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# Do Maps Guide the Way to NPD Success? Theoretical and Practical Aspects of Knowledge Mapping in Product Development

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**Abstract—New product development success largely depends on the ability to combine newly acquired information on customer demands and technological options with knowledge that exists within the company. Project organization and high employee turnover, however, make it difficult to be informed about what knowledge is available within the company and to access it successfully.**

**Knowledge maps, a popular concept in present knowledge management, offer a possible solution by "guiding the way to knowledge". Their purpose, structure and content varies greatly, as does their ability to capture different aspects of knowledge. This paper investigates the theoretical basis of different types of knowledge maps and investigates their applicability in development projects.**

## I. KNOWLEDGE AND KNOWLEDGE MAPS IN NPD PROJECTS

### *A. Knowledge issues in new product development projects*

New Product Development (NPD) undoubtedly is a knowledge-intensive process, which, according to Iansiti, can be interpreted as the combination of domain-specific knowledge and context-specific system knowledge [21]. Domain-specific knowledge can be attributed to various disciplines (e.g. marketing, software engineering, physics, material sciences, medicine) that exist independently of the immediate context of the product. It is usually easy to articulate and generalize and can therefore be captured and shared in reports, textbooks, and training programs [21].

In contrast to this, system knowledge describes the interactions between knowledge domains and their application context and is therefore always linked to a specific context, such as the use environment of a new computer tomography device or the particularities of a factory floor that a new grinding machine is intended for. Without context-specific system knowledge, it is impossible to integrate diverse knowledge bases from various disciplines into a coherent new product. However, dealing with system knowledge is not easy – very often it is difficult or even impossible to articulate because it includes tacit components, such as intuition, "gut-feel" and experience [21]. Tacit knowledge is almost invisible, because it is embedded in mental models of individuals, organizational decision processes and rules, production systems, and business processes [27]. It is furthermore "sticky", which means that it can only be transferred at great costs, e.g. through long-term observation or learning by doing [39].

All NPD processes build on both types of knowledge: domain-specific knowledge that is explicit or could at least be explicated, as well as on context-specific knowledge that – in parts – is tacit and impossible to codify. Knowledge management in NPD is therefore all but simple:

- NPD managers need to **identify the knowledge** that is important for their project, without disregarding the almost invisible system knowledge that cannot be easily spelled out in list of requirements, design review criteria and project handbooks. This is especially challenging, because NPD project are non-routine tasks: managers can only partially rely on their experience in defining the knowledge needs of a new project. Furthermore, important NPD parameters, such as customer demands, available product technologies, competing products, and legal regulations dynamically change. Formerly important knowledge can therefore become obsolete, while new knowledge domains need to be mastered.
- In order to be able to access the domain specific knowledge of experts from different fields and combine it with system knowledge, NPD managers need to **know where knowledge resides**. Knowledge sources are people, as well as information resources such as documents, databases and files. Especially in large organizations, where NPD managers do not personally know all potential experts and are not aware of all the information that is stored within the organization, knowledge detection can be a serious problem. It is aggravated by the fact that knowledge sources are not static: Employees create, alter and delete documents on a daily basis, thus changing the repository of codified knowledge. They also change the "knowledge in their brains" by undergoing formal training programs, by learning on the job, by gaining additional experience in new functions, and by forgetting knowledge that is outdated or that they have not used for some time. Furthermore, individuals within the organization change, e.g. when new employees join the company or when people are laid-off, retire or quit.
- The volatility of available knowledge sources does not only hamper knowledge detection but also puts the question of **knowledge retention** on the agenda of NPD managers. Because of the temporary nature of projects, knowledge that has been build and used in one project is easily forgotten when the project team splits up and is assigned to other projects of might still reside in the company but is never transferred to other projects. The problem of knowledge retention is therefore closely coupled with the problem of **knowledge application** or inter- and intra-project knowledge transfers.

- As pointed out before, important parts of NPD knowledge are difficult to explicate and cannot be easily stored in blueprints, reports, and memos. In order to retain this knowledge and re-use it in future projects, NPD managers have to be aware of the special role of people: they need to assign the people with the "right" experience to their teams, and possibly also involve experienced employees in more than one project at a time in order to enable the transfer of knowledge between ongoing and past projects [7]. Furthermore, they need to foster **knowledge sharing** between people who can contribute to NPD projects that they have not been officially assigned to. Communities of practice are an important means to do so [28].

When knowledge identification, knowledge retention, knowledge application and knowledge sharing are managed successfully, despite the above mentioned challenges (high importance of tacit knowledge, uncertain and changing knowledge needs; volatile knowledge sources; temporary character of projects; diverse knowledge backgrounds) they do not only improve the effectiveness and efficiency of NPD projects, but they help to build competitive advantages above and beyond the single project. These advantages can have long-lasting effects, because tacit knowledge in general and system knowledge in particular is not only difficult to detect and to transfer but consequently also difficult to imitate by competitors [18], [27].

Knowledge management issues therefore obviously matter in innovation management, as is reflected by small but growing number of contributions in literature: "An ability to understand and exploit the relationship between Knowledge Management and Innovation processes is of increasing significance in today's competitive business environments, where a dynamic capability to meet rapid change is an essential ingredient in achieving sustainable business success in volatile global and national marketplaces" [20].

### *B. State of the Art of Knowledge Mapping*

**Knowledge Maps** are one of many knowledge management solutions that could possibly "exploit the relationship between knowledge management and innovation processes" and provide an answer to the challenges of finding, retaining, sharing and applying knowledge that have been discussed above. As part of many intranet solutions or knowledge management systems, knowledge maps are becoming increasingly popular [e.g. 4].

However, with the exception of company whitepapers, brochures and websites, only a small body of KM literature intensively covers knowledge maps. Most authors merely mention them without discussing them in detail, focus on one type of knowledge map or describe cases of knowledge-mapping exercises without reflecting on their theoretical background or potential for generalization.

TABLE 1. TYPES OF KNOWLEDGE MAPS

| Publication | Types of Knowledge Maps mentioned or discussed |
|---|---|
| Haun: Wissensmanagement [16] | Association maps; Taxonomies; Causal maps; Argument Maps; Schema maps; Knowledge carrier maps; Knowledge asset maps; Knowledge flow maps; Knowledge structure Maps; Knowledge history maps;<br>as specialized knowledge maps furthermore: Yellow pages; Document maps; Knowledge landscapes |
| Wexler: Who, What and Why [44] | Competency Maps; Concept Maps; Strategy Maps; Causal Maps; Cognitive Maps |
| Eppler: Knowledge Maps [14] | Knowledge source maps; Knowledge asset maps; Knowledge structure maps; Knowledge application maps; Knowledge development maps<br>as a particular subgroups of knowledge maps furthermore: Cognitive maps and their subgroups (text and language analysis maps; classification maps; network maps; conclusive maps; schematic maps of cognitive structures) |

Even worse, some authors subsume all kinds of cognitive mapping approaches, IT structures and visualizations of knowledge under the term "knowledge map" with little consideration for the different theoretical basis, purpose, content and structure of these maps. This is reflected by Table 1 that shows the multitude of maps that are characterized as "knowledge map" in a selection of only three articles about the topic.

The growing interest in mapping can certainly be attributed to new technological possibilities, such as intranet technologies that make it relatively easy to integrate data from various sources and visualize them in "clickable" hypermedia formats. Mapping furthermore seems to correspond with the human tendency to use spatial concepts to understand time or other complex matters - it is not by coincidence, that in many business charts time is represented through different sized squares or arrows pointing in the future and that managers uses phrases like "to map out the future" or "to plan where we go from here".

As can be inferred from the multitude of different maps in Fig. 1, spatial visualizations come in all shapes and sizes. They range from relatively abstract charts to elaborate, highly visual metaphors such as landscapes with trees, rivers, ponds [14] or cities with blocks, private homes, and public buildings [34]. Maps are, among others, used to communicate strategies, such as technological goals or capabilities that are to be developed. Though naturally knowledge is the basis of these "strategy maps" or "knowledge development maps" [14], they clearly focus on disseminating strategic objectives.

Other types of maps–knowledge maps in the true sense of the word – target at improving knowledge processes on an operational level by improving access, use, generation and retention of knowledge. So far, there are only few systematic descriptions of knowledge maps, as well as their potential benefits and pitfalls. This paper attempts to close this gap by discussing two fundamentally different purposes of knowledge maps that can be summarized as "navigation" and "sensemaking" (see section II). Section III and IV present the objectives and practical application of knowledge maps for sensemaking (section III) and navigation (section IV) in general and in NPD processes and explain their implications for the respective other map function. Section V summarizes the results and concludes the paper.

## II. MAP FUNCTIONS: NAVIGATION AND SENSEMAKING

In several publication about mapping, the following anecdote can be found [42]:

> *"A small Hungarian detachment was on military maneuvers in the Alps. Their young lieutenant sent a reconnaissance unit out into the icy wilderness just as it began to snow. It snowed for two days, and the unit did not return. The lieutenant feared that he had dispatched his people to their death, but the third day the unit came back. Where had they been? How had they made their way back? Yes, they said, we considered ourselves lost and waited for the end, but then one of us found a map in his pocket. That calmed us down. We pitched camp, lasted out the snowstorm, and then with the help of the map we found our bearing. And here we are. The lieutenant took a good look at this map and discovered, to his astonishment, that it was a map of the Pyrenees."*

Though in some projects, NPD teams might feel like camping out in a storm, on first sight the anecdote bears little resemblance with the problems NPD teams encounter. It does, however, tell a lot about different functions of maps.

Geographical maps, like the map of the Pyrenees, help to **navigate in unknown territory**. They provide abstract models, leaving out some information and aggregating others. Because they adequately simplify reality, downsize it to the important aspects and add relevant information (e.g. about land ownership or planned streets), geographical maps are useful representations of a geographic setting. Geographical maps also are a good metaphor for **knowledge maps** as they are understood in present knowledge management literature. Knowledge maps help to navigate to sources of knowledge and information (e.g. people, databases) and structure the knowledge landscape by representing the elements and structural links of knowledge domains. Like geographical maps, they do not try to capture all aspects of knowledge, but simplify and focus on some aspects of it. This requires that someone – the cartographer – knows and understands the knowledge territory that is mapped and that in reality is much more complex than the map: as is the case with geographical maps, the knowledge map is not the territory but only a representation of it.

The Hungarian soldiers in the story use a (probably useful and adequately correct) representation of one territory – the Pyrenees – in another territory – the Alps. Usually one would expect this to end in disaster, but it does not in the case of the soldiers: they regain hope, build a camp and last through the storm. The story thus demonstrates a different function of maps: maps provide a reference point for action and get people moving. Weick summarizes the moral of the story "… if you're lost any old map will do" [42]. According to him, the important aspect about using maps is not so much the content of the map and its suitability for detailed navigation, but the way that this content is interpreted and continuously updated by the people who use the map. In doing so, the map users **make sense of their situation** and derive at an increasingly adequate mental model of reality. In order to be useful, mental models do not have to be correct – the soldiers in the story obviously started off with a very incorrect one – but need to continuously be adapted when new information on reality becomes available: "Just as a map of the Pyrenees gets people moving so they find their way out of the Alps, a map of the wrong competitor can get people talking so they find way into the right niche".

This view on knowledge maps is shared by researchers in the field of managerial cognition, who investigate the mental maps (also: cognitive maps) of decision-makers [1], [19]. Mental maps hereby contain the subjective knowledge that managers have and use, such as their knowledge on the general business environment, the future evolution of technologies or the probable moves of a competitor [19]. Managers naturally only know one reality – the reality that is represented in their mental models – and decide according to their understanding of "the real world". In that sense the mental (knowledge) map *is* the territory, even though it is only one possible representation of reality.

The two different views on knowledge maps – knowledge maps for navigation, that represent a knowledge territory and mental maps for sensemaking that are a knowledge territory – are rarely discussed separately in knowledge management literature, despite their different implications. The following chapters will therefore present both types of knowledge maps and then discuss their interdependencies.

## III. KNOWLEDGE MAPS FOR SENSEMAKING IN NPD

Sensemaking is the process by which individuals develop a mental representation of the reality that they encounter, such as the business environment they operate in or the NPD project they manage. They use their representations of the "real world" to understand information that they receive, to plan actions, and to predict future developments [42]. When new information becomes available (e.g. a competitor behaves in an unexpected way, a new technology evolves, customers express additional wishes.) this information can be (but is not always) used to confirm or to modify the existing construct of reality. Successful decision makers use adequate reality constructs, which are sometimes also referred to as cognitive maps or mental models, even though these terms have very different meanings in psychology.

In complex and dynamic systems, such as volatile business environments, decision-makers generally have difficulties to build adequate mental models, due to – among others - lacking, late or ambiguous feedback on their decisions and limited information processing capabilities. They furthermore often encounter difficulties to make maximum use of their existing mental models and e.g. wrongly forecast system changes, even though they are generally in line with their mental models – they do not fully use their subjective knowledge [12], [13], [36]

Researchers in psychology and managerial cognition have developed a variety of methods to research individual knowledge and how it is used in decision processes. They investigate what people know (knowledge contents), how their knowledge is organized in the human brain (knowledge structures, such as mental models) and how content and structure changes in the course of time. To elicit individual mental models, researchers often first collect all statements that hint at the person's knowledge content (e.g. by analyzing what he writes on note cards or what he says when thinking aloud or answering interview questions) and then elicit how this knowledge is structurally organized [30]. To do the latter, they check word frequencies and associations (How often are certain terms used? What terms are used together?), apply sorting techniques to learn how the research objects hierarchically organize knowledge and draw decision trees that show the line of argumentation used by the individuals whose knowledge is under investigation. In some research designs, individuals are furthermore asked to draw structural maps of a particular knowledge domain. The results of the many different knowledge mapping techniques are diverse and include frequency distributions, tree-structures, network diagrams and causal maps [19].

Fig. 1 shows a summary of knowledge mapping techniques that are used in the research of managerial cognition and are described by Huff [19]. Only some of these maps, namely the ones within the dotted line, usually come to mind when talking about knowledge maps. The other maps are much less visual and provide little or no spatial information.

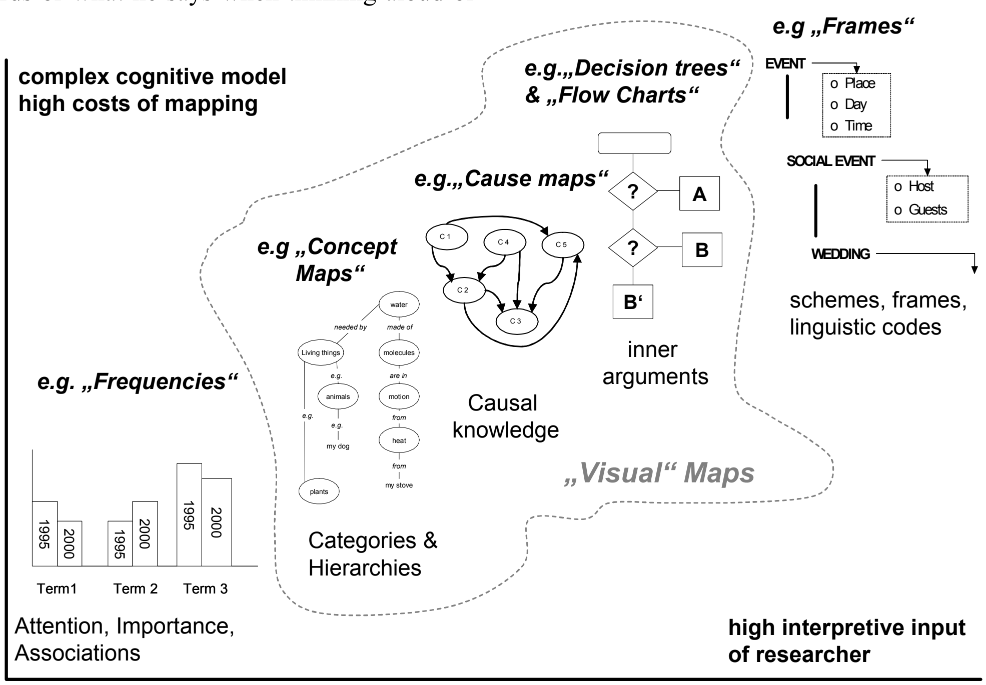


Fig. 1. Mapping in managerial cognition, as described by Huff [19].

Mapping techniques vary in purpose, underlying model of cognition, cost of mapping and need for interpretation. In general, mapping techniques that base on undemanding models of cognition and are easy to use and to interpret only have a very limited range. Counting word frequencies in manager interviews, press releases and annual reports (see left hand side of Fig. 1), e.g. can only capture a relatively small part of individual cognitive maps, though it shows important and evolving topics that have the managers' attention. Maps that show cognitive frames, schemes and linguistic codes give very broad views on managerial cognitive maps, they do, however, require a good deal of interpretation through the researcher and are therefore costly to produce and especially to prone misinterpretations [19]. Researchers, who attempt to capture the subjective knowledge of decision-makers, therefore need to carefully choose, which of the many elicitation techniques and visualizations that psychology provides they want to use.

The large "toolbox" of psychological research methods, certainly is an important (and presently underused) contribution to KM – since all of the methods described above elicit and represent subjective knowledge, they can be used to become aware of mental models and communicate about them. In that sense, all knowledge elicitation techniques in Fig. 1 support sensemaking.

Some, however, are regularly explicitly suggested to individuals that want to make better use of their individual knowledge, e.g. when preparing decisions or reviewing course work: (1) Maps that show **categories and hierarchies of concepts** and (2) Maps that focus on **causal relations between concepts**. Both types of maps will be exemplified through specific mapping techniques - concept and mind mapping and causal mapping - in the following sections.

*A. Concept and mind maps*

A lot of the knowledge in the human brain is acquired through language (as opposed to experience and observation), such as knowledge on historical facts, mathematical equations, or the function of the US congress. When language-based learning occurs, new knowledge is embedded into existing frameworks of knowledge that consist of so-called concepts and propositions between them. When we e.g. hear about a bird that we have never seen, we use our knowledge about the concept "bird" and its related concepts (legs, feathers, fly; beak, egg), as well as our understanding for propositions between concepts (birds have two legs; birds have feathers; most birds fly) to imagine the animal [2], [30].

The basic principle of concepts and propositions is the core of several psychological models of how the brain organizes knowledge, such as semantic nets or the notion of categorical knowledge. Often, these models are depicted as graphs, with nodes (often visualized as bubbles or squares) that represent the concepts and edges that stand for propositions. **Concept maps** provide one model for the hierarchical organization of knowledge: top-level concepts are abstract with few characteristics. Concepts on the levels below have detailed individual traits, as well as all the characteristic of the top-level concept. The propositions between concepts are described verbally and can represent any type of relation ("is part of", "influences", "can determine", "maybe disturbs", etc.) [29].

Concept maps have been extensively used in education to provide orientation about the structure of courses, textbooks and single lectures. Furthermore they are used to check the knowledge level of students by comparing the concept maps they draw (or that can be inferred from their statements) with a concept map that represents the teaching objectives [29].

Novak and Gowin describe concept maps as a way to facilitate learning by providing students with the means to externalize, question and improve their individual knowledge. Concept mapping therefore always requires the students to be accustomed to the multi-step method: In step 1, they jot down concepts of the knowledge domain that is to be mapped. As a starting point, they are sometimes provided with 6-8 key concepts on note cards. In step 2, they rank order the concepts, setting the most inclusive concepts on the top of the list and the most specialized one on the bottom. Based on this list, they build concept hierarchies in step 3, by linking the concepts through propositions ("linking words"). In the fourth and final step they search for cross links between concepts in different sections of the concept maps. When linking concepts, students often become aware of aspects of the knowledge domain that they have not thought off earlier. Additional learning can be achieved when students and teacher communicate about the students' maps and when students redraw them, based on the outcome of these discussions. Though it is the individual student that learns, this process can foster a collective understanding of a knowledge domain. Furthermore, it is possible to use concept mapping in team sessions and to jointly develop a concept map [29].

Concept mapping is theoretically convincing when one accepts the notion of learning as "fitting concepts into frameworks of categorical knowledge" and it seems to find some recognition in practice, as can be seen by the availability of concept mapping software packages, such as Decision Explorer ©, and Cmap Tools ©*.

A similar approach, though with a theoretical background that is slightly different from that of concept mapping, is mind mapping. Mindmaps, too, consist of concepts that are linked through propositions. They are, however, radially organized. The mapping process starts with a key topic in the center of a sheet of paper or a computer screen. More specific concepts are added to the map by drawing lines that branch from the central concept. These concepts are again expanded outward into branches and sub-branches. In the resulting mindmap the most specific aspects of the key concept are therefore at the edge of the map, the more general ones in its center [5]. As is the case with concept maps, mind maps can simply be built with paper and pencil, but software packages are available (e.g. Mindjet © or Mind Map ©)*

Concept and mind mapping are nonspecific approaches which are appropriate for knowledge domains that can be represented through language and are therefore applicable to large parts of NPD-relevant knowledge. They can e.g. be used to gain more clarity about the stakeholders of the design process, its objectives or a specific technical problem, either at the beginning of the NPD project or whenever new information makes a review of existing mental models advisable. The mapping process is hereby said to explicate knowledge that individuals and groups were not fully aware of before the mapping exercise and thus touches upon tacit knowledge. The visual nature of maps furthermore helps people to communicate about knowledge and can be helpful for people with different backgrounds when trying to develop a joint view on a particular knowledge domain.

Concept hierarchies are not all new to NPD, but are already being used to prioritize customer needs. Affinity diagrams [38], e.g., basically are concept maps with simple links. Concept mapping could enrich simple sorting techniques, as well as multivariate approaches [38] in order to obtain a more comprehensive understanding of customer needs. Such a combination of concept mapping, multidimensional scaling and cluster analysis has e.g. been described by Cousins and

MacDonald, who use the combined approach to learn about indicators of successful management training in product development projects [8].

Another concept map application in NPD has been suggested by Ramesh and Tiwana [32]. They use concept maps to model and store team knowledge in a software system for collaborative product development. The underlying idea of their approach is to surface knowledge on the development project (e.g. product functions, product attributes, prices, markets, technical requirements, components) and enrich it through contextual knowledge that often remains unexpressed in NPD projects, such as justifications of decisions, assumptions, and decision alternatives that have not been selected. Team members are therefore able to understand the interdependencies within the project, as well as underlying assumptions and prior decisions. The content of the collaborative knowledge base can be altered by authorized members of the development team and is updated whenever new information becomes available. Alterations do not lead to the deletion of prior content. Thus the system not only provides help in "making sense of the project" but also serves as a **knowledge history** map.

*B. Causal maps*

Causal mapping is characterized as a technique "for linking strategic thinking and acting, helping make sense of complex problems, and communicating to oneself and others what might be done about them" [3]. The outcomes of the mapping exercise, so called causal maps, are digraphs that consist of nodes ("concepts") and edges ("arrows") that represent causality.

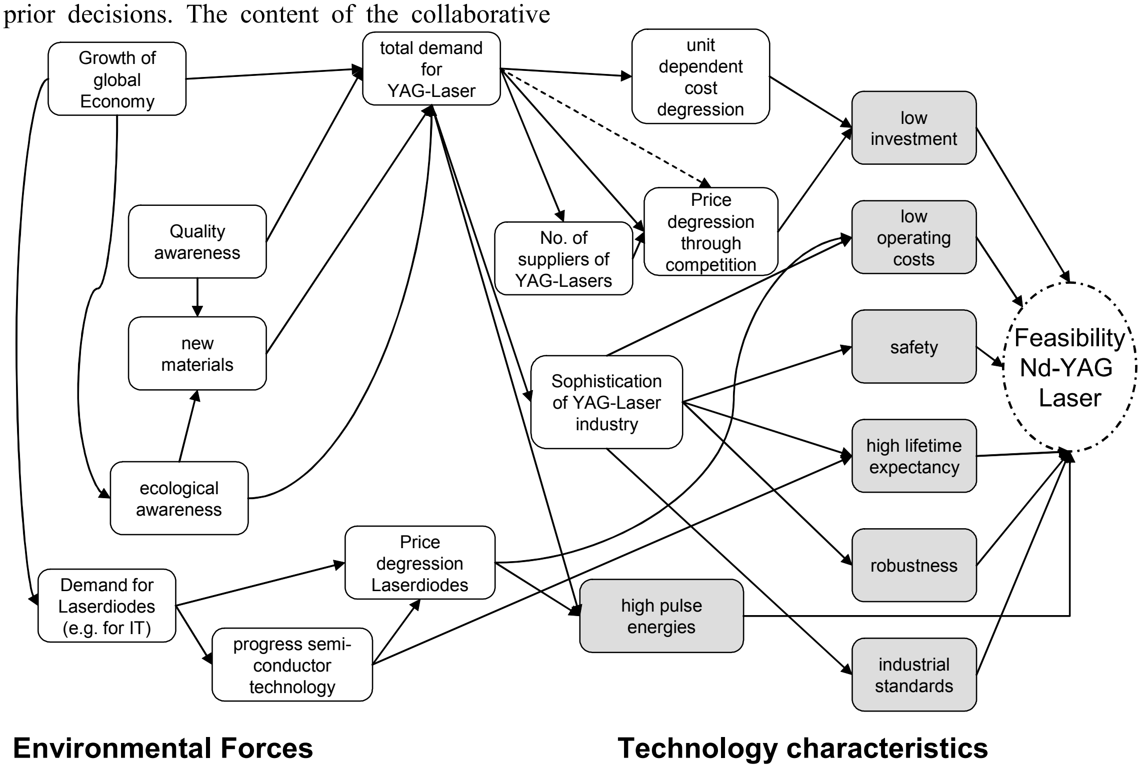


Fig. 2. Causal map of environmental forces and characteristics of a technology [23, p. 468].

Fig. 2 shows the positive and negative causal links (black and dotted lines) between environmental forces (white squares) and the desired characteristics (dark squares) of a specific technology (laser diode pumped Nd-YAG lasers). The example is taken from a case study and reflects the mental model of a technology manager [23]. It has been generated in order to investigate the possible future availability (or non-availability) and attractiveness of a particular product technology for a new product under development. One of the desired attributes of the new product technology is "high pulse energy". It is among others, causally influenced by the "total demand for YAG-Laser". When "laser demand" increases the concept "high pulse energies" increase as well. Furthermore, the concept "price reduction through competition" is causally decreased.

Causal maps are widely used to capture complex mental models of individuals [9], to provide a starting point for strategic business analysis [3] and to visualize systems for modeling and simulation design [37]. They are referred to with different names, such as cognitive maps [1], oval maps (for collectively generated causal maps [3]) influence diagrams, and patterns of interactions.

Causal maps are generated through individuals after they have been instructed in the mapping technique, through groups of experts in team sessions that are usually guided by a moderator or through researchers or knowledge engineers who infer knowledge maps from interview answers, thinking aloud protocols or written statements of the knowledge owner.

As is the case in concept mapping, the collection of knowledge content (the identification of key concepts, e.g. through brainstorming sessions) and the identification of knowledge structures (the actual drawing of the map with its links) are separate steps of the causal mapping process, because this reduces the cognitive demands on the map maker [30]. Other than the links in concept maps, arrows in causal maps only have one possible quality: they always reflect causality. In some cases, arrows are weighted to express the strength of causal relations [1]. Also, different types of causal relationships, such as conditional causality or curve-linear causality are sometimes expressed through symbols [1], [9].

Causal maps encode dynamic behavior ("something happens because and *after* something else has happened"), which is, however, not easily inferred from them: causal maps are complex and difficult to comprehend, especially when feedback loops occur or concepts are embedded in a long chain of causal links. Furthermore positive and negative incoming arrows (partially or totally) compensate each other and some concept changes can therefore not be determined [1]. A variety of approaches have been developed to analyze the structure and the underlying dynamics of causal maps, such as Vester's "paper computer". It represents a method to analyze the adjacency matrix of the causal map in order to identify concepts that actively influence other concepts (active variables), are mainly influence by other concepts (passive variables), are strong in both aspects (critical variables) or are neither very passive nor very active (buffer variables). Thus, variables with great leverage for system change or potential to stabilize the system are identified and can be considered in decision-making [23]. Axelrod furthermore suggests the use of graph theory to calculate the total effects of one concept on any other concept and discusses the necessary calculations [1].

An important extension of traditional causal mapping approaches are so-called "fuzzy cognitive maps" (FCMs). They apply principles and concepts of Fuzzy Set Theory and artificial intelligence to causal maps and thus make them computable, even though causal maps may contain concepts with different dimensions (e.g. in Fig. 2 "price of laser diodes in \$" and "pulse energies in J/cm²" ) and imprecise information on concepts and causality (e.g. A influences B "a little", "not so much", "to some extend") FCMs have first been introduced by Kosko [11], [25], [26] and have since been supplemented by a practice validated process model for Fuzzy Cognitive Mapping [23].

Using FCMs to make causal maps computable bears the potential to overcome one potential problem of causal mapping: though the approach is widely accepted as a possibility to improve the understanding of individuals, as well as collectives about a complex system [3], there is some indication that causal mapping does not impact decision making abilities severely. Apparently users find it difficult to interpret and use the dynamic properties of causal maps despite their visual nature. FCMs can be used to simulate the dynamic behavior of the knowledge domain that is represented by the causal map and can thus help decision-makers to get most out of their causal knowledge [23].

Causal mapping resembles concept or mind mapping with regard to the applicability (all knowledge domains that can be represented through language), use context (individuals, as well as groups) and purpose (elicitation, documentation and communication of knowledge structures for better sensemaking). Like concepts and mind maps, causal maps can therefore be applied in new product development, among others to better understand customer requirements (e.g. what are the casual influences on the customer's demand?) or to solve technical problems (e.g. what are the reasons for the component to fail?). A variety of similar applications are documented in literature: causal maps are regularly used in scenario analysis to identify environmental forces that influence the business (or NPD) environment [e.g. 40]. They are furthermore integral part of systems that computationally support product planning and development, such as the Bayesian net supported new product planning approach by Cooper [6], as well as an FCM-based action support system for the fuzzy front-end of product development, suggested by Jetter [22], [23], [35].The latter translates the mental models of NPD experts in the project development team into FCM models and thus makes them computable. The system models customer and technology requirements (including the environmental factors that impact them), as well as product components and their contribution to product quality, development time and development costs. Decision-makers can use the FCM system to simulate the effects of environmental changes, the results of decisions and the consequences of varying model assumptions. They can thus use their mental models to their full potential and improve them through an increased understanding of system dynamics.

### *C. The impact of sensemaking on navigation*

The knowledge mapping approaches that have been described in the last section and the systems that apply them, help individuals and groups to become aware of, think about and discuss their mental models. They thus provide an important means to support *successful* sensemaking.

Sensemaking can be understood as defining a territory – its key elements, boundaries, influencing factors, and structural and dynamical properties. This process is not only necessary to guide decisions but is also prerequisite for choosing the correct navigational (knowledge) map- you need to know your NPD project's objectives, success factors, risks, knowledge demands, resource limitations, etc. before you can point at knowledge that is relevant for it. To some extend, the situation is comparable to being lost in an unknown mountain site and having a world atlas at hand - you first need to check the territory before you can find the map that you want to navigate by. Sensemaking therefore lays the groundwork for all navigational knowledge maps.

Since mental models are moving territories, these foundations, however, are unsteady. The concept maps and causal maps that result from map supported sensemaking are therefore (at best) “snapshots” of mental models at one point in time and can be rendered wrong through continued sensemaking. When a new understanding of reality evolves, this can result in changed navigational needs and the necessity to modify navigational knowledge maps. Concept maps, mind maps and causal maps help in this process by explicating and documenting changes in mental models that could easily go unnoticed otherwise. They thus provide several types of input for navigational knowledge maps:

- They can be used at the start of navigational knowledge mapping to identify what knowledge domains, types of knowledge, knowledge sources and knowledge processes need to be represented in navigational maps.
- They can be regularly used to check if the navigational knowledge maps still point at knowledge that is considered valuable or if they possible represent outdated business models.
- They provide concrete input at least for some kinds of navigational knowledge maps, such as maps that use concept hierarchies as an organizing principle (see chapter V above).

## IV. KNOWLEDGE MAPS FOR NAVIGATION IN NPD

There is no simple, commonly accepted definition for knowledge maps that have the objective of navigation and the term is applied to very different graphical representation of knowledge from company yellow pages and flow graphs to semantic nets. Nevertheless, all definitions [4], [14] have a common denominator: they explain, that knowledge maps **do not contain the knowledge** of interest, **but point to where relevant knowledge can be found** in order to improve the efficiency and effectiveness of knowledge processes. Naturally, this requires the map to contain some form of meta-information on the location, accessibility and suitability of knowledge. In this article (navigational) knowledge maps are therefore defined as tools to visualize meta-information on tacit and explicit knowledge in order to improve the accessibility, use and retention of knowledge.

Partially following Eppler [14], knowledge maps can be differentiated according to their purpose:

- Knowledge source maps point the way to human experts and thus answer the question: Where is relevant knowledge?
- Knowledge structure maps outline the boundaries, elements and links of a knowledge domain and thus answer questions like: what are the key concepts, topics and necessary fields of expertise within one knowledge domain? How are they linked? How does the knowledge domain relate to others?
- Knowledge application maps show what knowledge has to be applied in a certain process stage or in a specific business situation. They answer the questions: How should knowledge be put to work? Where and when should it be used?

In order to be useful, navigational maps must meet several requirements that make knowledge mapping relatively costly:

- Knowledge maps must employ language of the map users (right vocabulary and symbols, adequate map metaphors) and have to be ergonomically designed, which requires expertise and high user involvement in the design phase [14, 44].
- Knowledge maps have to be kept up to date and have to be adjusted to changing business models or worldviews, as well as to changing knowledge resources. Especially the latter a highly dynamic: new knowledge resources are created, files are moved, changed and deleted, software applications are replaced, experts leave or join the organization, etc. Instead of (fully) relying on static links, many knowledge management solutions therefore create dynamic links between the navigational knowledge map and the resources it points to or create the knowledge map dynamically, based on the resources that are available. This is only possible, when meta-information on knowledge resources is available, such as the type of resource (report, micro-article, video clip, human expert), the topic or content of the resource (contains information on customer X; summarizes lessons learned of project Y), and its age. This meta-level information has to be organized in knowledge models in formats that can be used by a map making software applications that builds and updates navigational knowledge maps. Currently, system independent standards (e.g. XML Topic Maps) are evolving [31], [33].
- Knowledge maps are context sensitive: a map that is extremely useful for one group of users when accomplishing one particular task is totally useless for other users or other tasks. Maps are, however, only accepted, when they solve user problems. Some attempts are therefore made to offer users the right knowledge map automatically by considering their use context (e.g. the process step they are currently in) [e.g. 24].
- Knowledge maps, if successfully applied, represent important knowledge in a nutshell and therefore need to be protected from unintended use e.g. by competitors or head hunters [14].

A look at these requirements makes clear that knowledge mapping is resource demanding, especially when sophisticated solutions, such as user specific maps or maps with abilities for automated actualization, are implemented. The high efforts have to be carefully weighted against the benefits of knowledge map used, such as improved access and use of knowledge. This is all but simple: even though knowledge maps are said (among others) to yield high economic returns [44], there are no measures to validate this. The only available data are cases and best practice examples that usually do not quantify the benefits they postulate.

The benefits of navigational knowledge maps in the context of NPD projects are even more difficult to isolate and assess: it makes a huge difference, if knowledge maps are generated, maintained and used in a company-wide, synergistic knowledge management strategy and are therefore available to NPD managers in their every day work, or if they are created for the purpose of single projects that are only temporary organizations.

The following section will characterize the three different navigational knowledge maps introduced above and will discuss their potential benefits for NPD projects in different use situations.

*A. Knowledge source maps*

**Knowledge source maps**, sometimes also referred to as **Knowledge carrier maps**, can be interpreted as organizational charts that do not depict functions, responsibility and hierarchy, but expertise. They help NPD manager to identify experts in a specific knowledge domain so that they can find people for their team, as well as advisors for particular problems that cannot be solved within the team [14], [16].

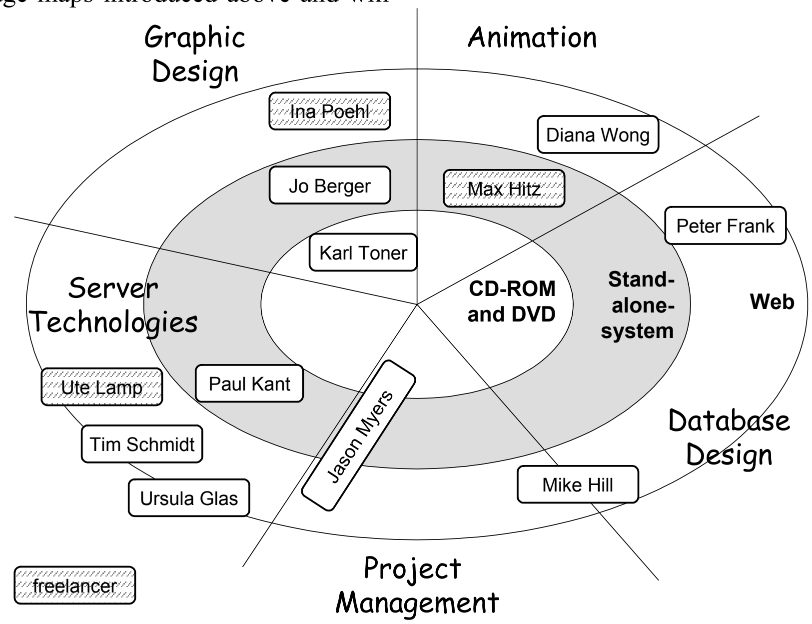


Fig. 3. Knowledge source maps - adapted from [14, p. 4; fig. 1].

Fig. 3 shows a simple knowledge source map for a multimedia company that offers and develops three different product groups (websites, stand-alone multimedia terminals and CD-ROMs/DVDs – see concentric circles). Relevant fields of expertise are depicted as sectors of the circles (graphic design, animation, database design, project management, server technologies). The names of the experts are placed according to their expertise: Jason Myers, e.g. is an expert in project management (regardless of the product), while Mike Hill has expertise in project management and database design for web applications. Additional information can be coded in the map, such as the fact that three people (Ute Lamp, Ina Poehl and Max Hitz) are freelancers.

Knowledge source maps can be extended through so called **Yellow or Blue Pages** that contain information on the individual internal experts (Yellow Pages) or external experts (Blue Pages), such as name, photo and contact data, position, fields and level of expertise (e.g. true expert, some experience, novice), membership in professional organizations, and personal interests [e.g. 10, 16].

When knowledge about the expertise of employees is available, it can naturally also be used to assess capabilities in given knowledge domains. E.g. in the map above, it becomes obvious that the company has no expert knowledge on database design for the domains of stand-alone multimedia terminals and CDs/DVDs. The same analysis can be made on a smaller scale, e.g. for project teams, by mapping the expertise of the team members or on a large scale by assessing the skill and expertise levels of all employees, including those that are not experts in any field. Results can be used to optimize the structure of project teams (e.g. no redundancies, all important knowledge domains covered) as well as to support human resource management in planning training programs and career paths and systematic knowledge retention. **Knowledge asset maps** support this assessment by visualizing individual levels of expertise [14].

In theory, knowledge source maps point at the location of explicit, as well as tacit knowledge and are therefore an important means to make system knowledge visible. In doing so, they can help to get the right people talk to each other and work together and thus provide an opportunity for improved knowledge use and sharing [10]. In practice, however, some problems have to be overcome. The assessment of individual expertise levels is all but easy: one possible approach that is sometimes mentioned in the context of Yellow Pages is to let the people in the map decide themselves in which areas they have expertise or interests and how they want to present themselves [e.g. 16]. Though this participative approach can be motivating to some employees and might solve privacy issues (everyone decides himself, what to publish) it has severe limitations: employees might not see the point in spending time and effort on filling and updating their page, they might feel uncomfortable to "brag about" their skills without being able to influence who reads their profiles, they might overestimated their knowledge because they want to "look good before the others", they might hide their expertise because they do not want to be the contact person "for all those rookies who don't know anything", they fear that lack of skills or knowledge redundancies become obvious and their job is at risk, etc. [for some of these concerns see 10]

The alternative to self-assessment – an "objective" outside evaluation –, however, is also problematic because knowledge is difficult to capture. Sometimes proxy attributes are therefore used (e.g. educational backgrounds, participation in training programs, present function, years of experience, numbers of projects involved etc.) that are – at best - an indicator for expertise but do not measure it. Other indicators are derived from the application of knowledge retrieval techniques that are used to analyze individual use patterns (uploaded documents, search terms, etc.): when, e.g., someone creates many files with JAVA code and regularly searches and downloads documents on the topic, it is assumed that he should have some expertise in this field. System knowledge can – to some extent – also be inferred form individual use behavior, e.g. by not only analyzing knowledge domains (e.g. JAVA programming, server technologies; procurement of machinery) but also contextual aspects (e.g. programming in projects that involved stand-alone-terminals; procurement of machinery from supplier X; procurement of machinery with turnkey contracts).

An alternative route to assess knowledge sources relies on the judgment of superiors and colleagues. Knowledge maps can e.g. be based on data that is collected from performances assessment in human resource management. Alternatively, data can be gathered by asking people to name e.g. five colleagues who they consider an expert in a specific domain [10]. Practitioners at IBM Sercon have supplemented this general approach through organizational network analysis [e.g. 41] in order to identify experts and communities of practice, but also islands of knowledge [43].

Knowledge source maps can make important tacit (system) knowledge available to NPD teams. They can be useful in the starting phase of NPD teams, when team members are not yet fully aware of their co-workers' expertise or in very large and dissipated teams, where team members cannot gain sufficient insight in their colleagues' capabilities. They might also proof useful for new team members, though they are not indispensable: when project teams consist of a strong core of people who know each others capabilities through prior cooperation, new team members can easily be guided to the right expert by colleagues and mentors. Knowledge source maps therefore seem more important to improve knowledge sharing *beyond* the single project by pointing at people at the rim of the project (e.g. researchers in basic RD, who are not directly involved in product development, legal advisors, outside experts in the market, etc.) or in different NPD projects. At the beginning of an NPD project, some knowledge needs are obvious and can easily be used to identify experts for the map (providing the problem of measuring expertise is solved!), while other knowledge needs only become obvious during the project. A project-specific knowledge source map will therefore most likely only contain experts that always comet to mind and are well-known anyway but will not be useful in the case of unplanned needs. In order to be effective, knowledge source maps therefore should be generated and maintained in a systematic knowledge management effort outside the temporary organization of an NPD project. To increase efficiency they should furthermore be linked to human resource management efforts.

### *B. Knowledge structure maps*

**Knowledge structure maps** provide access to knowledge resources (e.g. documents, software applications, contact data of experts) that cover a specific knowledge domain [141]. The most commonly known example of a knowledge structure map is the "table of content" of books: it represents a knowledge domain (the content of the book), subdivides it in elements (chapters), shows hierarchical relations between these elements (main chapter, subchapter) and points to the pages where knowledge content can be found. Similar hierarchical structures – so called taxonomies - are e.g. used to organize interfaces of websites (e.g. navigation trees) and cell phones. When used for navigation, the above mentioned concept and mind maps can also be considered knowledge structure maps. Knowledge structure maps, however, do not necessarily have to be organized through concepts and relations.

Fig. 4 shows a concept map for the 2001 NASA Mission to Mars that is used as the top-layer entrance page for a large set of hypertexted websites about the topic. By clicking on the concepts of the map, users can access resources on specific aspects of the Mars mission (e.g. lower level concept map, text documents, and pictures). It can thus convey structural knowledge even on complex matters, such as the immediate science goals of the mission (e.g. geologic history of Mars), its long-term contribution (will eventually lead to human missions), the domain specific knowledge it requires (understanding for life on earth, knowledge of astrobiology), its sub-missions (orbiters, landers, rovers), and its important issues and decisions (decisions for landing sites).

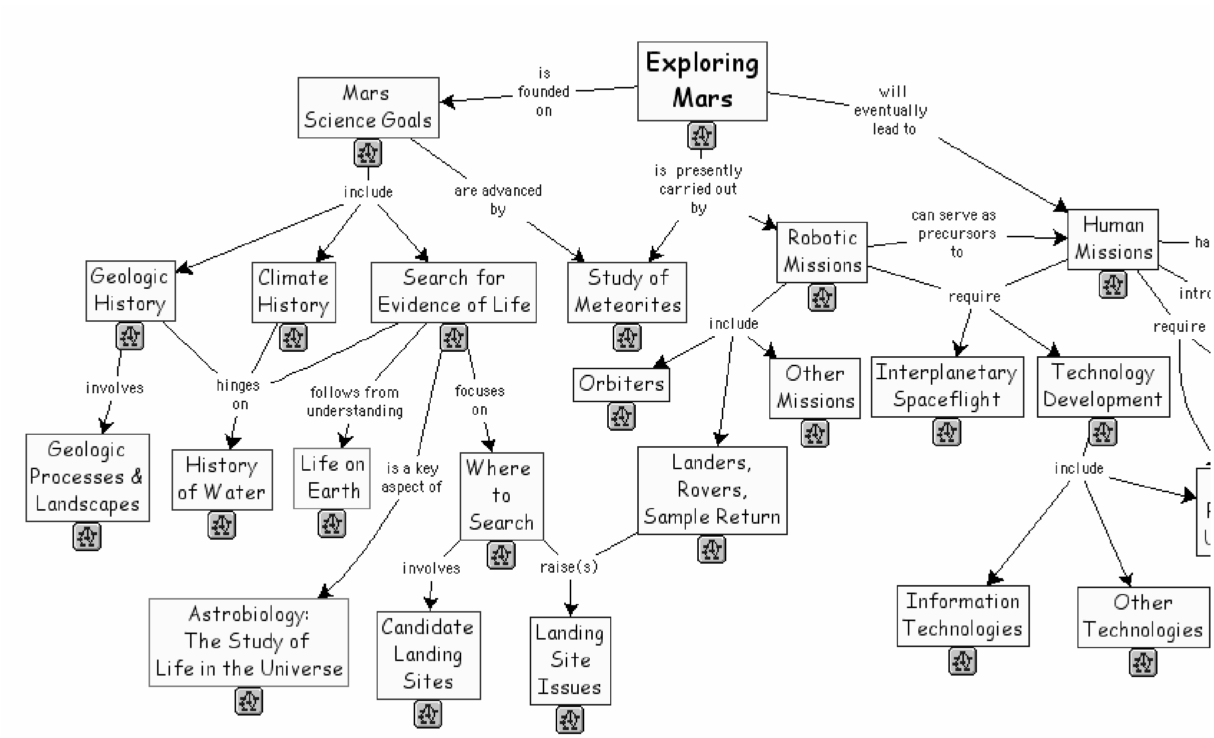


Fig. 4. Excerpt of a navigational concept map for the 2001 NASA Mission to Mars [retrieved from: http://cmex-www.arc.nasa.gov/CMEX/Map%20of%20Maps.html].

These topics must also be addressed by NPD projects and should be understood by all members of the project team, despite their different functional and educational background. A project-specific knowledge structure map, that is linked to project resources (e.g. people, handbooks, schedules, planning software, contracts, results of relevant prior product developments) can therefore be an important navigational tool that not only conveys navigational knowledge but also an understanding of the joint project tasks and their interdependencies. Simple project specific knowledge structure maps with static links to resources that are already available can be easily implemented with mind mapping and concept mapping software. The resulting maps provide a project-specific user interface with access to all resources that could also be accessed through other interfaces, such as browser software. They are, however, better at communicating how a particular knowledge resource is structurally embedded in the project and what function it serves.

In addition to project-specific knowledge structure maps, NPD projects can benefit from maps that represent knowledge domains that are relevant to many projects, such as aspects of a basic product technology or available market research tools and methods.

*C. Knowledge application maps*

Knowledge structure maps are not sequential– in Fig. 4 knowledge on landers can e.g. be found by people who started off with landing site issues, as well as by people who were interested in robotic missions. In contrast to that, knowledge application maps show the order in which knowledge resources should be used. They are basically representations of knowledge-intensive business processes that are supplemented by visualizations of the information and knowledge that is needed to master specific steps of the process [14].

Fig. 5 shows a process flow chart for a routine business process. To process steps ("assessment of credit worthiness" and "decision on credit conditions") are considered knowledge intensive and therefore supported by a knowledge application map. It shows sub-processes of the process step (e.g. find similar cases in case base; find expert; document the case history) and the knowledge resources needed for these steps (electronic case base, expert) [17].

The level of detail in which application maps model knowledge intensive processes and the underlying business processes varies greatly. In Fig. 5 the detailed knowledge sub-process "find expert" could e.g. be divided even further in process steps such as "define search context", "search yellow pages", "search documents of identified expert" and "assess their expertise" [17]. In contrast to that, Eppler presents the knowledge application map of a market research company that covers the firm's value chain in only four process steps (acquiring and generating data; summarizing, analyzing and interpreting data; administrating and storing data; presenting results to clients) all of which require the knowledge of specific methods (e.g. interview techniques and sample design to generate data; statistical analysis to interpret the generated data) that are documented in the knowledge map [14].

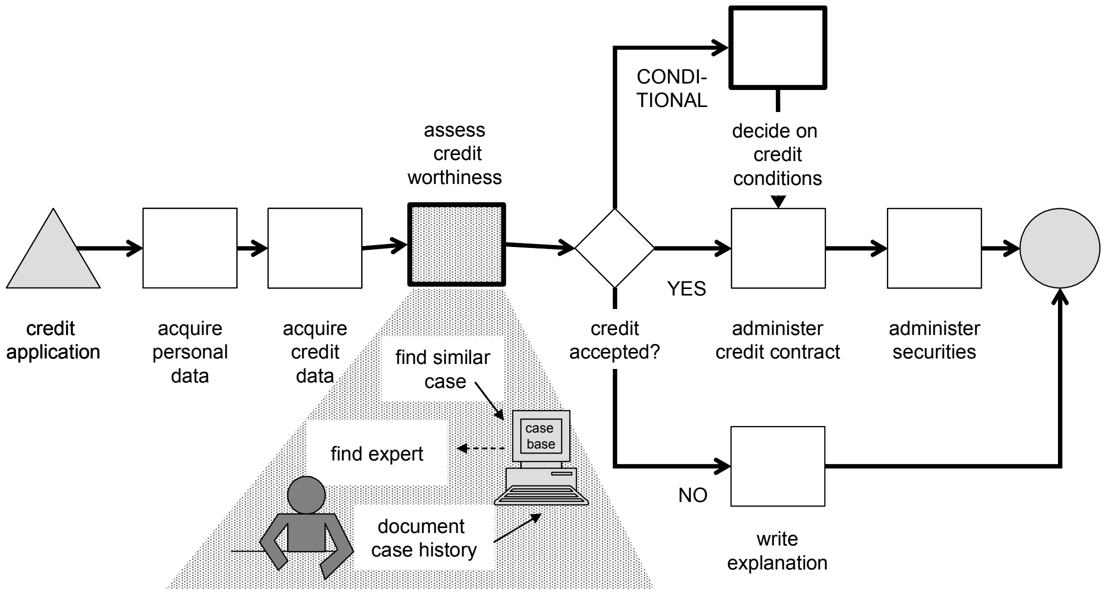

Fig. 5. Process flow and knowledge application map [adapted from 17].

The "correct" level of detail is naturally determined by the intended use of the knowledge application map. The map described by Eppler simply presents procedural knowledge and leaves it fully up to the user to decide, what process step he is currently in or which one of the offered methods he should use. In contrast to this pull approach, Kang et al. [24] and Hinkelmann et al. [17] suggest the use of knowledge (applications) maps in workflow management systems that control the execution of business processes, "push" knowledge resources towards users in accordance with their process needs and also guide the storage of results. Naturally for this type of application, knowledge maps have to give very fine grained descriptions of activities and knowledge resources. It is therefore doubtful, if ill-defined, non-routine processes, such as NPD projects, can efficiently be represented in similar systems [15], even though Kang et al. apply their concept to product development [24]. In most cases, however, knowledge application maps for NPD projects must certainly remain relatively rough sketches, which could be a serious limitation to future developments of workflow based NPD systems.

*D. The impact of navigation on sensemaking*

Navigational knowledge maps are man-made, cognitive artifacts that help members of the organization to perform [36]. They implicitly present mental models that are pertinent to the organization, such as the company's understanding of its knowledge domain, needed expertise, and value processes. However, they also influence the way in which people perceive and interpret reality and thus impact on mental models: When a knowledge source map presents experts and expert knowledge, it implies that it is the knowledge on the map that is relevant for the company and when a knowledge application map shows a process flow, it invites the assumption that all real-world variations of this process can be fit into this model. Artifacts thus create expectations.

The impact of expectations on perception has been extensively researched and has resulted in the statement "The eyes see only what the mind is prepared to comprehend." [quoted from 37]. To some extend, navigational knowledge maps prepare the mind in what to expect and can therefore inhibit people form "thinking out of the box". Sensemaking, the adaptation of mental representations to a changing reality might therefore not take place [36].

The expectations that are caused by navigational knowledge maps largely depend on their design. A broadly defined process that only offers, but does not prescribe the use of knowledge resources, e.g. certainly leaves more room for sensemaking than a detailed process application map. It might, however, be less efficient when it comes to re-use of knowledge. Map-makers need to keep this in mind during map making, e.g. by defining flexible processes during ideation, when innovation is mandatory and offering more detailed application maps in late NPD phases, when reuse of parts and documentation for knowledge retention are important.

## V. DISCUSSION AND CONCLUSION

This paper has analyzed the purpose and content of the large variety of knowledge maps that are currently presented in literature and has discussed them with regard to their applicability in NPD projects. The results can be summarized as follows:

Knowledge maps serve two different basic map functions - sensemaking and navigation – that are closely interrelated: Sensemaking defines the territory that navigation takes place in, while navigational maps influence the way in which sensemaking occurs. Both activities are supported by a distinct sets of maps and both need to taken into consideration during map making.

Sensemaking, as well as navigation, are particular pressing problems for NPD: Innovative products that create competitive advantage are only possible, when changes in the business environment are identified early and when mental models are continuously adapted to these changes. NPD success furthermore requires the combination of domain specific and (partially tacit and invisible) system knowledge from dissipated and volatile knowledge sources and thus involves highly demanding navigation tasks. Both types of knowledge maps are therefore important for NPD.

Maps for sensemaking have already been successfully applied in single NPD projects. Navigational knowledge maps that specifically consider NPD requirements, however, are still evolving. The generation and especially the continuous maintenance of these maps can be demanding, unless one relies on simple maps with small scope. More sophisticated maps are only efficient, when more than a few temporary projects benefit form it. Consequently, the generation and maintenance of navigational knowledge maps should be coordinated on the level of the entire company, rather than on the level of the single NPD project. With a capable knowledge management strategy in place, knowledge maps provide an important and promising means to solve the "knowledge issues" of NPD projects and can contribute to NPD success.

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[*] **Internet links to software tools**
To concept mapping software:
Cmap Tools © (http://cmap.ihmc.us/); Decision Explorer© (http://www.banxia.com/)
To mind mapping software:
Mindjet © (http.//www.mindjet.com); Mind Map© (http://www.mind-map.com)