Chapter 11
Overview and conclusions related to instructional theory and educational practice

The present study departed from several tangible and concrete problems related to the role of prior knowledge in learning.

In this chapter, an overview will be given of the general results of this study. These results will further be discussed in relation to their contribution to instructional and cognitive psychology and their implications for educational practice. Finally, some directions for further research will be outlined.

1 Research questions and results

The starting point of this investigation has been a variety of problems observed in the context of modular open learning: e.g. the problem of equal opportunities for all students at the start, the problem of multifunctionality of modules in modular education, the problem of sequence in which course modules are studied, the problem of differing students, the problem of making appropriate use of prior knowledge in a genuinely open learning situation. Prior knowledge is a central issue in relation to each of these specific topics.
To solve these problems, different research approaches and several phases have been followed. We formulated these phases in our introductory chapter as five central questions.

First, there is the question for the explication of the specific educational context for our study and a general theoretical framework for investigating prior knowledge.

The second question relates to a clear definition and operationalization of the concept 'prior knowledge'. How can prior knowledge be mapped?

The third question is: How can prior knowledge be measured for our purpose?
The fourth question tackles the specific relationship between prior knowledge and study results: What is the role and the influence of prior knowledge with respect to the learning process and academic results? Here, attention is not simply directed towards prior knowledge assessment; also of interest are the ways in which assessment information can be used. If there are different kinds of prior knowledge which influence learning, how can we use assessment results to optimize learning? Does prior knowledge of different students interfere with the multifunctional nature of Open University (OU)-courses?

The fifth question is: Is there evidence to assume that it is possible to construct a system or an instrument for adjusting instruction to the students' prior knowledge state? Such an instrument could be helpful e.g., to enhance information on the learning process, the study planning, the selection of subject-matter, and didactic tuition.

Our research approach has been of an applied nature. This fits in a rising trend, observed in recent cognitive and instructional science. After almost one hundred years of laboratory experiments in psychology, the demand for ecologically valid studies has increased sharply in recent years. Great importance is attached implementing research results in daily practice. Newell (in Neisser, 1976) describes a study of 59 experimental paradigms; he was probably the first to remark that only two of the paradigms were ecologically valid - playing chess and looking at the moon. In the eighties, the belief that cognition must be studied in its everyday environment and in the context of natural, purposeful activities has been growing. For this reason, this project has been carried out - as far as possible - in the normal tuition environment of the student, with reference to regular courses and relying on the normal learning tasks.

The results of our research have been helpful to find answers and solutions for the five questions put forward.

In chapter 1, a general context is given for our study of prior knowledge. First, the importance of the student's prior knowledge in modular education is stressed. It is concluded that modular education directs towards more efficient and effective education in profit of the learner, but that this goal will only be reached if prior knowledge is taken into account seriously. Second, using the information on domain-specificity of learning and on the students' prior knowledge are the primary conditions for the design of completely multifunctional modules. Third, lessons from earlier educational and cognitive psychological research are summarized. Of main importance are the information-processing view on human cognition and its influence in understanding individual differences. A dynamic, constructivist and knowledge-based approach to learning is part of the stated context.

In chapter 2 evidence is given for the effects of prior knowledge on learning outcomes and processes. Representative and well-known studies illustrate the impact of prior knowledge on study results. Next, different effects of prior knowledge on learning processes are reviewed. The facilitating effect of prior knowledge is seen as the most important positive effect on learning. However, this effect varies depending on the influence by different inherent qualities of prior knowledge (such as incompleteness, misconceptions, accessibility, availability, structure and amount).

Eight different theoretical approaches that give an explanation, mainly for the facilitative effect of prior knowledge on learning, are stated. These theoretical approaches are primarily concerned with successive phases during information-processing. These explanatory approaches that relate to the effect of prior knowledge can mainly be situated at the knowledge acquisition components level in the information-processing model. It seems that sifting out relevant new information, maximizing internal coherence of knowledge structures and comparing knowledge structures are the processes where prior knowledge plays a

major role. It is concluded that six of the explanatory approaches strongly refer to the structure of prior knowledge.

In chapter 3, prior knowledge terminology and the problems related to operationalizing concepts are scrutinized. After defining the basic terms, a conceptual map of the prior knowledge is proposed. A valid indexation of the prior knowledge state by means of expert judgement is presented, resulting in operational approaches to assess the prior knowledge state (PKS). Taking into account the data from the literature review and from an enquiry among experts, we focus in the last part of this chapter on our choice for research into the domain-specific prior knowledge.

Chapter 4 introduces our empirical studies. First, the choice for the domain of economics is argued. A second part summarizes the findings of studies focusing on direct and indirect effects of prior knowledge in economics education. In the next major part the reader is introduced to our specific approach to study the students' prior knowledge state. A variety of research directions or approaches have been followed: students' views on prior knowledge, the use of variables as indicators of the prior knowledge state, analysis of the quality and impact of the prior knowledge state by means of assessment and investigating the structure of the prior knowledge state.

> Our subsequent investigations are set up along these research directions, pursueing answers for the last three above-stated questions.
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> In the ex post facto studies (chapter 5 and 6), we focus on differences in prior knowledge state and on 'indicators' of the prior knowledge state in relation to study results, taking the facilitating effect of prior knowledge on study results for granted.
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> Since this research approach is not satisfactory, a new approach involving the prior knowledge state itself, instead of indicators, becomes the major focus of our studies. This invokes the construction of prior knowledge state tests (PKST). This is described in chapter 7. The PKST are applied in the three following chapters (8 to 10).

Ex post facto 1 (chapter 5) indicates differences in the prior knowledge state. Economics students seem to be better qualified than law students to study the course Economics & Money. The results suggest that differences in the prior knowledge state are to be found between economics students (ES) and law students (LS). These differences were derived from differences in pass rates and number of examination trials. These findings challenge the multi-functional nature of the course Economics & Money.

In ex post facto 2 (chapter 6), the expected differences between economics students and law students cannot be confirmed. These differences are not significant in terms of differences in university test scores. Nevertheless, there is a tendency

(based on multiple classification analysis) that economics students perform better than law students. Also other indicators are not helpful to clarify differences in prior knowledge. As a concequence, the hypothesis about the potential value of personal and contextual variables as indicators of prior knowledge is to be rejected. This is in congruence with findings of earlier research. At best it can be stated that previous university education is a possible indicator, but a very weak one since the population consists only of 10 % of such students and since it cannot be manipulated for instructional purposes.

An approach towards the assessment of the prior knowledge state (PKS) itself of students is set up in chapter 7. This chapter deals with the question of how to assess the PKS, more specifically it looks at how to develop prior knowledge state tests.

The study in chapter 8 concerning the quality and impact of the prior knowledge state in economics reveals that PKS tests show significant differences in PKS of economics and law students. Striking are the differences in the mathematics prior knowledge state and the optimal requisite prior knowledge state between both sub-populations. This fact again contradicts the multi-functional nature of the course 'Economics and Money'.

Our analysis reveals that most of the predictive power of the PKS is related to optimal requisite knowledge and mathematics knowledge. The results also show that study time is not a relevant independent variable to reflect differences in the prior knowledge state or having an impact on learning new subject-matter.

The study reported in chapter 9 elaborates the results of the above study and results in the following four conclusions. First, the variable 'student type' is not helpful to detect differences in the PKS within a population of students. The second conclusion is that the differences between the two groups can be made visible when looking at the specific components of the PKS. Striking are again the differences in optimal requisite PKS and mathematics PKS between both sub-populations. Third, the level of PKS predicts - to a certain degree - future learning results of students. It should be noted that the second general measure of the PKS (PKST2), comprising the optimal requisite test scores and the test scores for the subject-oriented PKS test, explains up to 42% of the variance in the posttest scores. One should remember that this study is done in an ecologically valid setting. Extended analysis reveals that optimal requisite prior knowledge is the most important component of the student's PKS.

Fourth, it is shown also that the estimation of PKS level through self-assessment by the students is not very reliable. The estimations do not reflect the levels of PKS as measured by the objective tests. This is also found in our study on students' views on prior knowledge (chapter 4). We can conclude that students self-assessment is not useful to assess their prior knowledge state, at least not in introductory courses in higher education.

The results of these studies are helpful to indicate directions for the next research. It looks promising to analyze in more detail the complex of components of the PKS. Up till now, PKS components have been defined in relation to the subject-matter level.

In chapter 10, other dimensions are put forward to analyze the students' prior knowledge states, going beyond the subject-matter level and based on our domain-specific prior knowledge state test.

In the first part of chapter 10, theories, models and practice-based strategies found in literature, are discussed in order to analyse the 'structure of knowledge' issue. Analysis of theories shows that the more structured the prior knowledge, the more flexible and easy the acquisition of new knowledge becomes. Additional support, especially for the hierarchical nature of the knowledge organization is presented in this chapter. This theoretical basis is exploited to define a set of 'dimensions' that are helpful to construct 'knowledge profiles'.

We introduce knowledge profiles as being graphs of scores of a group or individual on a prior knowledge state test. Four types of dimensions are identified: cognitive-psychological dimensions, educational-psychological dimensions, psychometrical dimensions and content-based dimensions.

In the empirical part of this chapter, data are provided that support the relevance and validity of the knowledge profile dimensions. Two approaches are adopted, based on data gathered during an investigation involving a large sample of university students. First, we analyze the extent to which the parameters along the dimensions give information about different components of the PKS. Second, we analyze the discriminatory power of the knowledge profile dimensions to make apparent PKS differences between a variety of student sub-populations.

To validate the different knowledge profile dimensions, their parameters are connected to the domain-specific knowledge state test-items and the extent to which these parameters along the dimensions give information about the components of the PKS, is analyzed.

The subsequent analyses look at the discriminatory power of the dimensions to detect the PKS differences between several student populations. Three analyses are documented. A first analysis compares knowledge profiles of economics and law students. No differences in their knowledge profiles are detected, which is in congruence with our earlier findings. Diploma type is not a good indicator for PKS differences. A second analysis involves students studying the same course in a different university context. UL (University of Limburg) and OU students do not differ in their mean % score, but profile analysis reveals significant differences in knowledge profiles. Also for students of the low-PKS and high-PKS groups, the third analysis, differences are found in their knowledge profiles. Several knowledge profile dimensions are thus relevant for differentiating between groups of students.

The results of chapter 10 are important since we succeed in defining and operationalizing a new and promising approach towards the analysis of prior knowledge. It is foreseen that in situations where there are significant differences between the PKS of specific subpopulations, the profile dimensions are helpful to

detect and dissect in more detail the strengths and weaknesses of the students involved. This might be a promising starting point for differentiated diagnostic and guidance approaches.

We agree with Pellegrino and Glaser (1979) that when we are able to specify cognitive components, we have information that enables us not only to predict performance on a criterion task, but also to do something about performance. We believe that the 'overall assessment prophecy' can be fulfilled (see Introduction) and that it is possible to adapt the conditions of instruction to individuals to maximize their potential for success.

2 Results in relation to instructional and cognitive psychology

Since Ausubel (1968) educational psychologists and other researchers have paid great attention to the importance of prior knowledge and this trend continues (De Corte, 1990b; Glaser, 1989; Simons, 1991). Indeed, the impact of prior knowledge seems, as discussed throughout this work, stronger than any other influencing variable and can therefore be seen as a determinant for future learning. However, the results are less clear than one should expect taking into account the results of former strictly experimental research.

The contribution of the present study to cognitive psychology can be summarized by the six following aspects: the conceptual framework, the evidence for the facilitating effect, the support for the hierarchical organization of prior knowledge, support for a high degree of interrelatedness between pieces of prior knowledge, evidence for the existence of different components of prior knowledge and the possibilities for investigating the PKS by means of knowledge profiles.

First, we have introduced a conceptual framework for research into the prior knowledge problem. This means that particularly refinement of concepts such as prior knowledge, knowledge profiles and dimensions have been aimed at. Such a framework is useful for further research and for communication between different researchers, investigating in this field of prior knowledge.

Second, the present study provides reasonable evidence for the generally observed facilitating effect of prior knowledge on study results.

Third, and this is perhaps the most important theoretical contribution, it supports the hypothesis that the prior knowledge base is organized in a hierarchical way, which implies that for several dimensions mastery of higher knowledge parameters assumes mastery of lower knowledge parameters.

Additionally, it is shown that the various pieces of prior knowledge integrated within a particular knowledge structure are highly interrelated.

These findings can be seen as empirical support for the theories that stress the structured and hierarchical nature of prior knowledge (chapter 10). Among others, Reigeluth and Stein (1983) mention that these theories lack that kind of support. Till now there was only few concrete evidence.

Fifth, the premise that prior knowledge is multiple in character and consists of different components is illustrated in this study. This implies that any component of prior knowledge can be nonexclusive and should be presented as such. There is no one form of knowledge with an exclusive monopoly on human cognition. The different components of the prior knowledge state all play a certain role within a complex structure.

Finally, the stated knowledge profiles have shown to make it possible to differentiate between groups and subgroups of students.

From a more pragmatic, i.e. instructional-psychological point of view, the structure-of-knowledge paradigm needs to be investigated in further detail in order to find more efficient ways for using instructional technology. Our research into ways of utilizing prior knowledge indicates e.g. that the different components of the PKS should be taken into account (i.e. at subject-matter level) and that components of the PKS along other dimensions can be helpful in educational settings for diagnosis and as a basis for educational support. Further, the possibilities to use PKS tests and profiles show to be promising: they provide a rational basis for flexible learning, i.e. for different entry levels of students, for individualizing learning materials, for providing individual support.

Perhaps it could be useful to reconsider instruction, at least in open learning environments, on the basis of a new educational model of the learning process (figure 1) in which the overall assessment takes a central place and the students' prior knowledge state is the starting point.

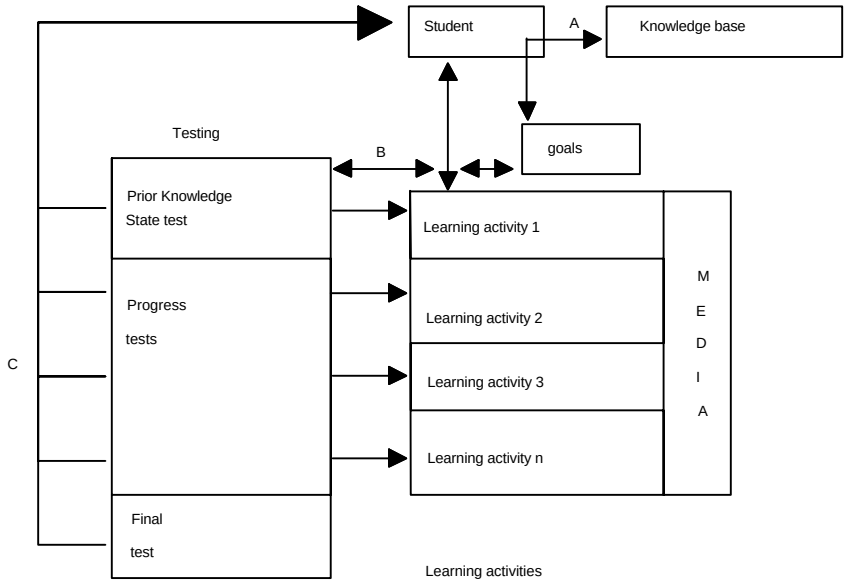

Figure 1: Components of the new model of the learning process

According to this model, the student starts with stating his learning goals. These relate to a certain part of the knowledge base (the content or the whole of a university's courses)(arrow A). After having taken a prior knowledge state test, the learning goals are reformulated (if necessary) and the students starts with the appropriate learning tasks (arrow B). During the learning process the student takes progress tests regularly to check his progress, to determine the required guidance and to identify the subsequent learning tasks (arrow C).

3 Implications for educational practice

The first implication for educational practice in higher education and particularly the Open University of Heerlen is that it is necessary to meet some requirements in order to produce truly multifunctional courses. To do so the prior knowledge state of students must be taken into account.

Second, in our view, this is only possible in electronic learning systems that allow flexible adaptations in the course materials to students' knowledge profiles. Third, since a PKS test is generally part of modular instruction, it is noteworthy that implementation of modular instruction generally implies several possibilities for the student on the basis of his prior knowledge, such as identification of strengths and weaknesses of students and skipping a module or working more quickly through it. If this is introduced into university courses and OU courses, it implicates that

students will be able to profit from these advantages and student flow could be raised significantly.

Fourth, today's trend in higher education to increase output and to raise student inflow causes new problems. The problem of pursueing two conflicting aims, such as a high output of student flow (little drop-out) and more open access, can in our view only be solved by taking the prior knowledge state of students into account. In this way, one can take advantage of what seems to be a dilemma. This is particularly the case for distance teaching universities, since they generally have even a larger percentage of drop-out than regular universities.

Therefore, it is recommended that universities and institutes for higher education:
- refine their assessment procedures to grasp the full nature of a students' prior knowledge state;
- incorporate prior knowledge state tests as a recurrent feature in courses and curricula; and
- extend the feedback function of support provisions by making use of the information obtained by prior knowledge state tests.

4 Further research

Although - in literature - the impact of prior knowledge is often stressed to this extent that all learning might even depend on it (Resnick, 1981), also other factors like other student characteristics do influence the learning process and can interact with the impact of prior knowledge. But, it is not yet clear which personal or contextual variables play a significant role in this context (Ferguson-Hessler, 1989). Differentiating between groups of students on the basis of such variables does not seem to make much sense for educational practice. Moreover, our research indicates that, if different variables are taken into account, prior knowledge always has the strongest general effect and overrules other variables in descriptive and explanatory models (see also Ethington, 1990; Bruinsma and Geurts, 1988). This pre-dominance of the prior knowledge state in learning brings Glaser (1987) to the conclusion that the assessment of prior knowledge should be stressed and more studies should be conducted to assess the knowledge state of the learner.

First, the results of the present prior knowledge project are helpful to set up a system in which the knowledge state of each student is measured at the start of his study. Further research with large samples will specify the size of the effect of introducing prior knowledge state tests on the student flow. Therefore, a standardized system for feedback on the PKS test results will be needed.

Second, the results of the present research are also helpful to set up a system in which the knowledge state of each student is regularly measured in relation to his progress. Since knowledge profiles indicate the weaknesses and the strengths in the mastery of domain-specific knowledge, student support can be enhanced. For both of the above stated research approaches, it will be helpful to investigate

profiles based on scores of successful learners for different target populations and different domains, and the nature of the difficulties experienced by high and low prior knowledge students. This will lead to an optimal required set of knowledge profiles for studying certain domains or courses. This provides the foundation for precise diagnosis of the performance of individuals over a domain and its subsets. In addition, it is interesting to look how a clear specification of the components used to structure the domain makes inductive generalization beyond the domain to situations which share those components possible.

One immediate development, as a result of the reported research, should be that testing becomes an essential, integral part of instruction in a more structural context of the university (i.e. the overall-assessment prophecy). The implementation of the prior knowledge state and knowledge profile assessment system should be optimized in an CAT (computer assisted testing) environment and further possibilities with adaptive forms of assessment should be tested, in order to make an interactive system and direct communication with the student based on objective measures possible.

"Show me your knowledge profile and I will tell you how much progress you have made in your study".