A THEORY OF THE TASK-BASED INFORMATION RETRIEVAL PROCESS: A SUMMARY AND GENERALISATION OF A LONGITUDINAL STUDY

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The aim of this article is threefold: (1) to give a summary of empirical results reported earlier on relations between students' problem stages in the course of writing their research proposals for a master's thesis and the information sought, choice of search terms and tactics and relevance assessments of the information found for that task; (2) to show how the findings of the study refine Kuhlthau's model of the information search process in the field of information retrieval (IR); and (3) to construe a tentative theory of a task-based IR process based on the supported hypotheses. The results of the empirical studies show that there is a close connection between the students' problem stages (mental model) in the task performance and the information sought, the search tactics used and the assessment of the relevance and utility of the information found. The corroborated hypotheses expand the ideas in Kuhlthau's model in the domain of IR. A theory of task-based information searching based on the empirical findings of the study is presented.

1. INTRODUCTION

Tom Wilson has contributed markedly during the years both to the theoretical and empirical bodies of knowledge in studies on information seeking. He has assessed and developed models in information behaviour research [1, 2] and recently studied empirically successive information searches [3]. In this article my aim is to combine these two lines of research using my own current research results as a point of departure. I have studied how students' problem stages in the course of writing their research proposals for the master's theses are connected to the types of information sought [4, 5], changes in search tactics and term choices [6], and patterning of relevance assessments of both references and full texts [7].

The framework of this study is Carol Kuhlthau's [8] model of the information search process enriched with some ideas from cognitive psychology. Kuhlthau has shown that phases in task performance differentiate the types of information searched for and the major ways of searching. The hypotheses of my study are based on her model. The basic hypothesis is that the stages of task performance are connected to the types of information searched for, to the changes of search tactics and terms and to relevance judgements. The derivation of the consequences from Kuhlthau's model naturally included refining some of its concepts

to fit the features of information retrieval. The explanatory factor of the model – problem stage – remained the same and some variables to be explained – information types, search tactics, term choices and relevance judgements – were specified and connected to the problem stages. In this article I will show how the results of the empirical studies mentioned refine Kuhlthau's model, and thus contribute to the growth of that theory.

2. WAGNER AND BERGER'S CONCEPTION OF THEORIES

Theoretical work is not an end in itself. It serves empirical research by providing ideas and predictions on how the central factors in a study object are interconnected. Thus, theories steer the researcher to select certain research questions and suggest what features to observe in the research object. They also help to explain patterns in observations. Growth of knowledge in science is assessed in terms of theory growth [9, 10].

Wagner and Berger [10] differentiate between three contexts of theoretical work: orienting strategies, unit theories and theoretical research programmes. In this article I will use the two latter as tools for comparing Kuhlthau's and Vakkari's results.

Unit theories deal directly with social processes. They essentially contain a set of concepts and assertions relating those concepts in an account of some social phenomenon, in our case information searching. Unit theories include propositions or hypotheses that can be tested and are intended as answers to specific research questions [10, 11]. The extent to which empirical testing provides support for the unit theories determines the degree of theoretical growth. Stinchcombe [9] lists ways in which growth may result from the empirical testing of theories: basically, (1) the more numerous the empirical consequences of a theory that are supported by observations; (2) the greater the variety of consequences that are supported; and (3) the more frequently those consequences are contradictory to the consequences of the most likely alternative theories, the more highly developed is the theory. Growth is seen as a direct consequence of increasing empirical support.

Empirical support – the relation of theory to data – is an essential feature of all scientific knowledge, and increasing empirical support is a prominent characteristic of much of what we refer to as growth [10]. However, if we want to analyse growth or change of theories, we have to do this in respect to other theories by comparing them. Theory-data linkages are insufficient for analysing theory growth. To describe the growth of theories fully presupposes that one also takes into account the relations between theories. For this purpose Wagner and Berger [10] introduce their concept of a theoretical research programme. It consists of a family of interrelated unit theories.

The comparison of unit theories and, thus, the analysis of growth presupposes that the theories have at least a few elements in common. As the theories consist of sets of concepts and sets of relations interconnecting those concepts we can identify two aspects of similarity in the structure of theories. Firstly, similarity means that the theories share a common conceptual machinery, i.e. the concepts of the theories are identical. This is called conceptual similarity. Secondly, given

that the theories satisfy this condition, the similarity of theories can be determined by comparing the sets of relations which interconnect the concepts in each theory. This is called factual similarity [12].

Growth of theories can be assessed in terms of their empirical support, specificity and comprehensiveness [10]. Knowing more means that the scientific community has accumulated more empirical evidence to back its theories, and that these theories, in turn, are broader in scope and can describe their research object more precisely. Moreover, advanced theories contain more empirical consequences (hypotheses) and thus more fruitful research problems [10].

Now we are able to formulate our research questions precisely. The aim is:

- to study how Kuhlthau's model is refined by the corroborated hypotheses from the studies by Vakkari by comparing the theoretical structures of the model and hypotheses; and
- to give a summary of the central findings of the empirical studies on relations between the student's problem stages in writing a research proposal for a master's thesis, and the information types searched for, the choice of search strategies and terms, and the relevance judgements made.

3. KUHLTHAU'S MODEL

Kuhlthau [8] has shown in a series of empirical studies that learning tasks and problem solving by students and library users consist of several stages. Her theory holds that people search for and use information differently depending on the stage of the process. The central concepts of Kuhlthau's model are presented in Table 1.

The finding of a focus is crucial in the search process. The focus is comparable to a hypothesis for accomplishing the task. Prior to focus formation thoughts are general, fragmentary and vague, and actions involve seeking background information. The searcher is unable to construct the task and unable to express precisely what kind of information is needed. Browsing library collections and discussions with other people are the most frequently used modes of information searching [8]. General background sources such as encyclopedias and review articles are mostly used at this stage [13]. After a focus has been constructed, the search for information becomes more directed. Thoughts about the task become clearer and more structured. A clearer understanding guides the person to seek relevant, focused information using the whole range of information resources. At the end of the process rechecking searches are made for possible additional information [14] .

4. VAKKARI'S STUDIES

It is obvious that the role of IR systems and the information they provide vary depending on the task and situation of the subject [13, 15–18]. The nature of an IR system is a function providing information to support people in taking purposeful action. In studying information searching the task performance process that generates it should be at the point of departure. The methodological

Table 1. *Main concepts in studies by Kuhlthau and Vakkari*

Kuhlthau's model	Vakkari's theory
Stages in the information search process	*Stages in task performance*
• Initiation	• Pre-focus
• Selection	• Pre-focus
• Exploraton	• Pre-focus
• Formulation	• Formulation
• Collection	• Post-focus
• Presentation	• Post-focus
Types of information	*Types of information*
• General information (background)	• General information (background)
• Specific information (relevant)	• Faceted background information
• Pertinent information (focused)	• Specific information
Sources of information	*Sources of information*
• Persons – information systems	• Persons – information systems
Relevance judgements	*Relevance judgements*
• Degree of usefulness	• Degree of relevance
	• Relevance criteria used
	• Type of contributory information
	• Precision
Search tactics	*Search tactics*
• Browsing or querying	• A categorisation containing 12 tactics
Search terms and operators	*Search terms and operators*
	• Number
	• Types (synonym, NT, BT, RT)
	• Operator types
Mental models	*Mental models*
• General or vague – clearer or focused	• General or vague – clearer or focused
	• Differentiation of conceptual structure[1]
	• Integraton of conceptual structure[1]

[1] Used as an auxiliary concept

implication is to analyse successive searches connecting them to the information requirements of the task as perceived by the subjects.

In order to analyse how the task performance process is connected to information searching, and information retrieval in particular, a study was made of how the stages of writing a research proposal for a master's thesis were related to the information types searched, to the search tactics and term choices, and to the relevance judgements of references and full texts. The results of the project have been published in four papers. The changes of search tactics and terms during the process are reported in Vakkari [6], relevance assessments and criteria are

analysed in Vakkari and Hakala [7], the contributing information types in the searched documents are described in Vakkari [4], and the sources used in the process are explored in Vakkari and Pennanen [5].

From the angle of systems design the major limitation of the study is that it did not include variables describing IR techniques. The choice was conscious. Our knowledge about the search activities of the subjects during task performance is limited [17, 19]. We first have to understand their key elements properly before it is reasonable to explore which IR techniques might be efficient tools to support searching in various conditions generated by the task process. The intention is to include IR techniques in the research design in the next phase of our project.

5. MAJOR CONCEPTS

Table 1 lists the basic concepts in Kuhlthau's and Vakkari's studies. In the following we will briefly introduce and comment on the concepts from the angle of IR. The reader can find more information about the definitions in the original studies.

The explanatory variable in both projects was stages in task performance. The term used by Kuhlthau is stages in the information search process. In our study the six original categories in Kuhlthau's model were condensed into three. Pre-focus stages included the steps of initiation, selection and exploration. Focus formulation was identical in both studies. Post-focus stages contained collection and presentation stages. The choice to use three categories was methodological. It was improbable that we would be able to differentiate all the phases in the four month period of the proposal writing. Thus, we decided to concentrate on the stages before and after the focus formulation, which is the most crucial phase in the process [8, 20].

In both studies [4, 8] the information searched for was categorised into three classes. In both general background information is information which cannot be described in detail and which is used to frame the task at hand and to explore the general topic. By 'specific information' Kuhlthau [8, p. 39] understands information that relates to or applies to the matter at hand and has a connection or fits with the topic under investigation. In Vakkari 'faceted background information' is information about the broad sub-fields of the topic which have not been expressed in detail. 'Pertinent information' in Kuhlthau [8, p. 39] refers to information that has a more decisive and significant relationship to a topic than relevance and is related to personal information need. 'Specific information' refers in Vakkari [4] to information which has been expressed in detail uncovering the central variables of the task at hand. It seems that Kuhlthau differentiates between topical relevance and situational relevance of information in her definitions of the two latter categories [21, 22], whereas Vakkari uses as his criterion the degree of the specificity of information. In addition to that distinction, Vakkari utilises another categorisation of information in terms of its contribution to the task.

Both Kuhlthau and Vakkari differentiate source types between human information sources and information systems. Both distinguish between several source types within the major groups, the difference being that Vakkari takes more types of information systems into account.

Kuhlthau's study did not report direct relevance assessments by the subjects.

She included them in her definition of information types. Vakkari's [4, 7] studies contained relevance assessments of references and full texts, criteria for them and the contributing information in documents. Vakkari [6] also studied how choice of search terms and tactics resulted in different rates of precision in searches.

For Vakkari 'mental model' is used as an auxiliary concept. A synonym for mental model is 'cognitive structure' or 'conceptual structure'. A mental model can be described as consisting of concepts and their relationships. 'Differentation' refers to the number of concepts in the conceptual structure of a subject. 'Integration' refers to the amount of interrelations between the concepts [13, 23, 24]. Although our data contain material about the changes in the understanding of the topic by the students, it was not possible to infer meaningful mental models from it that could have been used to explain aspects of information searching. Without empirical indicators we were forced to use 'mental model' as an auxiliary concept for explaining variation in search activities. In this role 'the mental model' of the subjects was connected to the stages of Kuhlthau's model. It was supposed that in the beginning of the process the mental model is undifferentiated (diffuse) and fragmentary. At the end of task performance the knowledge structure is differentiated and integrated. Thus, we inferred the features of the mental model from the stages of the task performance process.

Search tactics in information systems in Kuhlthau can be roughly termed as browsing and querying. Vakkari [6] developed a classification scheme including twelve search tactics based on the work by Bates [25], Fidel [26] and Wildemuth and her colleagues [27]. Vakkari [6] also included variables describing search terms and operators in his research design whereas these were left outside the scope of Kuhlthau's study.

The role of mental models during the task performance differs in the two studies. Kuhlthau [8, pp. 43–51; 14, p. 367] describes the thoughts concerning the task on the trichotomies 'general – narrowed – focused' and 'vague – clearer – clear'. It seems that the distinctions are used in her model more as predicates of the stages in the information search process than to explain the types of information sought for or search strategies. However, Kuhlthau uses these constructs in both ways, emphasising the former.

5.1. Conceptual and factual similarity of the studies

'Conceptual similarity' refers to the degree of common conceptual machinery in the studies [12]. Table 1 reveals that Kuhlthau's and Vakkari's studies share several common concepts. The explanatory factor, stages in the task performance, is identical. The auxiliary concept, the mental model, is more differentiated in Vakkari's hypotheses. The greatest differences in variables to be explained are in information types, relevance judgements, search tactics, terms and operators. Most of these are not included in Kuhlthau's model.

'Factual similarity' refers to the interrelations between the concepts [12]. Both studies share the common explanatory factor. Due to the richer conceptual machinery of factors to be explained in the studies by Vakkari they have more interconnections with the explanatory factor. Thus, the set of hypotheses by Vakkari is more specific and has more explicated empirical consequences in the domain of IR than the model by Kuhlthau. However, the problem domains of

the two studies are not identical. Kuhlthau's study aims at explaining information searching more in general terms, whereas Vakkari concentrates more on explaining activities in information retrieval and searching. We will return to this matter when comparing the corroborated hypotheses in these studies.

6. DATA AND METHODS

The subjects were eleven students from the Department of Information Studies at the University of Tampere who had attended a seminar on preparing a research proposal for a master's thesis. It took place over a period of four months during the spring term of 1999. At the beginning of the seminar the students selected a topic and by the end they had come up with a research proposal.

Data for describing their understanding of the task, problem stage, search tactics and relevance assessments were collected in several ways during the process. Subjects were asked to make a search in the *LISA* database three times during the seminar: when the seminar had just started, in the middle and when the students were finishing or had completed the proposal. The aim was to acquire data at the pre-focus, focus formation and post-focus phases. Pre- and post-search interviews were conducted in each case. The students were asked to think aloud during the search session. The transaction logs were kept and the thinking-aloud was recorded. The accepted sets of bibliographic records were printed out and evaluated by the students in terms of relevance criteria and their usefulness.

The students also kept a research diary recording their ideas, thoughts and feelings as well as a structured search diary recording ideas sought, documents found, their sources, and their relevance and contribution in terms of useful information. They wrote in the diaries three times, at the ends of each of the first three months. The finished research proposals were also collected. The reader will find more details in each particular article.

There is an important methodological question to be dealt with in order to be certain that the variation in search tactics is explained by the increase in domain knowledge of the students (i.e. the stages of task performance). It is also possible that the changes in tactics during the process could be explained by the increasing search expertise of the students. This means that the students would learn to use the system in more ways at each search session. The increase in search skills would then explain the increased use of OR operators and parallel, browse and monitor tactics in the course of the project [6].

Certain features of the research design do not support the latter presupposition. Firstly, the study subjects were graduates in information studies, who had participated in courses in information retrieval. These also included the use of *LISA*. It is evident that these students were aware of the role and use of OR operators and various search strategies in IR. We can conclude that the search expertise of the students was fairly advanced, and relatively constant, and thus controlled in the research design. Secondly, we can expect that the use of OR operators, and thus parallel tactics was possible due to the differentiating and enriching conceptual structure about the topic by the students. Although we were not able to give an explicated account of the conceptual structures based on the data, the data do, however, support this inference. The results from cognitive psychology also

demonstrate that increase in domain knowledge is connected to the differentiating and integrated knowledge structure of the subjects [28, 29]. It is not plausible to suppose that in the beginning the students had a fairly rich conceptual machinery but were unable to utilise it due to limited search skills. The results of our study also speak against this argument. We were able to show that in the first search session those students who were least advanced in Kuhlthau's model used the fewest search terms and AND operators compared to those who had proceeded further in the model [6]. We can conclude that in our case the variation in search tactics depended on the growth in domain knowledge and not in the search expertise.

7. THE MAIN RESULTS OF THE EMPIRICAL STUDIES

Next we will briefly summarise the main results presented in the four articles. We will begin with the findings concerning search terms and tactics, continue with the relevance experienced and usefulness of the documents and finish with the results about the sources used for obtaining the documents.

In general, all the students proceeded in their task at varying paces according to Kuhlthau's model. In the first search session, the students were moving from topic selection to exploration of the topic. In the middle of their task they were typically exploring the topic and trying to formulate a research problem. By the end of the project they were logically in the presentation stage, but while half of the students had been able to construct a focus, the other half were still involved in constructing it. A detailed analysis of the students' problem stages can be found in Vakkari and Hakala [7].

7.1. Search terms and tactics

Our study [6] demonstrated that the students' problem stages during task performance were systematically related to their choice of search terms and tactics. The students' growing and focusing understanding of the task led them to use more and more specific search terms, more and more varied operators as well as more tactics in the course of their project.

Terms   When selecting their topics, the students represented them with a few search terms. As their mental models differentiated, the vocabulary in the searches grew in each round with synonyms, narrower and related terms. Broader terms were dropped, especially in the last round. Students were able to express the topics with a larger and more specific vocabulary in the successive searches [6]. This is consistent with Wang's findings [30] on researchers' vocabulary changes generated by information needs at request, document selection and post project stages.

Tactics   Only some tactics and patterns of tactics depended on the stage of the task performance and subjects' state of knowledge. Others were related to the size of the retrieved set, which was independent of the phase of the process.

The students began the search either by introducing all the search terms or entering only a fraction of the terms in the initial query. The former tactic was

called 'Exhaust' and the latter 'Select'. As the task performance proceeded, the students' use of Exhaust decreased and Select increased. Those who used Exhaust were not as far advanced in their process, and their conceptual constructs were less developed than those who started with Select. The former group was able to represent only a couple, in the first round, of search terms. Exhaust tactics were typically followed by operational moves, limitation of language or printing year, which did not require conceptual changes in the query [26].

In all stages of the project Select was followed by Intersect – which was the most used tactic – or the Vary tactic depending on the size of the retrieved set. If the set was large, Intersect was a typical move. If the set was small, Vary was the preferred option. In Vary, the number of terms was similar to those of the preceding move, but one term was substituted with a new one. It was typically used when the students tried to expand a small set. An alternative for Vary was Reduce in enlarging the size of a set. It consists of reducing the number of terms in a query, and was used less frequently. It was selected when the search reformulation was more complex than average and was introduced after three tactical moves. Vary was used in earlier phases of the query reformulation.

The students began to use more synonyms and parallel terms when their knowledge of the topic increased. This was reflected in the increasing use of Parallel tactics search by search. It was the second most common tactic at the end of the process.

Those features in the searches yielding high precision (the share of relevant and partially relevant references of all references) were the use of more precise and parallel terms and their combination by OR operators in facets producing Parallel tactics. The mere use of AND operators (Intersect) with few facets containing only one term each led to search results with a lower precision. The use of precise terms in a query results naturally in a precise search result. The findings also demonstrate that an active utilisation of synonyms and parallel terms for increasing recall seemed to lead to a higher precision compared to other tactics like Intersect. The explanation for this is that queries consisting of facets with several and perhaps specific terms have more discriminatory power than queries consisting of an intersection of facets expressed with a single and possibly vague term each, given that the number of facets is the same. As a result the former queries retrieve sets containing proportionately more relevant references. The results also demonstrate that students with a more structured domain knowledge tend to formulate queries with more facets (with greater complexity) and with more specific terms (with greater specificity and coverage) resulting in a higher share of relevant items.

This study has shown a systematic and many-sided connection between the students' growing domain knowledge and their IR interaction in successive search sessions. The growth in domain knowledge seems to predict users' IR interaction in successive search sessions if the subjects' search expertise is equal.

Supporting searching   We found that the degree of students' knowledge of the topic predicts their ability to express search terms and formulate tactics. The less they know, the fewer, broader and more vague terms they use and the shorter queries and simpler tactics they formulate. Brajnik et al. [31] have shown that in

more difficult problems, where users may fail to achieve a good conceptualisation, automatic query reformulation does not help them in achieving a better search result. The obvious conclusion is that people with scarce domain knowledge need support to expand and differentiate their conceptual model of the topic [17, 25]. This would help them to develop ideas on how to structure the topic and how to express their vague information needs in greater detail. Equipped with synonyms and the narrower terms provided by the system they could reformulate their query using terms with greater discrimination. This would result in finding more relevant information items.

Our findings support the previous claim. We found that queries containing facets with terms combined by OR operators produced a higher share of relevant references than queries containing facets represented by one term and combined by AND operators. This result suggests that, in addition to support in finding appropriate vocabulary, the users also need help in formulating the query, especially in using OR operators. Interfaces, which would suggest to users that they utilise Parallel tactics, would support them in retrieving a higher proportion of relevant information items.

7.2. Relevance and contributing information in documents

The findings in Vakkari and Hakala [7] show that the students' problem stage during task performance is related to the use of relevance criteria in assessing retrieved references and consequently documents.

As the students moved from the beginning of the process to its middle the share of relevant references decreased, that of partially relevant references remained constant and that of irrelevant references increased. There was a differentiation between clearly relevant and other references. The differentiation remained on the same level as the students progressed to the final stage of their projects. The results suggest that when students have chosen their research topic and are exploring it, they become knowledgeable and their mental constructs become discriminatory, which enables them to distinguish more clearly between highly relevant and other references.

The changes in relevance criteria of references remained relatively modest throughout the task performance. The biggest change in a criterion between the stages was 10%, the next being at the level of 5%. These findings resemble Batemann's [32]. The relevance criteria for assessing the full texts changed more than those for judging the references in the course of the process. The significance of information types increased compared to topicality, especially in the middle of the process. It is evident that the relevance of the documents is easier to assess on the basis of full text than on its surrogates [33].

The major groups of relevance criteria expressed by the students for assessing references changed slightly during the process. Information content was clearly the major predictor of the relevance of the references in each stage of the project. The most crucial factor in this group was topicality. The information type of the document indicated by the reference mattered in the beginning and middle stages of the task, but its significance diminished towards the end. References to general background and theoretical information especially were chosen most from the

initiation to the focus formulation stages, but to a lesser extent at the collection and presentation stages. At those stages, references to methodological sources were accepted.

The results suggest that subjects are not searching for documents on the topic in general, but on particular aspects of the topic reflecting the stage of the task performance. The variation of the importance of information types in the course of the process is an indication of this. General background and theoretical information were judged relevant in the beginning of the process. At that stage subjects were searching for information giving an overall picture of the topic and providing various conceptualisations of it in pursuit of a structured and focused problem. The relevance of these types of information diminished when the focus was constructed. It seems plausible that individuals actually mean different things when they speak about topical information. They are seeking information that would contribute to their understanding in performing the task.

7.3.   Aspects of topicality

The findings reported in Vakkari [4] confirm that the topicality of documents refers to different types of information depending on the stage of the task [21]. The students were asked to describe the information sought for and the contribution of the documents they had obtained in their search diaries. The categorisation for the contributing information types was created by combining categories emerging from the data with ideas by Kuhlthau [8] and a classification of citation types by Suhonen and Rautio [34]. The categories were background information, theories and models, methods, cases, facts, empirical results and focused information.

The results show that the students' progressively more structured mental models caused them to search for information in terms of the specificity of information, and the types of contribution they construed from the information in documents. At the beginning their representation of the task was undifferentiated. It led them to look mostly for general background information. The contribution of the documents found consisted typically of background information about the topic as well as models and conceptualisations of it. Most of the texts obtained were assessed as being partially relevant, because the students were unable to identify clearly what was not relevant at this stage [4].

In the focus formation stage the students frequently searched for faceted background information. The documents obtained typically supported the process by providing still more background information and theories, but to a lesser extent. Texts with methodological advice or information about cases gained more footing. Towards the end of the process the students were searching mainly for specific information. They used the documents obtained to gain focused information and empirical research results [4].

The results suggest that it is possible to construct tentative categories for contributing information types at least for the domain studied. It seems that these categories can be understood to a great extent as being facets of topicality if topicality is what the document is about as the user sees it with respect to the task at hand [22]. The results also suggest that it is not only the topicality as such, but these aspects of topicality that are decisive when the subjects judge the relevance

and usefulness of the documents [7]. The results confirm that what is felt to be contributive information depends on the mental model of the subject, and consequently, on the phase of the task performance process [13].

7.4.   Sources of documents

Vakkari and Pennanen [5] showed that there is a systematic connection between the students' problem stages while writing a research proposal and pointers (means of identifying documents) to useful literature as well as sources for obtaining the documents.

We found that in the pre-focus stages the students were mostly searching for background information and theories and models for framing their research proposal. At this stage their means for identifying useful documents were concentrated on three ways of searching: they sought literature most frequently by using TAMCAT (the OPAC of their university library), by consulting supervisors and by relying on their own prior knowledge [5].

At the focus construction phase the students still mostly sought background information and models, but methods and focused information were gaining in salience. The range of pointers used at this phase was more comprehensive than in the beginning. They found the references most commonly by consulting TAMCAT, supervisors or other OPACs.

In the final phase the students clearly sought most specific information, but methods and empirical research results were also useful. These types of information were identified by means of TAMCAT, supervisors and chaining. The role of TAMCAT and other OPACs was especially crucial in finding specific information. The role of supervisors for hinting at specific information was surprisingly minor. However, at the post-focus phase the range of pointers and information resources used was at its most comprehensive compared to previous stages. This finding is consistent with Kuhlthau's [8] model.

Although the documents found in *LISA* searches made a very modest contribution to the writing of the research proposals, other information systems, mainly the OPACs used, had a crucial role in identifying contributory information sources throughout the whole process and especially in the post-focus stages. Thus, information systems have a significant role in the whole information-seeking process of students preparing their research proposals.

All in all, we have been able to demonstrate that the stages of Kuhlthau's [8] model, and thus, the increasing differentiation of the subjects' mental model has a systematic impact on the information types sought, on the choice of search terms and tactics as well as on the assessment of relevance and contribution of the references found and full texts acquired in the task performance process.

8.   COMPARISON OF EMPIRICAL FINDINGS

Next we will compare the corroborated empirical consequences in Kuhlthau's and Vakkari's models in order to assess how the latter has refined the former. We will start by listing the findings in both studies and by analysing their relations in terms of conceptual and factual similarity in order to show the growth pattern. After that we will construct a theory of the IR process in task performance based

Table 2.   *A comparison of findings supported in studies by Kuhlthau and Vakkari*

Kuhlthau's model	Vakkari's theory
As the task performance process proceeds	
Types of information sought	*Types of information sought*
1. The share of general (background) information declines and the share of pertinent (focused) information grows	1. The share of general (background) information declines and the share of specific information grows
2. The share of specific (relevant) information increases in the middle and decreases in the end of the process (curvilinear relation)	2. The share of faceted background information increases in the middle and decreases in the end of the process (curvilinear relation)
Contributing information types	*Contributing information types*
	3. The use of background information and theoretical information declines especially in the post-focus stage, whereas the utilisation of documents containing methods, empirical results and focused information grows
Degree of relevance	*Degree of relevance*
3. Degree of usefulness	4. The share of relevant references decreases, the share of partially relevant references remains constant and the share of non-relevant references increases from the beginning to the middle of the process. The difference between relevant and other references (partially relevant and non-relevant) remains at the same level from the middle to the final stage of the project
Relevance criteria	*Relevance criteria*
	5. The proportion of information content, especially topicality, as a relevance criterion remains constant
	6. The significance of the user's experience and preferences grows and the importance of information types declines as predictors of relevance
Search terms, operators and tactics	*Search terms*
4. The searchers' ability to express precisely what information is needed grows	7. The number of search terms used increases
5. The degree of efficient and effective interaction between the system and the user increases	8. The number of synonyms, narrowers terms and especially related terms increases and the number of broader terms decreases
	⇨ The subjects are able to express the topic with a larger and more specific vocabulary in the successive searches
	Operators
	9. The number of AND and OR operators used increases
	10.The proportion of AND operators declines and OR operators grows
	⇨ The number and variety of operators used increases
	Search tactics
	11.The number of search tactics used increases
	12.Among search formulation tactics the number of Intersect, Vary and Parallel tactics increases
	13.The portion of Intersect tactics diminishes and that of Parallel tactics increases resulting in a higher precision of search results
	14.The frequency of monitoring moves and browsing of search results grows
	15.The share of conceptual search tactics increases and that of operational tactics diminishes

on the hypotheses in the articles by Vakkari. We wish to emphasise that the reconstruction of Kuhlthau's model is limited to those parts that have implications for Vakkari's results. Thus, the reconstruction does not cover the whole model and does not do justice to its richness in all respects.

The list in Table 2 is a summary of empirical major consequences supported in both studies divided according to the central factors to be explained.

As stated earlier the explanatory factors – the stages of the task performance process – are identical in both studies. Both refer to the mental model of the subjects as an intervening factor between the stages of the task performance and information actions. Kuhlthau [8] distinguishes the thoughts of the subjects during the process as vague or clear. Vakkari [13] uses the mental model as an auxiliary concept, which includes two dimensions. In the model differentation refers to the number of concepts and integration to the number of interrelations between them.

We noted earlier that the factual similarity of the studies is significant, even though Vakkari has refined some of Kuhlthau's major concepts concerning search tactics and terms as well as relevance judgements and the contribution of information in documents. When both use an identical explanatory factor and the later study uses more and more specific concepts inferred mainly from the previous one, this implies that the latter study refines the theory provided by the earlier one. As both studies share a common theoretical structure, the growth of the theory is linear and signifies an increase in the depth of knowledge [12]. It means that Vakkari's theory is more specific in the domain of information retrieval. Table 2 reveals that the empirical consequences supported in Vakkari's studies are more numerous and greater in variety than Kuhlthau's. Variety refers here to the various dimensions of information searching, especially information retrieval. Vakkari's results systematically support Kuhlthau's model of the information search process.

9.   A THEORY OF TASK-BASED IR PROCESS

Based on the hypotheses in Vakkari's studies we can outline a theory of the information search process in task performance (Figure 1). It is an idealisation of the findings summed up in this article (the hypotheses presented in Table 2).

The theory is naturally very tentative because of the restricted number of cases in the studies that were used for generating it. However, the results from our studies on different aspects of information searching cohere with each other. They are also in line with the findings of cognitive psychology on domain expertise, reasoning and concept learning [28, 29]. Moreover, Kuhlthau's [8] model supports systematically our findings. It is not only empirical evidence from our studies that justifies the theory, but its coherence with more general theories of information seeking and domain expertise [35, pp. 103–169]. The theory calls naturally for both empirical testing and conceptual refinement. Our next step in elaborating the theory is to collect fresh empirical data with more numerous research subjects to test it, and to include variables describing IR techniques in the research design. The future will show how the theory relates to the empirical and theoretical work by Tom Wilson in studying successive searches.
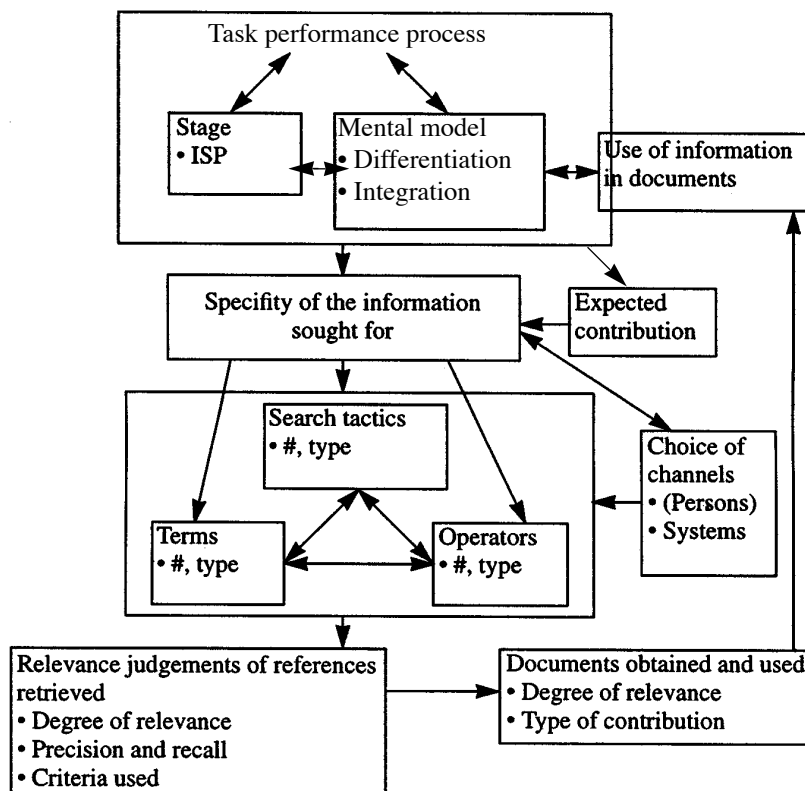
Figure 1. *A theory of the task-based IR process*

Our results and theory demonstrate clearly that the information sought, search tactics, term choices and relevance judgements as well as the contributing types of information in documents depend systematically on the stage of the task performance process and the mental model of the searcher. The obvious conclusion is that it is productive to study information searching and information retrieval in particular as a process in connection with the task that generates it. This is in line with Tom Wilson's [2] suggestion to move from the micro-level analysis typical of the dominant paradigm of IR research to analysis of information retrieval from the broader perspective of information seeking. Thus, by understanding the task of the searchers we will be able to create research results, which will also provide useful information for designing information systems.

REFERENCES

1. Wilson, T.D. On user studies and information needs. *Journal of Documentation*, 37(1), 1981, 3–15.
2. Wilson, T.D. Models in information behaviour research. *Journal of Documentation*, 55(3), 1999, 249–270.
3. Wilson, T.D. Exploring models of information behaviour: the 'Uncertainty'

Project. In: Wilson, T.D. and Allen, D., eds. *Exploring the contexts of information behaviour*. London: Taylor Graham, 1998, 55–66.

4.   Vakkari, P. Relevance and contributory information types of searched documents in task performance. *Proceedings of SIGIR 2000 Conference, Athens 2000*. NewYork: ACM, 2000, 2–9.

5.   Vakkari, P. and Pennanen, M. Sources, relevance and contributory information of documents in writing a research proposal. A longitudinal case study. In: *Proceedings of the ISIC 2000 Conference* (to be published 2000).

6.   Vakkari, P. Cognition and changes of search terms and tactics during task performance: a longitudinal study. In: *Proceedings of the RIAO 2000 Conference*. Paris: CID, 2000, 894–907.

7.   Vakkari, P. and Hakala, N. Changes in relevance criteria and problem stages in task performance. *Journal of Documentation*, 56(5), 2000, 540–562.

8.   Kuhlthau, C. *Seeking meaning*. Norwood, NJ: Ablex, 1993.

9.   Stinchcombe, A. *Constructing social theories*. New York: Harcourt, Brace & World, 1968.

10. Wagner, D. and Berger, J. Do sociological theories grow? *American Journal of Sociology*, 90, 1985, 697–728.

11. Vakkari, P. and Kuokkanen, M. Theory growth in information science: applications of the theory of science to a theory of information seeking. *Journal of Documentation*, 53(5), 1997, 497–519.

12. Kuokkanen, M. and Savolainen, J. The growth of sociological theories. A structuralist alternative to seeking theoretical continuity. *Quality and Quantity*, 28, 1994, 345–370.

13. Vakkari, P. Task complexity, problem structure and information actions. Integrating studies on information seeking and retrieval. *Information Processing & Management*, 35(6), 1999, 819–837.

14. Kuhlthau, C. Inside the search process: information seeking from the user's perspective. *Journal of the American Society for Information Science*, 42(5), 1991, 361–371.

15. Belkin, N., Seeger, R. and Wersig, G. Distributed expert problem treatment as a model for information system analysis and design. *Journal of Information Science*, 5(5), 1983, 153–167.

16. Checkland, P. and Holwell, S. *Information, systems and information systems*. Chichester, New York: John Wiley, 1998.

17. Ingwersen, P. Cognitive perspectives of IR interaction: elements of a cognitive IR theory. *Journal of Documentation*, 51(1), 1996, 3–50.

18. Järvelin, K. On information, information technology and the development of society: an information science perspective. In: Ingwersen, P., Kajberg, L. and Pejtersen, A.M., eds, *Information technology and information use*. London: Taylor Graham, 1987, 35–55.

19. Robertson, S. and Hancock-Beaulieu, M. On the evaluation of IR systems. *Information Processing & Management*, 28(4), 1992, 457–466.

20. Byström, K. and Järvelin, K. Task complexity affects information seeking and use. *Information Processing & Management*, 31(2), 1995, 191–213.

21. Saracevic, T. Relevance: a review of the literature and a framework for thinking on the notion in information science. *Journal of the American Society for Information Science*, 26, 1975, 321–343.

22.   Schamber, L. Relevance and information behavior. *Annual Review of Information Science and Technology*, 29, 1994, 3–48.

23.   Driver, M. and Streufert, S. Integrative complexity: an approach to individuals and groups as information processing systems. *Administrative Science Quarterly*, 14, 1969, 272–285.

24.   Gavin, H. *The essence of cognitive psychology*. London: Prentice Hall Europe, 1998.

25.   Bates, M. Where should the person stop and information interface start? *Information Processing & Management*, 26(5), 1990, 575–591.

26.   Fidel, R. Searchers' selection of search keys: III searching styles. *Journal of the American Society for Information Science*, 42(7), 1991, 515–527.

27.   Wildemuth, B., Jacob, E., Fullington, A., de Blieck, R. and Friedman, C. A detailed analysis of end-user search behaviors. In: *Proceedings of the 54th ASIS Annual Meeting*, 1991, 302–312.

28.   Heit, E. Knowledge and concept learning. In: Lamberts, K. and Shanks, D., eds. *Knowledge, concepts and categories*. Hove: Psychology Press, 1997, 7–41.

29.   Patel, V. and Ramoni, M. Cognitive models of directional inference in expert medical reasoning. In: Feltovich, P., Ford, K. and Hoffman, R., eds. *Expertise in context: human and machine*. Menlo Park, Calif.: AAAI Press, 1997, 67–99.

30.   Wang, P. User's information needs at different stages of a research project: a cognitive view. In: Vakkari, P., Savolainen, R. and Dervin, B., eds., Information seeking in context. London: Taylor Graham, 1997, 307–318.

31.   Brajnik, G., Mizzaro, S. and Tasso, C. Evaluating user interfaces to information retrieval systems. A case study. In: *Proceedings of SIGIR '96, Zürich, 1996*, 128–136.

32.   Bateman, J. Changes in relevance criteria: a longitudinal study. In: *Proceedings of the 61st American Society for Information Science Annual Meeting*, 35, 1998, 23–32.

33.   Harter, S. Psychological relevance and information science. *Journal of the American Society for Information Science*, 43(9), 1992, 602–615.

34.   Suhonen, P. and Rautio, P. *Yhteiskuntatieteiden tietovirrat ja suomalainen tutkija* (Information flows in social sciences and the Finnish researcher.) Academy of Finland. Publications 2/1981, 1981.

35.   Suppe, F. *The semantic conception of theories and scientific realism*. Urbana, Chicago: University of Illinois Press, 1989.

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