ongelmista, on siirrytty entistä monimutkaisempiin todellisen elämän ongelmiin ja laajaa alakohtaista tietämystä edellyttäviin tehtävätyyppeihin. Viimeaikaisen eksperttiystutkimuksen kohteena on ollut mm. lääketieteellinen diagnosointi, juridinen päätöksenteko ja arkkitehtoninen suunnittelu. Keinotekoisten oppikirjaongelmien sijaan tutkimuksessa on alettu käyttää entistä realistisempia ongelmanratkaisutehtäviä, samalla kun on pidetty tärkeänä mahdollisimman aidoissa, reaalimaailman ongelmia vastaavissa tilanteissa tapahtuvaa tiedonhankintaa.

Varhaisessa eksperttiystutkimuksessa yleisimpiä olivat kognitiivisten taitojen oppimista kuvaavat lähestymistavat. Näistä tunnetuimpia on informaation prosessointiteoriaan pohjautuva ja sitä oppimisen osalta täsmentävä Andersonin produktiosääntöjen malli. Tässä mallissa kuvataan erityisesti ns. deklaratiivisen tiedon muuttumista harjoittelun seurauksena proseduraaliseen eli toiminnalliseen muotoon. Toisaalta kanonisoiduissa lähestymistavoissa skeeman käsitettä on käytetty kuvaamaan henkilön pitkäkestoisen muistin yleisiä tietorakenteita. Skeeman käsitettä on pidetty asiantuntijuuden tutkimuksessa hyödyllisempänä kuin produktiosääntöjen mallia sikäli, että se mahdollistaa merkityksellisten tietosisältöjen alaspesifin kuvaamisen. Alakohtaista sisältöspesifiä kuvaamista, joka pyrkii ns. funktionalistiseen selittämiseen, on ajankohtaisessa eksperttiystutkimuksessa pidetty tarkoituksenmukaisena.

Viimeisen kymmenen vuoden aikana eksperttiyden tutkimuksen valtavirrassa on oletettu, että alan sisältöspesifi tietämys edustaa asiantuntijuuden keskeistä selitysperustaa niin huipputaituruuden kuin professionaalisen asiantuntijuudenkin kohdalla. Kognitiivisia huipputaitoja koskeva tutkimus, jota on tehty esim. shakinpeluun alueella, on merkittävästi rikastuttanut käsitystä ihmisen muistijärjestelmän toiminnasta. Alan johtavat tutkijat ovat äskettäin esittäneet käsityksen erityisen hakujärjestelmän - pitkäkestoisen työmuistin - olemassaolosta niillä taitureiden toiminta-alueilla, joilla he ovat kehittäneet huipputaituruuteen rinnastettavan osaamisen.

1980-luvulta lähtien tehty eksperttiystutkimus, joka on kohdistunut runsaasti alakohtaista tietämystä ja useiden vuosien pituista harjoittelua vaativille tehtäväalueille, on tuottanut suhteellisen yhdensuuntaisen käsityksen siitä, millaisia eroja on osaavien, taitavien ja kokeneiden eksperttien tai taiturien sekä aloittelevien, vähemmän taitavien tai oppimisensa alkuvaiheessa olevien noviisien välillä. Eksperttien suoritusnopeuden ja vähäisemmän virheiden määrän lisäksi on voitu osoittaa, että eksperttien ja taiturien toimintaa luonnehtivat seuraavat laadulliset piirteet:

* Ekspertit havaitsevat oman alansa aineistoa laajoina mieltämisyksikköinä.
* Eksperteillä oman alan ongelmat ovat edustettuna syvätasoisesti; he esim. luokittelevat ongelmia pikemminkin niiden ratkaisumallien kuin niiden pinnallisten piirteiden perustella.
* Eksperttien havainnointi on hyvin valikoivaa siten, että he kohdistavat tarkkaavaisuutensa tehtävän olennaisiin puoliin ja jättävät epärelevantit seikat vaille huomiota.
* Eksperteillä heidän oman alansa tietämys on organisoitunut ongelmanratkaisun kannalta tarkoituksenmukaisella tavalla; esim. lääketieteellisessä diagnosoinnissa kokeneiden lääkäreiden biomedikaalinen tietämys on kapseloitunut kliiniseen muotoon.
* Ekspertin tietorakenteet ovat organisoituneet hierarkkisesti; ne ovat useampitasoisia ja niiden osat ovat toisiinsa paremmin linkittyneitä kuin noviiseilla.
* Ekspertit luokittelevat oman alansa ongelmia abstraktien korkeatasoisten periaatteiden mukaisesti.
* Ekspertit käyttävät noviiseja enemmän aikaa ongelman alustavaan analysointiin; he rakentavat tehtävästä tai ongelmasta itselleen yksityiskohtaisen käsityksen, ennen kuin ehdottavat ratkaisumenetelmää.
* Eksperteillä on paremmat itsevalvonta- ja itsearviointitaidot kuin noviiseilla.

Alakohtaisten toimintastrategioiden osalta eksperttien ja noviisien eroja koskevat tutkimustulokset ovat ristiriitaisempia. Esimerkiksi tietokoneohjelman suunnittelua tutkittaessa on havaittu, että ekspertit käyttävät sekä yleisestä yksityiskohtiin etenevää (top-down) strategiaa että opportunistista strategiaa.

Ekspertti - noviisi-vertailuihin perustuvia tutkimuksia on kritisoitu siitä, että ne antavat liian staattisen ja yksipuolisen kuvan eksperttiydestä. Erityisesti monilla professionaalisen toiminnan alueilla, joissa toimintaympäristöt ja työvälineet muuttuvat nopeasti, ekspertti - noviisi-paradigma myös helposti luo harjoittelun ja kokemuksen määrää yliarvioivan käsityksen eksperttiyden kehityksestä ja oppimisesta. Sellaisten huonosti määriteltyjen ja avointen tehtävätyyppien kohdalla, jollaisia suunnittelutehtävät ja tietojärjestelmien kehittäminen edustavat, kapea-alaisten koetehtävien käyttö on myös rajoittanut sitä, millaisia tietämyksen osa-alueita tehtäväratkaisu edellyttää. Niinpä ekologisesti validien tehtävätyyppien käyttöä alan tutkimuksessa on pidetty tärkeänä.

Ekspertti - noviisi-vertailujen rajoituksista käydyssä keskustelussa on runsaasti korostettu ns. kontekstuaalisen tiedon merkitystä asiantuntijuuden keskeisenä komponenttina. Eräissä asiantuntijuuden kehitystä kuvaavissa malleissa on korkeatasoista asiantuntijuutta kuvattu prosessiksi, jossa asiantuntijan toiminta ja päätöksenteko ohjautuvat toimintaympäristöstä käsin niin voimakkaasti, että hän on involvoitunut osaksi kontekstiaan. Myös tietojärjestelmien suunnittelua ja kehittämistä koskevassa keskustelussa on viime vuosina entistä painokkaammin tuotu esiin järjestelmän käyttäjiä ja asiakkaiden kontekstia koskevan tiedon merkitystä. Toistaiseksi kuitenkin empiiristä tutkimusta on hyvin niukasti siitä, miten kontekstuaalinen tieto on edustettuna suunnittelija-asiantuntijan toiminnassa ja ongelmanratkaisussa ja miten sen huomioon ottaminen on yhteydessä esim. strategisen ja menetelmätiedon hallintaan asiantuntijaksi oppimisessa.

Soveltavan kognitiivisen psykologian piirissä tehdyssä eksperttiystutkimuksessa on pidetty lupaavina lähestymistapoja, joissa analysoidaan kokemuksen laadun ja eksperttiyden laadun välisiä yhteyksiä. Myös eksperttipedagogisiin opetuskokeiluihin kohdistuvat tutkimukset ja eksperttiyden tuottamiseen tähtäävät seuranta- ja pitkittäistutkimukset on nähty tarpeellisiksi, jotta voitaisiin paremmin ymmärtää, millaisia ovat eksperttiyden hankkimisen ja kehittymisen kannalta suotuisat oppimisympäristöt.

Eksperttiyden kehittymistä, hankkimista ja oppimista koskevassa keskustelussa on toistuvasti asetettu kysymys, mikä tekee esim. työkokemuksesta eksperttiyttä kehittävää. Kuitenkaan toistaiseksi ei ole paljoa tutkimustietoa siitä, miten eksperttiyden laatu on yhteydessä henkilön taustakokemuksen laatuun - kokemukseen, joka on hankittu todellisissa professionaalisissa ongelmanratkaisutilanteissa. Kokemuksen laadusta puhuttaessa ei myöskään ole paljoa keskusteltu siitä, miten kokemus tulisi ymmärtää. Tulisiko kokemus nähdä esim. objektiivisesti mitattavana määrällisenä parametrinä vai ennemminkin henkilön omana subjektiivisesti koettuna ja yksilöllisesti konstruoituna kertomuksena hänen oppimishistoriastaan.

Luvussa 2.6. tarkastellaan, miten kokemus on ymmärretty tähänastisessa eksperttiystutkimuksessa. Tarkastelu osoittaa, että henkilön (elämän)kokemuksen merkitys on yleisesti tunnustettu jo psykologian varhaisesta muistitutkimuksesta lähtien, mutta vallitseva muistin yleisiä rakenteita ja kapasiteettia määrittelevä kokeellinen tutkimusparadigma on lähinnä pyrkinyt vain kontrolloimaan henkilön taustakokemuksen merkityksen mahdollisimman hyvin. Sikäli kun kokemusta on myöhemmässä kognitiivisen psykologian piirissä tehdyssä eksperttiystutkimuksessa käsitelty, se on useimmiten pelkistetty määrälliseksi parametiksi. Kokemuksen laadun osalta on toistaiseksi hyvin summittaista tietoa, joka rajoittuu ihmisen varhaisiin kehitysvaiheisiin.

Yksityiskohtaisimmin kokemuksen laadun ja eksperttiyden välisiä yhteyksiä on tarkasteltu viime vuosina tehdyssä huipputaituruuden tutkimuksessa, jossa on etsitty harjoittelun laadun (mm. sen ajoituksen ja esim. vuorokausirytmin) ja yleisemminkin oppimisympäristön laadun yhteyksiä taituruuteen. Huipputaituruuden edellyttämän harjaantumisajan osalta tutkimukset ovat tähän mennessä melko yhdensuuntaisesti osoittaneet, että tällaisen taituruuden hankkimiseen esim. shakinpeluun, musiikin ja liikunnan alueilla vaaditaan vähintään noin kymmenen vuoden intensiivinen ja oikein ajoitettu harjoittelukokemus. Työelämässä vaadittava professionaalinen asiantuntemus on yleensä luonteeltaan varsin normatiivista, eikä se tässä mielessä ole verrattavissa huipputaituruuteen. Työelämän oppimisympäristöt eivät myöskään voi vastata intensiivisiä harjoitteluympäristöjä. Kuitenkin huipputaituruutta koskevat tutkimukset voivat antaa viitteitä siitä, millaiset ympäristöt ovat jatkuvan oppimisen kannalta suotuisia ja mikä tekee vuosia kestäneestä kokemuksesta asiantuntijaksi oppimisen kannalta kehittävää.

Tässä tutkimuksessa lähtökohtana on pyrkimys tutkittavan asiantuntijuuden alaspesifiin ymmärtämiseen. Koska tarkastelun kohteena on suunnittelu- ja kehittämisasiantuntijuus, luvussa 2.7. tarkastellaan, miten suunnittelu on aikaisemmassa tutkimuksessa ymmärretty inhimillisenä toimintana. Kognitiivisen lähestymistavan piirissä suunnittelua on kuvattu huonostimääriteltynä ongelmana, johon ei ole olemassa yhtä ainoaa oikeaa ratkaisua. Suunnittelun määrittelyä reflektiivisenä ja situationaalisena toimintana luonnehditaan näitä lähestymistapoja edustavien kriittisten koulukuntien pohjalta.

Tutkimusongelmiksi täsmentyivät seuraavat kysymykset:

* Millaista on tietojärjestelmien suunnittelu- ja kehittämisasiantuntijuus luonteeltaan?
* Miten tietojärjestelmien suunnittelu- ja kehittämisasiantuntijuus on yhteydessä henkilön työ- ja opiskelukokemukseen?
* Miten korkeakouluopintojen loppuvaiheeseen sijoitettu käytännön työelämään suuntautuva projektiopiskelujakso vaikuttaa suunnitteluasiantuntijuuden kehittymiseen?
* Millaiseksi voidaan luonnehtia korkeatasoista tietojärjestelmien suunnittelu- ja kehittämisasiantuntijuutta?
* Mikä on metakognition rooli suhteessa asiantuntijuuteen?
* Millaisia kehitysjatkumoja voidaan havaita suunnittelu- ja kehittämisasiantuntijuuden oppimisessa ja hankkimisessa?

Metodit

Empiirisissä tutkimuksissa käytettiin pääasiassa ekspertti - noviisi-poikkileikkausasetelmaa, jossa aloittelijoita eli noviiseja verrattiin alan kokeneisiin ammattilaisiin (ekspertteihin). Poikkileikkausasetelman lisäksi tutkimuksessa käytettiin opiskelijoiden osalta seuranta-asetelmaa, joka kattoi tietojärjestelmän suunnittelijoiden korkeakouluopintojen loppuvaiheeseen sijoittuvan seitsemän kuukauden projektiopintojakson.

Tutkittavina henkilöinä oli kolmannen ja neljännen vuoden tietojärjestelmätieteen yliopisto-opiskelijoita (n=40) sekä tietojärjestelmien suunnittelun ammattilaisia ja asiantuntijoita (n=40), jotka olivat viidestätoista eri yrityksestä ja oppilaitoksesta sekä yliopiston ainelaitokselta. Työkokemusta omaavat suunnittelijat (ekspertit) oli valittu satunnaisotannalla vanhojen opiskelijoiden rekisteristä. Ohjelman ymmärtämistä koskevassa tutkimuksessa, jota raportoidaan ensimmäisessä artikkelissa, tutkittavina oli toisen ja kolmannen vuoden tietojenkäsittelytieteen yliopisto-opiskelijoita (n=12), jotka olivat suorittaneet Cobol-ohjelmointikurssin (noviisit). Eksperttiohjelmoijien ryhmä koostui lähiympäristön yrityksistä vähintään samantasoisen koulutuksen saaneista ohjelmoijista ja suunnittelijoista (n=12), jotka olivat käyttäneet Cobol-ohjelmointikieltä vähintään kahden vuoden ajan samantyyppisellä sovellusalueella kuin mitä tutkimuksessa käytetty ohjelmointitehtävä edusti.

Tiedonkeruumenetelminä käytettiin yksilötestaustilanteessa esitettäviä ja mahdollisimman autenttisia tehtävätilanteita edustavia tehtäviä ja menetelmiä. Tätä tukimusta varten kehiteltiin ns. käsitteellisen mallin rakentamis- ja arviointitehtävä (CMCR), jossa henkilöitä pyydettiin rakentamaan heidän omaan käsitykseensä perustuva käsitteellinen malli käyttämällä magneettitaulun liikuteltavilla laatoilla esitettyjä valmiiksi annettuja tai itse tuotettuja alan keskeisiä käsitteitä kuvaavia termejä. Rakentamisprosessiin liittyi ääneenajattelu ja työskentelyn videointi. Välittömästi tämän jälkeen tutkittavat henkilöt haastateltiin käyttäen tukena videoitua mallin rakentamista kuvaavaa esitystä. Tutkittaville esitettiin myös pienimuotoisia esseetehtäviä, joilla kartoitettiin heidän käsityksiään tietojärjestelmän kehittämisestä. Henkilöiden opiskelu- ja työkokemushistoriasta sekä heidän työtilanteestaan hankittiin tiedot haastattelemalla. Lisäksi tutkittaville esitettiin pienimuotoinen suunnittelutehtävä ratkaistavaksi, myös tähän liittyi ratkaisun jälkeen tehty haastattelu. Strukturoituja arviointilomakkeita käytettiin mm. mallin rakentamistehtävässä annettujen käsitteiden tuttuuden määrittelyssä sekä tietojärjestelmän suunnittelijoiden toimenkuvan kartoituksessa.

Tietojen arvioinnissa ja analysoinnissa nojauduttiin pääasiassa sisällönanalyyttisiin menetelmiin. Arviointijärjestelmien kehittämiseen osallistui tietojenkäsittelytieteen edustajia ja suoritetuissa rinnakkaisarvioinneissa päästiin yleensä luotettaviin (yhtäpitäviin) luokituksiin. Kvalitatiivista ja kvantitatiivista kuvausta käytettiin toisiaan täydentävästi. Laadullisesti erilaisen asiantuntijuuden kuvauksessa käytettiin mm. käsitekarttoja sekä tyyppikuvauksia, joita havainnollistettiin tapauskuvauksilla.

Henkilöiden kokemustaustasta analysoitiin työkokemuksen pituuden lisäksi kokemuksen laatua esim. siltä osin, millaisia menetelmiä suunnittelijat olivat käyttäneet ja tällä hetkellä käyttivät työssään sekä millainen professionaalinen ja toiminnallinen rooli heillä oli omassa työorganisaatiossaan. Opiskelijoiden osalta kartoitettiin heidän projektityönsä luonnetta ja heidän mahdollista aikaisempaa työkokemustaan.

Artikkelit ja niiden yhteenveto

Ensimmäisessä artikkelissa analysoidaan metakognition ja eksperttiyden välistä suhdetta tietokoneohjelman ymmärtämisessä. Tutkimuksessa etsitään vastausta kysymykseen, miksi oman toiminnan metakognitiivinen valvonta ja ohjaus, jonka yleensä oletetaan parantavan suoritusta komplekseissa kognitiivisesti vaativissa tehtävissä, oli parantanut ohjelman ymmärtämistä kokeneiden eksperttiohjelmoijien ryhmässä, mutta ei sen sijaan noviisiohjelmoijilla. Aikaisemman tutkimustiedon pohjalta oletettiin, että tuloksellinen metakognitiivinen oman toiminnan ohjaus ja monitorointi edellyttää adekvaattia tietoisuutta niistä kognitiivisista strategioista, joita henkilö käyttää ja soveltaa omassa toiminnassaan, tässä tapauksessa ymmärtämisprosessissa. Lisäksi oletettiin, että tuloksellinen oman toiminnan valvonta ja ohjaus edellyttää metakognitiivista tietoa ohjelmatehtävästä ja itselle soveltuvista ymmärtämisstrategioista.

Eksperttien ja noviisien vertailu, joka perustui Cobol-kielisen päivitysohjelman ymmärtämistehtävään, osoitti, että eksperttien metakognitiivinen tieto ohjelmatehtävästä oli hyvin yksityiskohtaista ja kattavaa; ekspertit näyttivät keskittyivät usein ohjelmointityyliä koskeviin seikkoihin, mikä oli harvinaista noviiseilla. Noviisien tehtävää koskeva tieto oli huomattavasti diffuusimpaa ja ylimalkaisempaa kuin eksperteillä. Eksperteillä oli yleensä metakognitiivista tietoa ihanteellisista ymmärtämisstrategioista, ja suurin osa heistä myös toimi tämän ihannestrategian mukaisesti. Sen sijaan vain noin puolella noviiseista oli käsitys ihanteellisista ymmärtämisstrategioista, ja heistäkin vain puolet toimi tämän ihannekäsityksen mukaisesti. Eksperttien omaa toimintaa koskeva metakognitiivinen tietoisuus, joka koski sekä käytettyjä ymmärtämisstrategioita että ymmärtämisessä ilmeneviä vaikeuksia, oli myös huomattavasti adekvaatimpaa kuin noviiseilla.

Metakognitiivisen toiminnan ohjauksen ja monitoroinnin sekä ohjelman ymmärtämistuloksen välillä oli merkitsevä yhteys silloin kun metakognitiivisen tiedon ja tietoisuuden osuus kontrolloitiin; ilman tätä kontrollia yhteys ei ollut merkitsevä. Tulosten katsottiin osoittavan, että sekä metakognitiivinen tieto että adekvaatti tietoisuus omasta toiminnasta ovat edellytyksenä sille, että toiminnan metakognitiivinen säätely ja ohjaus voivat olla välittömästi tuloksekkaita. Näyttää siltä, että vähintään kahden vuoden työkokemus, jota tässä käytettiin eksperttien valinnan kriteerinä alan koulutuksen lisäksi, on edellytyksenä sille, että tietoisuus omista toimintastrategioista on riittävän kehittynyt, jotta myös toiminnan tietoisuuden ja toiminnan ohjauksen välinen toimiva vuorovaikutus on mahdollista. Noviiseilla metakognitiivisen tietoisuuden, tiedon ja toiminnan ohjauksen välisen vuorovaikutuksen hataruuden sekä mk-tietoisuudessa ja tiedossa ilmenevien puutteiden katsottiin selittävän sitä, että toiminnan metakognitiivinen ohjaus ei heillä ollut välittömästi tuloksekasta.

Toisessa artikkelissa, joka on kommentti Lordin ja Levyn esittämään inhimillisen toiminnan monitasoiseen kontrolliteoriaan, tavoitteena on kontribuoida esitetyn teorian kehittelyyn oppimista koskevan ulottuvuuden osalta. Teoriaa esitetään täsmennettäväksi lisäämällä siihen eksperttiyden kehittymistä sekä eksperttiyden ja metakognition suhdetta koskevaa tutkimustietoa. Tavoitteena on kontrolliteorian ekologisen validiteetin lisääminen niin, että se voisi paremmin kuvata ja selittää inhimillisen toiminnan ja sen kontrolloinnin eri tasojen välistä suhdetta. Artikkelissa tuodaan esille ekspertti - noviisi-paradigman puitteissa hankittua tutkimustietoa siitä, miten toiminnan ohjaus ja kontrolli muuttuu oppimisen seurauksena. Tässä yhteydessä hyödynnetään myös ensimmäisessä artikkelissa kuvattuja tuloksia, jotka koskevat metakognition eri komponenttien suhdetta sekä niiden yhteyttä kokemuksen seurauksena kehittyneeseen eksperttiyteen. Dreyfusin ja Dreyfusin (1986) esittämän viisitasoisen eksperttiyden kehitysmallin avulla havainnollistetaan, miten toiminnan ohjaus ja kontrollointi muuttuu eksperttiyden kehityksen ja oppimisen seurauksena.

Kolmannessa julkaisussa tarkastelun painopiste siirtyy toimintastrategioista alaspesifiin tietoon, joka tässä koskee tietojärjestelmien kehittämistä. Tutkimuksen tavoitteena on kartoittaa, millaisia käsityksiä alan ammattilaisilla ja opiskelijoilla on tietojärjestelmien kehittämisestä ja miten nämä laadullisesti erilaiset käsitykset ovat yhteydessä henkilöiden oppimis- ja kokemustaustaan. Alaspesifin tiedon kartoittamisessa käytettiin pääasiallisena menetelmänä tutkimusta verten kehitettyä käsitteellisen mallin rakentamis- ja arviointitehtävää (CMCR).

Noviisien ja eksperttien vertailu osoitti, että nämä ryhmät erosivat toisistaan ennen kaikkea siinä, miten laaja-alainen näkökulma heillä oli tietojärjestelmien kehittämiseen. Enemmistö (47.5 %) eksperteistä hahmotti tietojärjestelmän kehittämisen työorganisaation näkökulmasta, mutta noviiseilla tämä oli harvinaista. Enemmistö noviiseista hahmotti tietojärjestelmän kehittämisen yksilöllisen käyttäjän näkökulmasta, sitä piti tärkeänä noin kolmannes (32.5%) noviiseista.

Asiantuntijuuden laadullisia eroja ja niiden yhteyksiä henkilöiden kokemustaustaan havainnollistettiin muuntamalla eräiden erityyppistä kokemustaustaa omaavien asiantuntijoiden (alan professorin ja tietojärjestelmiä kehittävässä yrityksessä pitkähkön työkokemuksen omaavan systeeminsuunnittelijan) representaatiot Novakin ehdottamiksi käsitekartoiksi, joissa kartan hierarkia kuvaa asioiden tärkeysjärjestystä ja joissa käsitteiden väliset linkit on sisällöllisesti spesifioitu. Noviiseilla havaittiin yleisesti melko rajoittunut tietojärjestelmän kehittämisvaiheisiin keskittyvä representaatio, johon käyttäjän näkökulma oli vaikeasti integroitavissa.

Kokemuksen laadun ja eksperttiyden laadun välisten yhteyksien yksityiskohtaisempi analyysi etenkin kummankin ryhmän poikkeavien tapausten osalta täsmensi työkokemuksen merkitystä asiantuntijuuden kehittymisessä. Yleispäätelmänä todettiin, että tietyn pituinen työkokemus on välttämätön, mutta ei riittävä edellytys korkeatasoisen asiantuntijuuden kehittymiselle. Käytännön johtopäätöksenä esitettiin korkeakoulupedagogisia suosituksia, jotka koskevat tarvetta ottaa koulutuksen aikana paremmin huomioon opiskelijoiden työharjoittelussa saamia oppimiskokemuksia, jotta ne eivät jäisi omaan lokeroonsa ja integroitumatta korkeakouluopetuksessa välitettävään oppikirjatietoon. Työelämän urasuunnittelussa korostetaan asiantuntijuutta kehittävän henkilöstösuunnittelun merkitystä työorganisaatioiden tuloksellisuuden kannalta.

Neljännessä artikkelissa tarkastellaan suunnitteluasiantuntijuuden oppimista ja hankkimista strategisen ja kontekstuaalisen osaamisen näkökulmasta. Joillakin professionaalisen osaamisen alueilla, kuten lääketieteellisessä diagnosoinnissa, on esitetty asiantuntijuuden kehittymistä kuvaavia malleja, joissa on osoitettu, miten alan ongelmanratkaisussa käytettävä tietämys muuttaa muotoaan käytännön kokemuksen kautta tapahtuvan oppimisen seurauksena. Suunnitteluasiantuntijuuden kohdalla tällaiset kehitysmallit toistaiseksi puuttuvat.

Tietojärjestelmien kehittämisasiantuntijuudessa on perinteisesti pidetty tärkeänä uusimpien menetelmien, työvälineiden ja strategisten mallien osaamista. Viime vuosina näiden rinnalla on tosin alettu korostaa yhä enemmän ns. kontekstuaalista tietoa, joka koskee suunniteltavan järjestelmän tulevia käyttäjiä ja käyttäjäyhteisöjä sekä asiakkaita, joille tuote on tarkoitettu. Miten näitä suunnitteluasiantuntemuksen eri osa-alueita koskeva tietämys omaksutaan koulutuksen, ensimmäisten käytännön harjoittelukokemusten ja myöhemmän työelämässä saatavan kokemuksen seurauksena, on toistaiseksi huonosti ymmärretty. Tässä osatutkimuksessa selvitettiin, miten strateginen ja kontekstuaalinen tietämys on edustettuna eri kokemustaustan omaavien henkilöiden suunnitteluongelman ratkaisussa ja millaisia mahdollisia kehitysjatkumoja voidaan todeta strategisen ja kontekstuaalisen tiedon omaksumisessa.

Ekspertti - noviisi-vertailuasetelman lisäksi tässä tutkimuksessa käytettiin seuranta-asetelmaa, jonka avulla analysoitiin, millaista oppimista tapahtuu korkeakouluopintojen loppuvaiheeseen sijoitetun seitsemän kuukauden pituisen työelämään suuntautuvan projektiopintojakson aikana. Vähintään kahden vuoden suunnittelukokemuksen omaavia suunnitteluasiantuntijoiden ongelmanratkaisuja (n=40) verrattiin opintojakson alku- ja loppuvaiheessa olevien korkeakouluopiskelijoiden ongelmanratkaisuihin. Suunnittelutehtävän valinnassa kiinnitettiin erityistä huomiota siihen, että tehtävä edustaisi kaikille tuttua sovellusaluetta ja näin mahdollistaisi siihen liittyvän kontekstitiedon hallinnan.

Projektiopintojen seurauksena tapahtuvia muutoksia analysoitiin ns. siirtymätaulukkojen avulla, minkä lisäksi vertailtiin erikseen opintojakson alku- ja lopputestauksissa esitettyjä ratkaisuja eksperttien ratkaisuihin. Tulokset osoittivat, että projektiopinnot, jotka samalla edustivat opiskelijoille ensimmäistä käytännön suunnittelukokemusta, olivat vahvistaneet ensisijaisesti opiskelijoiden strategista osaamista. Sen sijaan kurssi ei ollut laajentanut heidän kontekstuaalista osaamistaan.

Etenkin eksperttien kohdalla suunnittelutehtävien ratkaisujen variaatio oli huomattava. Aineistosta voitiin kuitenkin identifioida viisi laadullisesti erilaista ratkaisumallia, joihin 88% kaikista ratkaisuista voitiin sijoittaa. Ratkaisumalleina kuvataan 1) asiantuntijakeskeinen työvaihemalli, 2) yksilöllinen ja vuorovaikutteinen prototyypin rakentamismalli, 3) asiakaskeskeinen samastumismalli, 4) neuvotteluorientoitunut markkinalähtöinen malli ja 5) laaja-alainen yhteistoiminnallinen lähestymistapa.

Projektioppimisen seurauksena tapahtui siirtymä asiantuntijakeskeisestä työvaihemallista yksilölliseen ja vuorovaikutteiseen prototyypin rakentamismalliin. Projektiopinnot näyttivät myös pienentävän sovellettavien ratkaisumallien laadullista variaatiota. Eksperttien soveltamissa ratkaisumalleissa oli kaiken kaikkiaan enemmän laadullista vaihtelua kuin noviisien käyttämissä malleissa varsinkin projektiopintojen loppuvaiheessa. Vain kohtuullisen työkokemuksen omaavien eksperttien ryhmästä voitiin merkittävässä määrin löytää korkeatasoista asiantuntijuutta edustavaa laaja-alaista yhteistoiminnallista ratkaisumallia, ja tätäkin esiintyi vain noin viidenneksellä (18.9%) eksperteistä.

Henkilöiden kokemustaustan ja sovelletun ratkaisumallin välisten yhteyksien laadullinen tarkastelu osoitti, että henkilöiden käyttämissä malleissa heijastuu hyvin voimakkaasti heidän työorganisaationsa funktionaalisesta asemasta peräisin oleva ongelmanratkaisustrategia. Tämä ilmeni erityisesti 3- ja 4-mallien kohdalla, jotka myös edellyttävät erilaista professionaalista roolia ja näin ollen myös erilaista strategista tietämystä kuin muut ratkaisumallit. Henkilön työkokemuksen pituuteen olivat selvimmin yhteydessä 1-, 2- ja 5-mallit, joista korkeatasoista asiantuntemusta edustavaa mallia käyttävillä henkilöillä oli vähintään viiden vuoden työkokemus suhteellisen vakaassa organisaatioympäristössä.

Asiantuntijuuden kehittymistrendit, jotka aineiston perustella voitiin hahmottaa, ilmenivät siirtymänä professiokeskeisestä kohti vuorovaikutteista työtapaa; yleisestä ja kontekstista irrallisesta ratkaisumallista kohti yksilöllistä ja erityistapaukset huomioivaa ratkaisutapaa; strategista ja metodista (miten) osaamista painottavasta toimintaulottuvuudesta kohti laaja-alaisempaa kohteen määrittelyä ja sen käyttötarkoitusta (mitä ja miksi) korostavaa toimintaulottuvuutta; yksilöllisestä tai yksinomaan käyttäjäkeskeisestä työskentelytavasta kohti vuorovaikutusta ja käyttäjän mukaanottoa itse suunnitteluprosessiin korostavaa ratkaisumallia. Tuloksista keskusteltaessa tarkastellaan näiden trendien yhteyksiä mm. tietojärjestelmätieteen paradigmojen kehitystrendeihin.

Viidennessä julkaisussa tarkastellaan kontekstuaalista tietoa suunnitteluasiantuntijuuden kehittymisessä. Tarkastelu perustuu pääasiassa käsitteelliseen analyysiin, mutta siinä hyödynnetään myös aiemmissa empiirisissä tutkimuksissa saatuja tuloksia. Aluksi määritellään professionaalisen tiedon kolme komponenttia; praktinen, formaalinen ja metakognitiivinen tieto. Tämän jälkeen tarkastellaan, miten suunnittelutoiminta on ymmärretty kognitiotieteen piirissä ja miten sitä on tutkittu tämän viitekehyksen puitteissa. Kognitiivisen psykologian viitekehyksessä suunnitteluongelmia on pidetty ns. huonosti määriteltyinä ongelmina, joissa tehtävän tavoitetila on epätäydellisesti ja sumeasti määriteltävissä eikä ongelmaan näin ollen löydy yhtä ainoaa oikeaa ratkaisua. Myös ratkaisutapoja on useita, ja ongelmanratkaisu edellyttää useiden tietämysalueiden integrointia.

Oppimisen ja kognition tutkimuksen alueella on viime vuosina noussut keskustelun kohteeksi oppimisen ja kognition tilannekohtaisuutta korostava ns. situated learning- lähestymistapa. Tämän lähestymistavan puitteissa oppiminen on ymmärretty ensisijaisesti yhteisölliseksi ja sosiaaliseksi prosessiksi, joka merkitsee identiteetin vähittäistä rakentamista asiantuntijakäytäntöjä edustavissa yhteisöissä. Situated learning paradigman lisäksi myös eksperttiyden tutkimuksessa on 1990-luvulla korostettu entistä voimakkaammin kontekstiin liittyvän tiedon ja osaamisen merkitystä.

Artikkelissa tarkastellaan erilaisia konteksti-käsitteen määrittelyjä ja arvioidaan niiden merkitystä suunnittelueksperttiyden uudelleenmäärittelyssä. Eksperttiyden kontekstuaalista luonnetta pidetään määrittelyn lähtökohtana, mutta toisaalta kiinnitetään huomiota siihen, että kontekstin äärimmäisten korostusten ei tulisi johtaa asiantuntijan kokemushistorian kieltämiseen tai sen redusointiin yksinomaan työpaikan tilannekohtaisiin diskursseihin. Tältä pohjalta ehdotetaan ns. kontekstuaalis-kehityksellisen paradigman kehittämistarvetta.

Yleiskeskustelu ja johtopäätökset

Yleiskeskustelussa tehdään teoreettisia ja metodologisia johtopäätöksiä, joita perustellaan sekä tutkimuksessa tuotetuilla empiirisillä tuloksilla että viittauksilla ajankohtaiseen kokemus-käsitteestä käytävään kriittiseen keskusteluun. Keskustelussa eksperttiyden laadun ja kokemuksen laadun välisestä suhteesta osoitetaan, että tietojärjestelmän suunnittelijoiden asiantuntijuuden laatu määräytyy ensisijaisesti asiantuntijan funktionaalisen roolin perusteella. Tämä rooli syntyy siitä asemasta, joka henkilöllä on omassa työorganisaatiossaan, hänen suhteissaan asiakkaisiin ja tuleviin tietojärjestelmän käyttäjiin sekä ohjelmisto- ja laitemarkkinoihin. Asiantuntijuuden laatu näyttää määrittyvän sen perusteella, millaisen funktionaalisen roolin asiantuntija on omaksunut suhteessa näihin taustatekijöihin.

Tällainen asiantuntijuuden määrittyminen puhuu voimakkaasti myös asiantuntijatiedon kontekstuaalisen luonteen puolesta. Voidaan väittää, että konteksti ei ainoastaan muodosta ympäristöä tai olosuhteita tai luo edellytyksiä asiantuntijalle. Pikemminkin asiantuntijuus on ikäänkuin syväväriäytynyt sen yhteisön mukaisesti, jossa se on edustettuna.

Tämä ei kuitenkaan ole koko totuus. Huolimatta asiantuntijatiedon kontekstuaalisesta luonteesta asiantuntijuuden laadun muotoutumisessa on aina myös mukana henkilön kehityksellinen taso ja kokemushistorian tuottama oppimistausta. Tietojärjestelmän suunnittelijoiden kehityksellinen tarkastelu osoitti, että asiantuntijuuden hankkimisen alkuvaiheessa keskitytään yleensä alakohtaisen menetelmäosaamisen eli strategisen tiedon hallintaan. Menetelmäasiantuntijuuden hankkimiselle oli myös tyypillistä voimakas professio-keskeinen orientaatio.

Seuraavassa vaiheessa menetelmäasiantuntijuus näyttää siirtyvän taka-alalle, samalla kun sen tilalle tulee keskittyminen suunnittelun kohteeseen, itse tietojärjestelmään ja sen ominaisuuksiin. Kohteen määrittelyssä korostuu tällöin voimakkaasti asiakkaiden yksilöllisyyden huomioonottaminen ja vuorovaikutteiden työskentelytapa.

Seuraavassa vaiheessa korostuivat laadullisesti erityyppiset asiantuntijaroolit sekä työskentelytapojen monimuotoisuus. Asiantuntijuuden kehittymisen korkeinta tasoa luonnehti asiakasnäkökulman laaja-alainen huomioonottaminen niin, että asiakas/käyttäjä nähtiin kontekstinsa määräämänä sekä monenlaisten vaikuttavien tekijöiden ja rajoitteiden kentässä toimivana ja vuorovaikutuksessa elävänä subjektina. Tällä tasolla asetettiin miten- ja mitä-kysymysten lisäksi myös miksi-kysymyksiä, joiden avulla perättiin suoritettavien tehtävien tarkoituksenmukaisuutta. Korkeatasoiselle suunnitteluasiantuntijuudelle oli lisäksi tyypillistä useiden vaihtoehtoisten menetelmäratkaisujen näkeminen ja näiden kriittinen arviointi suhteessa kontekstiin ja sen rajoitteisiin.

Ajankohtainen keskustelu professionaalisen asiantuntijuuden normatiivisesta luonteesta on tuottanut kuvauksia, joissa työelämässä vaadittavaa asiantuntijuutta on luonnehdittu mm. adaptiiviseksi, reflektiiviseksi, luovaksi, innovatiiviseksi ja vuorovaikutteiseksi. Näissä luonnehdinnoissa on yleensä taipumus ylikorostaa jotakin tiettyä puolta asiantuntijuudessa, samalla kun unohdetaan se, että korkeatasoinen asiantuntijuus edellyttää aina rikasta, monitahoista ja hyvin järjestäytynyttä alakohtaista tietoperustaa sekä myös alan menetelmien monipuolista hallintaa. Vasta näiden pohjalle rakentuva adaptiivisuus tai reflektiivisyys, joka sisältää käsityksen mm. itselle parhaiten soveltuvista menetelmistä ja rajoituksista omassa osaamisessa, voi tarjota vankan pohjan professionaaliselle asiantuntijuudelle sekä sen kehittämiselle.

Muodikkaissa ihmisen muutosvalmiutta, joustavuutta ja täydellistä työorganisaatioiden ja tuotantoelämän tilannekohtaisiin ehtoihin mukautumista korostavissa malleissa on usein paradoksaalisesti saatettu kokonaan kieltää henkilön aiemman kokemuksen merkitys ja sen tuottaman osaamisen merkitys. Inhimillisen toiminnan tilannekohtaisuutta voimakkaasti korostavat mallit voivat ovat hedelmällisiä sikäli, että ne voivat edistää asiantuntijuuden kontekstuaalisen ja yhteistoiminnallisen luonteen ymmärtämistä ja tältä pohjalta tapahtuvaa asiantuntijuuden uudelleen määrittelyä. Yksinomaisessa toiminnan tilannekohtaisuuden korostuksessa on kuitenkin se vaara, että asiantuntijuutta kantava ihminen, joka elää ja hankkii kokemuksia myös työelämän ulkopuolisissa ympäristöissä, kuten koulutuksessa, vapaa-aikana ja perheensä parissa, pelkistetään ainoastaan työpaikan diskursseissa toteutuvaksi historiattomaksi ja hetkellisille tilanteille alisteiseksi olennoksi. Tämän vuoksi asiantuntijuuden uudelleenmäärittelyssä tulisi toiminnan kontekstuaalisuuden lisäksi ottaa lähtökohdaksi myös ihmisen kehityksellinen ulottuvuus.

Käytännön johtopäätöksenä päädytään ehdottamaan opetussuunnitelmallisia periaatteita, joiden mukaan erilaisten opetusmuotojen ja opetusmenetelmien vaikuttavuuden ja toimivuuden katsotaan kytkeytyvän siihen, mikä on oppijan kulloinenkin osaamisen ja asiantuntijuuden taso. Esimerkkinä erilaisten opetusmuotojen soveltuvuudesta asiantuntijuuden kehityksen eri tasoille kuvataan viisiportainen asiantuntijuuden kehitysmalli, jossa eräitä korkeakoulutuksessa sekä aikuis- ja ammatillisessa koulutuksessa käytettäviä opetusmenetelmiä suositellaan sovellettavaksi eri oppimis- ja kehitysvaiheessa.

Jatkotutkimuksen tarpeesta. Lisätutkimusta tarvitaan selvittämään, miten asiantuntijatiedon eri komponentit integroituvat oppimisen ja kehityksen myötä ja miten ne ovat edustettuina eksperttisuunnittelijan toiminnassa. Tällöin suunnittelutyön yhteistoiminnallinen ja vuorovaikutuksellinen luonne tulisi ottaa suunnittelutehtävän määrittelyn lähtökohdaksi. Lisätutkimusta tarvitaan myös siitä, miten professionaalisen asiantuntijuuden kehittyminen on yhteydessä aikuisen kognitiiviseen ja persoonallisuuden kehittymiseen, sekä millaiset tekijät edistävät ja ehkäisevät kehitystä.

Opetuksen ja oppimisen tutkimuksen alueella tarvitaan kenttäkokeiluihin ja autenttisiin tilanteisiin perustuvia tutkimuksia siitä, millaista oppimista tuottavat erilaiset eksperttipedagogiikan muodot, kuten projektioppiminen, työharjoittelussa oppiminen sekä monipuolista informaatio- ja kommunikaatioteknologiaa hyödyntävät vuorovaikutteiset oppimisympäristöt. Tässä yhteydessä tulisi pyrkiä kehittelemään sellaisia tiedon keruun ja analyysin välineitä, joissa oppimisprosessia koskevan tiedon keruu tapahtuisi mahdollisimman pitkälle automatisoituna ja joissa tiedon analyysissä päästäisiin suuria tietomääriä ja niiden esitystä pelkistäviin, havainnollistaviin ja kuvittaviin menetelmiin.