How IT Supports Knowledge Discovery and Learning Processes on the Web

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Abstract

This conceptual paper examines how IT can support individuals, and in turn their organizations, in learning about and knowing their external environment on the Web. Specifically, a theoretical framework is developed to identify the sets of tool characteristics, collectively referred to as levels, which are proposed to support different modes of learning and learning processes. In addition, extensions to the 4I organizational learning process model [11] are proposed, specific to searching and learning on the Web: 1) adding a fifth process – information foraging and search term development, and 2) adding a fourth level to the learning process – machine-level. Understanding which types of tools are useful in different learning contexts has implications for learning effectiveness and may help firms understand how to 'manage' their learning [49].

1. Introduction

Learning about the environment is an important activity for organizations [12]. Some view the gathering of information about the environment as a basic requirement for organizational survival [12]. Others suggest it promotes growth [37] and improved competitiveness [12]. Further, the ability to understand and interpret information about the external environment enables entrepreneurial action, defined as the behaviours required for exploiting superior insights about the market relative to competitors [41, 50]. "Intuitively, it makes sense that the firm that knows more about its customers, products, technologies, markets, and their linkages should perform better" [48 p. 126]. The process of knowing the environment involves gathering information about the environment - including trends, events, laws and regulations, competitors, markets, technology, suppliers, partners, and customers - and interpreting that information in order to learn and take purposeful action. Sources of information about the environment can be classified as internal or external to the organization, and as personal or impersonal [12, 28]. The benefits and challenges vary with each type of source [28]. The World Wide Web is a rich *external* source of information about the environment and is used extensively by organizations [10]. However, the sheer volume and the dynamic nature of information on the Web make it challenging for individuals to locate and make sense of this information. Information technology (IT) can support individuals and organizations in learning about the environment from Web-based sources of information.

Past research has explored how IT can support individual learning about the external business environment for the benefit of their organization. Examples of tools include executive support systems (ESS) [44, 45] and Web-based competitive intelligence tools [9]. Past research has also looked at how specific design characteristics of these tools, or tool features, and the use of these features supports two different learning modes – mental model maintenance and mental model building [44] – as well as learning effectiveness [39]. However, additional research to investigate the relationship between technology tools, various learning aspects and learning outcomes is needed [1, 39].

Further, past research has shown that having access to specific kinds and different levels of knowledge can be instrumental in enabling individuals to notice opportunities in the environment that may otherwise be hidden [14]. Accordingly, there is a call for organizational learning theorists to develop finer distinctions between knowledge categories [14]. Understanding which tools or tool characteristics are suitable for different learning contexts and knowledge types may help organizations more effectively develop their knowledge management strategy and systems.

In this research, I propose to address these calls for additional research by exploring how different types of tools or design characteristics support different aspects

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of learning about the external environment on the Web. Specifically, I look at the type of knowledge acquired and as a result, the mode of learning supported. In addition, I look at the individual learning processes supported. By exploring multiple aspects of learning and proposing how different tool characteristics support different levels of these aspects, I hope to make an important contribution to the IS literature.

This paper is organized as follows. First, prior research on knowledge, learning and supporting IT tools is reviewed. Next, a theoretical framework identifying the tool characteristics that support different learning modes, learning processes and types of knowledge is proposed, followed by a discussion of the potential applications of this framework. To conclude, the limitations, future research opportunities and contributions will be discussed.

2. Literature review

In this section the literature on knowledge, knowledge-discovery tools, learning modes and learning processes is reviewed.

2.1. Knowledge

Knowledge has been defined in a number of different ways [see 1], based on a number of philosophical perspectives [1, 35]. Of these perspectives, three views of knowledge seem particularly relevant in the context of Web-searching and learning – object, state of mind and capability. As an *object*, knowledge is viewed as something to locate and manipulate [1]. Once located, knowledge can affect an individual's *state of mind* in terms of their understanding and mental models [1]. Lastly, the *capability* view of knowledge suggests that this change in understanding can increase the range of potential behaviors [1, 23, 26]. Accordingly, the following definition of knowledge encompasses these three views: knowledge represents information with direction, which enables action and decisions [4] and increases the capacity for effective action [23, 26].

2.2. Tools for knowledge discovery on the web

Knowledge discovery involves the development or acquisition of new knowledge based on either the analysis of data and information, or the integration and reinterpretation of prior knowledge [4]. External knowledge discovery refers to the discovery of knowledge outside the organization and therefore developing an understanding of its environment. The Web, while one of the top sources of information for businesses [10], presents a number of knowledge discovery challenges, for example information overload. Accordingly, the Web is the context for the external knowledge discovery explored in this paper.

Search engines, tools commonly used to locate knowledge on the Web, enable users to query across a domain of content, based on a set of search criteria. A search engine typically produces a long list of results, listing the Web sites that relate to the search criteria, sorted by relevance [4]. Relevance criteria, which can vary across search engines, are crucial because they influence the type of knowledge discovered by the individual and learning that results. An example of a relevance algorithm is the page ranking approach used by Google, which uses a 'global' computation to calculate the relevance of a page, based on how the rest of the world assesses that page's relevance (i.e., by linking to that page themselves) [8]. However, global relevance does not necessarily mean that the page is the most interesting and relevant in this individual's particular context. More advanced search tools organize and display results in clusters and knowledge maps[1] in order to help the user understand the deeper structure of the results. In addition, the semantic Web, which extends the current Web by attaching well-defined meaning to information through the use of ontologies [5], can support the discovery of knowledge on the Web that is more relevant to the individual's context.

2.3. Learning modes

Learning can be viewed as either cognitive development, focusing on changes to mental models, behavioural development, focusing on changes in behaviour or actions, or both [16, 21]. The focus in this research will be on learning as cognitive development since the focus of this paper is on the discovery of new knowledge, not on the new behaviours that result from this knowledge discovery.

Mental models, also referred to as cognitive structures [34], schemas [20], theories of action [2, 22], and frames [3], are frameworks to help simplify and organize information [11, 13, 22, 26]. Rather than containing individual pieces of data, mental models are aggregates of data [22, 26] and knowledge structures, which represent knowledge as a complex network of concepts with abstract attributes, values, relationships and rules [3]. Learning is both enabled and constrained by mental models; useful for interpreting and making sense of environmental information, but affect what the individual looks for and perceives in the environment

[1] A knowledge map represents the results in a graphical map, with nodes (circles) as web sites and lines linking the nodes together to represent common key words between nodes [10].

[21, 26]. Mental models that remain unexamined and unchanged can blind the individual or organization to potentially important opportunities or threats in the environment [13].

Based on cognitive learning theories (e.g. Norman [33], Piaget [38] and Maier [30]), Vandenbosch and Higgins [44] proposed two modes of learning: mental model building and mental model maintenance. The first mode, mental model building, involves the creation of new mental models. When new concepts do not fit into existing mental models or disconfirm current models, mental models may be fundamentally changed in order to align with this new knowledge [44]. The second mode of learning, mental model maintenance, involves the confirmation of existing mental models. When new information fits into existing mental models, this information is added to and helps validate the existing mental model [44].

In the organizational learning literature, additional learning modes have been discussed [17]. Reinventive learning [17] and innovation [19] involve questioning and making fundamental or radical changes to existing mental models. Similar to reinventive learning, formative learning involves creating entirely new mental models in order to provide a new understanding of existing information [17]. Reinventive, innovation and formative learning are most similar to the mental model building mode discussed above, as well as double-loop learning, which involves surfacing, challenging and changing mental models [2]. Adjustive learning [17] and adaptation [19] involve making incremental changes and refinements to existing mental models. Adjustive learning and adaptation are similar to Norman's [33] tuning mode of learning, where mental models are slowly refined and updated over time. Lastly, operative learning [17] and replication [19] involve validating and reinforcing existing mental models. Operative learning and replication are most similar to mental model maintenance.

2.4. Learning process

The organizational learning process has been conceptualized as a multi-level dynamic process, including both feed-forward and feedback processes [11]. These processes span the individual, group and organizational levels, and include the following: intuiting, interpreting, integrating and institutionalizing (referred to as the 4I model). The key individual cognitive processes, the focus here, are intuiting and interpreting. Intuiting involves pattern recognition and the development of insights into past patterns and future possibilities [11]. Interpreting begins as an individual process and moves to a group process. The process of interpreting involves developing models for understanding, bringing out meaning, and developing shared mental models amongst managers [11, 12]. Figure 1 depicts the organizational learning process.

The feed-forward process of organizational learning is an exploratory process that translates individual and group insights into learning that is institutionalized via 'organizational learning systems' [11]. Whereas the feedback process involves exploiting institutionalized learning, which guides individual thinking and action [11]. However, institutionalized routines, norms and mental models are slow to change and, thus, may constrain and hinder future learning and exploration [32].

Other organizational learning models have included processes such as scanning, learning [12], reconceptualizing the problem, deciding to search, search and evaluate, and development [31]. The scanning, search and evaluation processes can be conceptualized more broadly as information foraging, which refers to the process of seeking information, as well as assessing and choosing information sources based on the expected value of information and expected cost of locating and extracting this information [40].

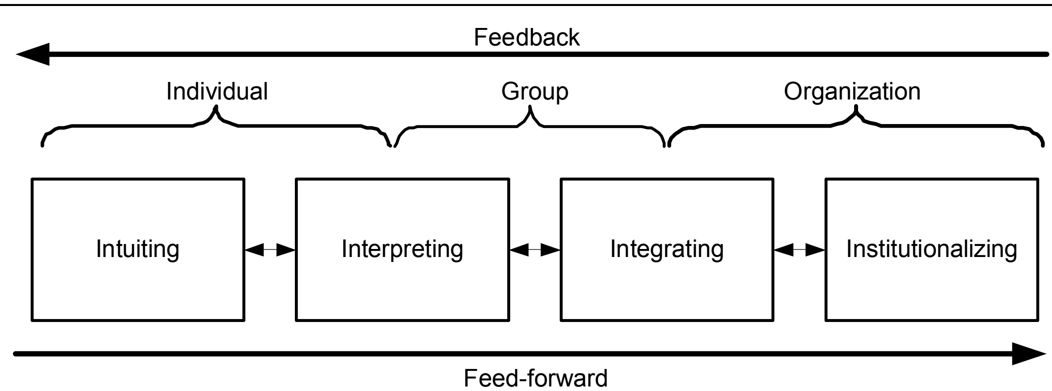

Figure 1. Organizational learning process (adapted from Crossan et al. [11])

2.5. Learning and IT

Past research has explored how IT can support learning effectively. The executive support system (ESS) literature has looked at the modes of learning supported by ESS, depending on how the ESS is used and characteristics of the user. Vandenbosch and Higgins [44] explored the relationship between how the ESS was used by executives – for scanning or focused search – and the resulting mode of learning – mental model maintenance or mental model building. In a separate study, Vandenbosch and Huff [45] explored, amongst other things, which system characteristics influenced scanning behaviour in an ESS. For example, the ability to integrate information from different sources and flexibility in how information can be used were found to be important system features that supported scanning behaviour [45].

The organizational learning literature has explored the impact of different types of tools (e.g. knowledge repositories and communication tools such as email) on learning processes within the organization – exploitation and exploration [25]. Using computational modeling, both speed of learning and variance of knowledge were found to differ across types of tools, thus supporting exploitive and explorative processes differently [25].

The virtual learning environment (VLE) literature examined the important design dimensions of a VLE, specifically the degree of learner control, to support learning effectiveness [39]. Similarly, Leidner and Jarvenpaa [29] explored the types of tools and technologies that best support different learning models (objectivist, constructivist, collaborative, cognitive information processing, and sociocultural)[2] in the business school environment. However, further work is needed to understand the importance and suitability of different tool design elements in different learning environments and different learning models [39].

2.6. Integration: knowledge, learning and IT

The four concepts discussed above – knowledge, tools, learning modes and processes – are interrelated. Learning modes describe the degree to which mental models – internal representations of knowledge – change. The learning process helps explain *how* mental models are changed and affect future learning. The 4I organizational learning process model [11] is used in the theoretical framework developed below because it describes how mental models are created at the individual, group and organizational levels and how these mental models affect interpretation and sense-making. Thus, it enables an integrative analysis of learning mode and process.

Finally, tools can support individuals and organizations in the discovery of knowledge. Discovery initiates a learning process involving intuiting and interpreting, guided by existing mental models and resulting in updates to those mental models. This learning process can also be supported by tools.

In the following section, a theoretical framework is proposed that describes a series of relationships between tool characteristics, which are grouped together in different levels, and the type of knowledge discovered, learning mode supported and learning processes supported.

3. Theoretical framework

The learning modes identified by Vandenbosch and Higgins [44] – mental model maintenance and mental model building – encompass most of the learning modes described by Norman [33], Maier [30] and Piaget [38]. However, there is a third mode of learning described by Norman [33] that is mentioned, but not explicitly included in their research model because it was not applicable in the ESS context being studied. The third mode of learning is tuning, a mode that involves the continual adjustment of knowledge within an existing mental model. Existing knowledge is refined, made more efficient, specialized and embedded into the mental model as one encounters more experience or data to refine and update the details of that knowledge. Thus, existing mental models are refined and specialized expertise is developed [33]. Thus, the following three modes of learning are included in this framework:

1. *Mental model maintenance*: confirmation and validation of existing mental models [44].
2. *Mental model tuning*: refinement and updates to existing mental models [33].
3. *Mental model building*: creation of new mental models or fundamental changes to existing mental models [44].

The amount of learning and change to existing mental models rises from mode 1 (mental model maintenance) to mode 3 (mental model building).

As explored in other system domains such as ESS [44, 45] and VLE [39], it is useful to understand what tool functionality, in general, supports different modes of learning on the Web. Dworman et al. [15] discuss two types of questions that are relevant for searching in either structured (e.g. databases and indexed text-based search and retrieval systems) or unstructured sources of data (e.g. full-text documents): 1) questions about

[2] See Leidner and Jarvenpaa [29] for a detailed discussion of these learning models.

trees, and 2) questions about the forest. Questions about trees are 'record-oriented' questions [15]. In other words, these questions are about specific things. This relates to the 'mental model maintenance' mode of learning since the answers to these specific questions help to confirm and validate existing knowledge. This is supported by past research linking *focused-search* behaviour to mental model maintenance [44]. From a technology perspective, tools that support searching for specific things (i.e. focused search) should be suited to 'mental model maintenance', for example standard search engines such as Google (www.google.com).

The questions about the forest are pattern-oriented questions [15]. In other words, finding patterns of relationships amongst words and concepts in the case of textual data. Finding new relationships between related concepts can help individuals refine and update existing mental models with new connections that fit into these mental models. Thus, questions about patterns relates to the 'mental model tuning' mode of learning. Tools that highlight patterns and display them to users should support this mode of learning, for example clustering tools such as Vivisimo (www.vivisimo.com), or knowledge mapping tools such as Kartoo (www.kartoo.com).

The third learning mode, mental model building, may not involve a distinct question; rather, the question may be vague and unarticulable. Mental model building may involve looking and scanning for unknown connections. This is supported by past research linking *scanning* behaviour to mental model building [44]. Kimbrough refers to these types of unknown connections as "surprising associations" or low-probability relationships [27]. Norman [33] suggests that structuring, a mode related to mental model building, involves sudden changes in knowledge and the restructuring of knowledge. These unknown relationships highlight connections that are indirect and linked through an intermediate connection [18]. Kimbrough refers to questions oriented towards unknown relationships as "Raynaud questions" after Swanson, the information scientist who discovered a medical intervention for Raynaud's disease by looking for these indirect connections across the medical literature [27]. From his search, Swanson was able to make a connection between Raynaud's disease, blood viscosity, and fish oil. This led to the discovery that dietary fish oil supplements could help alleviate the problems associated with Raynaud's disease, an indirect connection that was not found in any of the documents reviewed [42, 43].

These unknown and indirect connections can lead to the discovery of novel knowledge – knowledge that is unknown to the organization but that is relevant, interesting yet indirectly connected [24, 46, 47]. Tools that can help individuals find these unknown and indirect connections are most suitable for mental model building. However, tools of this nature are rare. There are some tools that can look across a document collection (for example the Core of Discovery [27]), however, there are no tools that I am aware of that can perform this function across the Web. Table 1 summarizes the proposed connections between learning modes, types of questions addressed and supporting tools. The general tool characteristics proposed to support different learning modes are summarized in Table 2. For level 1 and 2 tools, the characteristics were developed by generalizing the functionality within each family of tools proposed to support a specific learning mode. For level 3, the general characteristics were developed as part of a novel-knowledge discovery design theory, discussed in detail in Jenkin et al. [24].

Table 1. Learning modes and supporting technologies

Learning Mode	Description	Supporting Questions and Answers	Supporting Technologies
Mental Model Maintenance [44]	Confirm and validate mental models [44].	**Questions**: Specific, record-oriented questions [15, 44]. **Answers**: Focused, specific knowledge.	Search engines, semantic web technologies. **Tool Examples**: Google
Mental Model Tuning [33]	Existing knowledge is refined, made more efficient, specialized [33].	**Questions**: General, pattern-oriented questions [15]. **Answers**: Patterns, relationships between related concepts.	Categorization tools, ontology development tools, semantic web technologies. **Tool Examples**: Vivisimo
Mental Model Building [44]	Creates new mental models [44], involving sudden changes and restructuring of knowledge [33].	**Questions**: Vague or unarticulable. **Answer**: Novel knowledge and "surprising associations" [27].	Text mining tools. **Tool Examples**: Unknown[1]

Table 2. General characteristics of knowledge-discovery tools

Tool Level	General Characteristics	Tool Examples
Level 1	1. Searches across a domain of content using keywords entered by the user. (*, #) 2. Produces list of results matching search terms. (*) 3. Includes links to relevant content and meta-knowledge of that content. (*, #) 4. Sorts results by relevance / similarity to search terms (for example, weighted keyword scores, and page ranking). (*)	Google, Yahoo, Altavista, Infoseek, Ask Jeeves, Dogpile, Metacrawler*
Level 2	1. Includes characteristics of level 1 tools (where noted *). 2. Groups results into clusters of similar content, thus identifying various dimensions of the search term and related concepts. (#) 3. Allows user to drill down into clusters for more detailed results. (#)	Kartoo, Vivisimo, NorthernLight, Excalibur, Autonomy, Verity**
Level 3	1. Includes characteristics of level 1 and 2 tools (where noted #). 2. Distills and summarizes results to a limited set. 3. Directs user's attention to most interesting, relevant and novel results that are indirectly connected original search term. 4. Provides a measurement of interestingness to enable evaluation of results. 5. Reframes existing knowledge about the search term entered. 6. Supports users in challenging existing mental models regarding search term entered.	Athens 1.0 (partially)[24]

Notes: * Both Dogpile and Metacrawler have some features that are consistent with level 2, such as asking the user 'Are you looking for x?' and allowing the user to drill down into different search word combinations. ** Now part of Autonomy's product offerings.

In addition to the differences in modes of learning supported, it is proposed that the three levels of tools support individual learning processes differently. As discussed above, the two individual cognitive learning processes are intuiting and interpreting. In order to integrate different organizational learning process models, information foraging [40], a very relevant process in the context of searching and learning on the Web, is added as a fifth learning process to the 4I organizational learning process model [11]. Information foraging, in the context of Web-searching, may support the individual learning process of *intuiting* – cognitive processes involving pattern recognition and developing insights – and *interpreting* – developing models for understanding and bringing out meaning [11].

The development of appropriate search terms is important for locating information on the Web. The development of search terms is an intuitive and inductive process, which starts with the intuiting process and feeds into the information foraging process. When the initial search term(s) do not provide the desired results, the intuiting process feeds back into the information foraging process for an additional iteration. Thus, the development of search terms connects the intuiting and information foraging processes, forming an iterative loop (see Figure 2 below). The degree to which different levels of tools support each of these four learning processes – search term development, information foraging, intuiting and interpreting – is discussed below.

Level 1 tools, for example standard search engines, automate the information foraging process for individuals by locating information and assessing its usefulness for the individual based on the search terms provided. The long list of results that are returned by most search engines creates information overload [7, 10] and does little to support the individual intuiting and interpreting processes. However, these processes are less important when individuals are looking for specific knowledge. Level 1 tools rely solely on the individual for the development of search terms, which requires intuition and induction.

Level 2 tools help to organize and display results in clusters and knowledge maps in order to help the user find relevant and interesting results based on the search terms entered. Level 2 tools automate information foraging and partially support the interpretation process – assigning meaning to information. For example, a knowledge map can highlight clusters related to a topic and the relationships between these clusters, making it is easier for the individual to understand the topic, sub-topics and relationships between them. However, knowledge maps can become so large that a user has difficulty understanding the scope of the map and difficulty finding what is most interesting. Thus, intuiting – developing insights and recognizing patterns – may be difficult. Level 2 tools also rely on the individual for the development of search terms.

The goal of level 3 tools is to help discover novel knowledge – knowledge that the individual or organization is not currently aware of, that is relevant, and indirectly connected to what the individual or organization knows [24, 46, 47]. All knowledge discovered is new to the recipient; the important distinction is the degree of 'newness' and surprise to the recipient. One of the distinguishing features of novel-knowledge discovery (NKD) tools, as differentiated from the other levels, is that the tool directs the individual's attention to what they should do or learn next based on what is indirectly connected, yet related to the search terms provided [46] (see Table 2 for a summary of tool characteristics). This feature will help reduce the information overload problem experienced in the other levels. As discussed above, tools at levels 1 and 2 use relevance algorithms that tend to bury interesting results in long lists, or require significant browsing. Level 3 tools are proposed to point the individual's attention to a smaller number of interesting and relevant ideas in the result set.

In addition to automating information foraging, level 3 tools fully support the interpreting process and

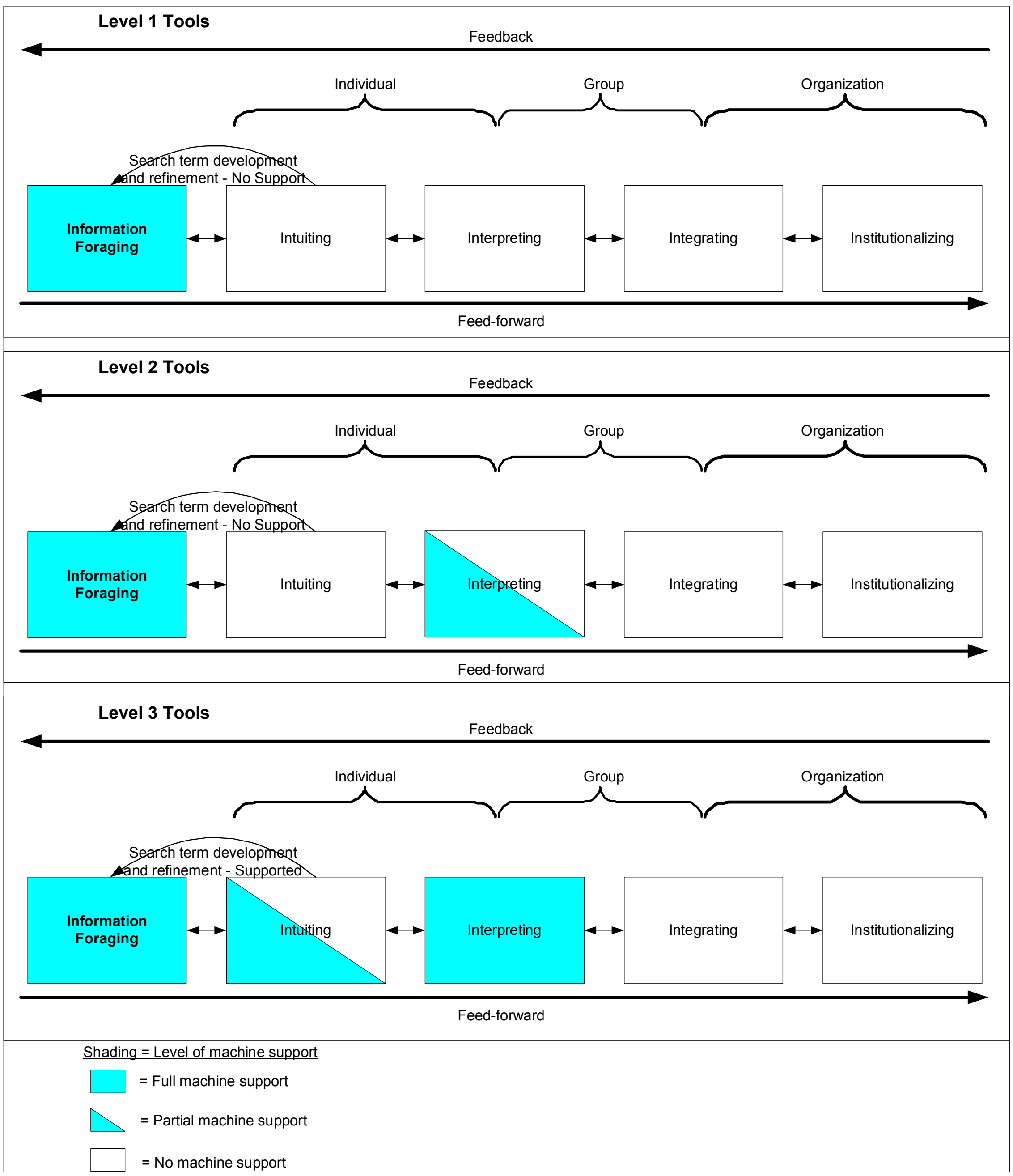

Figure 2. Proposed extensions to the 4I model and tool support for individual learning processes (adapted from Crossan et al. [11])

partially support the development of search terms. Since the user, by the definition of novel knowledge, does not know what he or she is looking for, level 3 tools should refine the search terms initially provided by the user or at least be less reliant on search term precision. Further, in order to discover indirect connections that are related in a meaningful way to the initial search terms, level 3 tools need to be able to assess and choose the series of logical connections that will likely lead to meaningful results for the user, for example the connections between Raynaud's syndrome, blood viscosity and fish oil in the case of Swanson's discovery [18, 42, 43]. Level 3 tools also help partially support intuiting – pattern recognition and the development of insights – by directing an individual's attention and insight to novel and potentially important knowledge.

Figure 2 depicts the proposed extensions to the 4I organizational learning process model [11] and how tool levels 1, 2 and 3, respectively, support individual level learning processes differently.

4. Discussion

In each organizational setting there exist different sets of questions about the environment to which analysts, managers and executives seek answers. The types of questions, and more specifically the resulting answers (see Table 1 above), influence the learning mode enacted. The type of question or desired mode of learning is context specific. In some situations, individuals may want to validate what they know, therefore, mental model maintenance is the goal and standard search tools can enable this mode. In other situations, an individual involved in the innovation process may want to find novel knowledge and radically modify their mental models [for example see 31]. In this case, a level 3 tool may best support this learning mode and goals. Further, the learning mode may affect the amount of cognitive support desired in the individual learning process. For example, in mental model maintenance, the individual may only desire support in the information foraging process. However, in mental model building, a higher degree of support for interpretation and intuiting may be desired due to the complexity of the learning task. Thus, a tool that supports these processes, such as a level 3 tool may be quite useful.

Each individual has a unique set of mental models and experiences, which influences how the question is framed and search terms developed, as well as how the results are interpreted. For example, one individual might view the knowledge as novel and find interesting new opportunities as a result. Another individual might find the knowledge confirms what they already know. Thus, the support that tools 1 through 3 provide and the affect on the type of knowledge discovered, learning mode enacted and learning processes supported depends on the individual's perceptions and prior knowledge.

In addition, it is important to note that this theoretical framework is not meant to reflect deterministic relationships between tools, learning modes and processes. Although a level 3 tool may effectively and efficiently support mental model building and discovery of novel knowledge, it is still possible to discover novel knowledge and change mental models with a level 1 or 2 tool. However, it might require more effort or serendipity to do so.

The theoretical framework developed above suggests groups of tool characteristics that are proposed to be most suitable for supporting different processes and learning about the external environment. For practitioners, understanding which types of tools might be useful in different learning contexts may assist them in developing their knowledge management strategy and systems, and enable them to 'manage' their learning about their external environment [49]. For example, firms that are interested in recognizing strategic opportunities arising in the environment may be interested in acquiring or developing level 3 tools.

From a research perspective, this theoretical framework integrates different streams of literature related to learning, knowledge and IT. By suggesting sets of tool design characteristics and linking these to multiple aspects of learning, this framework provides researchers with a basis to analyze existing tools, develop new tools for learning and suggest additional design characteristics.

The focus of this paper was on learning using external and impersonal sources of information. While parts of this framework may apply to other sources, for example external and personal or internal and impersonal, the different challenges associated with these contexts would likely result in modified tool characteristics and different levels. Investigating these other contexts is outside the scope of this paper, but an interesting avenue for future research.

5. Conclusion

The goal of this paper was to understand how IT can support individuals, and in turn their organizations, learn about and know their environment. Specifically, a theoretical framework was developed to identify the sets of tool characteristics, collectively referred to as levels, which are proposed to support different modes of learning and learning processes. In this theoretical framework, levels of tools, modes of learning and processes of learning are proposed to relate to one another. Certain tool characteristics are proposed to better support different learning modes, which describe the extent to which an individual's mental models are modified, and learning processes.

This paper extends past research that has linked tools to other learning contexts [e.g. 29, 39, 44, 45]. Thus, this research addresses calls for additional research into how different tool characteristics support different aspects of learning [39] including finer distinctions of knowledge categories [14], and how IT can support the modification of mental models [6, 36, 44]. Further, two extensions to the 4I organizational learning process model [11] have been proposed, specific to searching and learning on the Web: 1) adding a fifth process – information foraging process and search term development, and 2) adding a fourth level to the learning process – machine-level.

The theoretical framework developed in this paper is conceptual in nature and requires empirical validation. Thus, future research should test the degree to which the tool characteristics and proposed relationships to learning modes and processes are valid in an organizational context. For example, an experiment comparing tools at each level and measuring the perceived effects on learning process support and mental models could be conducted. Examining the effects of level 3 tools on mental model building and how the resulting learning flows through the group and organizational levels would be another interesting avenue for future research.

6. Acknowledgements

The author would like to thank Yolande Chan, David Skillicorn, Jim McKeen and Ann Majchrzak for helpful comments provided on earlier versions of this manuscript. They are grateful to the Social Sciences and Humanities Research Council of Canada for funding provided.

7. References

[1] Alavi, M., and Leidner, D.E. Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS Quarterly*, 25, 1 (2001), 107-136.

[2] Argyris, C., and Schon, D.A. *Organizational learning*. Reading, MA: Addison-Wesley, 1978.

[3] Barsalou, L.W. Frames, concepts, and conceptual fields, in *Frames, fields, and contrasts: New essays in semantic and lexical organization*, Kittay, E. and Lehrer, A., (eds). Hillsdale, NJ: Erlbaum, 1992, 21-74.

[4] Beccerra-Fernandez, I.; Gonzalez, A.; and Sabherwal, R. *Knowledge management: Challenges, solutions, and technologies*. Upper Saddle River, NJ: Pearson Prentice Hall, 2004.

[5] Berners-Lee, T.; Hendler, J.; and Lassila, O. The Semantic Web. *Scientific American*, May 2001 (2001).

[6] Boland, R.J.; Tenkasi, R.V.; and Teeni, D. Designing Information Technology to Support Distributed Cognition. *Organization Science*, 5, 3 (1994), 456-475.

[7] Bowman, C.M.; Danzig, P.B.; Manber, U.; and Schwartz, M.F. Scalable Internet resource discovery: research problems and approaches. *Communications of the ACM*, 37, 8 (1994), 98-107.

[8] Chen, H., 2001, *Knowledge Management Systems: A Text Mining Perspective*. The University of Arizona: Tucson, AZ.

[9] Chen, H.; Chau, M.; and Zeng, D. CI Spider: A tool for competitive intelligence on the Web. *Decision Support Systems*, 34, 2002 (2002), 1-17.

[10] Chung, W.; Chen, H.; and Nunamaker Jr, J.F. A visual framework for knowledge discovery on the web: An empirical study of business intelligence exploration. *Journal of Management Information Systems*, 21, 4 (2005), 57-84.

[11] Crossan, M.M.; Lane, H.W.; and White, R.E. An organizational learning framework: From intuition to institution. *Academy of Management Review*, 24, 2 (1999), 522-537.

[12] Daft, R.L., and Weick, K.E. Toward a model of organizations as interpretation systems. *Academy of Management Review*, 9, 2 (1984), 284-295.

[13] Day, G.S. Managing the market learning process. *The Journal of Business & Industrial Marketing*, 17, 4 (2002), 240-252.

[14] Dutta, D.K., and Crossan, M.M. The nature of entrepreneurial opportunities: Understanding the process using the 4I organizational learning framework. *Entrepreneurship Theory and Practice*, 29, 4 (2005), 425-449.

[15] Dworman, G.O.; Kimbrough, S.O.; and Patch, C. On pattern-directed search of archives and collections. *Journal of the American Society for Information Science*, 51, 1 (2000), 14-23.

[16] Fiol, C.M., and Lyles, M.A. Organizational learning. *Academy of Management Review*, 10, 4 (1985), 803-813.

[17] Gnyawali, D.R., and Stewart, A.C. A contingency perspective on organizational learning: Integrating environmental context, organizational learning processes, and types of learning. *Management Learning*, 34, 1 (2003), 63-89.

[18] Gordon, M.D., and Lindsay, R.K. Toward discovery support systems: A replication, re-examination, and extension of Swanson's work on literature-based discovery of a connection between Raynaud's and fish oil. *Journal of the American Society for Information Science*, 47, 2 (1996), 116-128.

[19] Gray, P.H., and Meister, D.B. Knowledge Sourcing Effectiveness. *Management Science*, 50, 6 (2004), 821-834.

[20] Hargadon, A.B., and Douglas, Y. When innovations meet institutions: Edison and the design of the electric light. *Administrative Science Quarterly*, 46, (2001), 476-501.

[21] Hargadon, A.B., and Fanelli, A. Action and possibility: Reconciling dual perspectives of knowledge in organizations. *Organization Science*, 13, 3 (2002), 290-302.

[22] Hedberg, B. How organizations learn and unlearn?, in *Handbook of organizational design*, Nystrom, P.C. and Starbuck, W.H., (eds). London: Oxford University Press, 1981.

[23] Huber, G.P. Organizational learning: The contributing processes and the literatures. *Organization Science*, 2, 1, Special Issue: Organizational Learning: Papers in Honor of (and by) James G. March (1991), 88-115.

[24] Jenkin, T.A.; Chan, Y.E.; and Skillicorn, D.B. 2007. *Novel-Knowledge Discovery - Challenges and Design Theory*. *In The Proceedings of The Annual Conference of the Administrative Sciences Association of Canada*. Ottawa, Canada.

[25] Kane, G.C., and Alavi, M. 2005. *Information technology and organizational learning: An investigation of exploitation and exploration processes*. in *Proceedings of the Twenty-Sixth International Conference on Information Systems*. Las Vegas.

[26] Kim, D.H. The link between individual and organizational learning. *Sloan Management Review*, 35, 1 (1993), 37-50.

[27] Kimbrough, S.O. Core of Discovery Executive Briefing: Capabilities of Practical Reasoning's Core of Discovery. http://opim-sun.wharton.upenn.edu/~sok/asadai/cod-exec-brief.html. *[Accessed Jan 7, 2007]*, (2001).

[28] Kourteli, L. Scanning the business external environment for information: evidence from Greece. *Information Research*, 11, 1 (2005), 1-16.

[29] Leidner, D.E., and Jarvenpaa, S.L. The use of information technology to enhance management school education: A theoretical view. *MIS Quarterly*, 19, 3 (1995), 265-291.

[30] Maier, N.R.F. Reasoning in humans: III. The mechanisms of equivalent stimuli and of reasoning. *Journal of Experimental Psychology*, 35, (1945), 349-360.

[31] Majchrzak, A.; Cooper, L.P.; and Neece, O.E. Knowledge reuse for innovation. *Management Science*, 50, 2 (2004), 174-188.

[32] March, J.G. Exploration and exploitation in organizational learning. *Organization Science*, 2, 1, Special Issue: Organizational Learning: Papers in Honour of (and by) James G. March (1991), 71-87.

[33] Norman, D.A. *Learning and Memory*. San Francisco: W.H. Freeman, 1982.

[34] Nystrom, P.C., and Starbuck, W.H. To avoid organizational crises, unlearn. *Organizational Dynamics*, 12, 4 (1984), 53-65.

[35] Orlikowski, W.J. Knowing in practice: Enacting a collective capability in distritbuted organizing. *Organization Science*, 13, 3 (2002), 249-273.

[36] Orlikowski, W.J., and Gash, D.C. 1991. *Changing frames: Understanding technological change in organizations*. in *Academy of Management Best Paper Proceedings*. 51st Annual Meeting, Miami Beach, FL, August.

[37] Penrose, E.T. *The theory of the growth of the firm*. White Plains, NY: M. E. Sharpe, 1959.

[38] Piaget, J. *The Construction of Reality in the Child*. New York: Basic Books, 1954.

[39] Piccoli, G.; Ahmad, R.; and Ives, B. Web-based virtual learning environments: A research framework and a preliminary assessment of effectiveness in basic IT skills training. *MIS Quarterly*, 25, 4 (2001), 401-426.

[40] Pirolli, P., and Card, S. 1995. *Information foraging in information access environments*. in *Proceedings of the SIGCHI conference on Human factors in computing systems*. Denver, Colorado, United States: ACM Press/Addison-Wesley Publishing Co.

[41] Sambamurthy, V., Bharadwaj, A., and Grover, V. Shaping agility through digital options: Reconceptualizing the role of information technology in contemporary firms. *MIS Quarterly*, 27, 2 (2003), 237-263.

[42] Swanson, D.R. Fish oil, Raynaud's syndrome, and undiscovered public knowledge. *Perspectives in Biology and Medicine*, 30, 1 (1986), 7 - 18.

[43] Swanson, D.R. Medical literature as a potential source of new knowledge. *Bulletin of the Medical Library Association*, 78, 1 (1990), 29-37.

[44] Vandenbosch, B., and Higgins, C. Information acquisition and mental models: An investigation into the relationship between behaviour and learning. *Information Systems Research*, 7, 2 (1996), 198-214.

[45] Vandenbosch, B., and Huff, S.L. Searching and scanning: How executives obtain information from executive information systems. *MIS Quarterly*, 21, 1 (1997), 81-107.

[46] Vats, N., and Skillicorn, D.B., 2004, *The ATHENS system for novel information discovery*. Department of Computing and Information Science, Queen's University, Technical Report 2004-489.

[47] Vats, N., and Skillicorn, D.B. 2004. *Information discovery within organizations using the Athens system*. in *Proceedings of the 2004 Conference of the Centre for Advanced Studies on Collaborative Research*. Markham, Ontario.

[48] Zack, M.H. Developing a Knowledge Strategy. *California Management Review*, 41, 3 (1999), 125-145.

[49] Zack, M.H. The strategic advantage of knowledge and learning. *International Journal of Intellectual Capital and Learning*, 2, 1 (2005), 1-20.

[50] Zaheer, A., and Zaheer, S. Catching the wave: Alertness, responsiveness, and market influence in global electronic networks. *Management Science*, 43, 11 (1997), 1493.