FINAL?

The power of a question: A case study of two organizational knowledge capture systems

Lynne P. Cooper
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
lynne.p.cooper@jpl.nasa.gov

Abstract

Designers have many options for how to encode knowledge, although most are based on declarative representations. This paper explores the use of questions to represent knowledge. Practioner experiences implementing two knowledge resources using a question-based representation are described. In both resources, the use of "questions" was chosen as both a non-threatening way of engaging users and for its value in initiating thinking processes. Both systems have succeeded in capturing the interest of users and serve as valuable components of the organization's knowledge capture program. This paper describes the systems, the underlying design approach, and results from system evaluation. Since the goal of any knowledge resource is to facilitate the reuse of knowledge, it is important to understand the impact that different knowledge representations could have on system acceptance. This study raises several research issues based on experiences using the unusual representation of "questions" in knowledge resources.

1. Introduction

Knowledge transfer is the process through which knowledge acquired in one situation is applied to another [5]. Knowledge transfer can generally be subdivided into knowledge sharing (the process by which an entity's knowledge is captured [3]) and knowledge reuse (the process by which an entity is able to locate and use shared knowledge [1]). The goal of knowledge capture efforts is to codify knowledge and make it available for use by a larger community. There is, however, a significant difference between codifying knowledge and engaging personnel to actually make use of this knowledge.

The likelihood of knowledge being reused is affected by characteristics of the knowledge itself, and characteristics of the participants in a knowledge exchange such as the ability to absorb new knowledge [9], the use of broad search strategies [2,6], the source's willingness to share knowledge [22,29], and the closeness of the relationship between the source and recipient, [4,13,23].

In innovative contexts, knowledge reuse will involve adaptation as previous knowledge and capabilities are applied in novel and creative ways to new situations. Rice and Rogers [25] proposed the concept of "reinvention" to describe how practices are often changed as they are adopted and implemented. Clark [8] and Star and Griesemer [28] have suggested the importance of shared artifacts to facilitate knowledge sharing with tacit, ambiguous knowledge, such as that required to support innovation. Third parties who can convey the credibility of knowledge when the sources are unknown to users can also aid in reuse [21]. The ability of a company to generate new combinations of existing knowledge is referred to as combinative capabilities [19]. This capability has been posited to be a strategically significant resource to a competitive organization.

Building useful knowledge systems to support innovative work environments therefore requires careful attention to characteristics of the content, of the source of the content, and of the intended end user. Since the knowledge system acts as an intermediary between the original source and potential recipients, users may benefit from a representation that approximates the relationship that would exist during a more direct

transfer of knowledge. Questions are an intrinsic part of exchanges between sources and recipients, and therefore could serve as a useful representation for knowledge transfer. The following revelatory case study [32] describes two systems built upon the central representation of knowledge as questions.

2. Design Approach

The design approach for the systems discussed in this paper evolved pragmatically from the need to support the adaptive application of knowledge in the innovative context of an R&D organization. The goals were to build systems that would (a) ensure content quality, (b) support scanning as well as deeper access, and (c) engage the user. There was also a desire to minimize maintenance and knowledge acquisition efforts.

Content quality refers to having material that is credible, relevant to the target user, up-to-date, and accurate. The user needs to immediately recognize that the resource as a whole is valuable, and that it has a high probability of containing information applicable to his or her current knowledge needs.

Since the environment is one of innovation, it is reasonable to assume that any knowledge gained through the system will need to be adapted in some way to meet the context of the user. Therefore, the entry point must support rapid evaluation by the user for *potential* relevance, with deeper access to the information to determine *actual* relevance. Finally the presentation of the material needs to engage the user. From a user interface standpoint, this leads to a desire for simple, intuitive interactions, an attractive presentation, ease of access, and an organization of the content that appears natural.

From a content perspective, however, the actual representation of the information also serves as a form of engagement. There are multiple options for how to codify potentially reusable knowledge. Boose [7] identifies a variety of methods to represent expertise (e.g., cognitive maps, decision tables, rules, scripts) and different knowledge types (e.g., causal knowledge, terminology, constraints, example cases, procedures, relations, facts, uncertainties). Most representations use declarative methods, where the knowledge is presented as a statement or fact for the user (e.g., document management systems, experts directories, how-to manuals) or embedded as factual data in the system (e.g., decision support systems).

Taking a cue from classical Socratic method, questions are a natural form, particularly in a science and engineering organization, and especially appropriate when the goal is learning. The choice of questions as the knowledge representation was inspired by the initial framing of an organizational problem as "getting the right questions asked" as compared to "getting the right answers."

One highly visible use of questions in knowledge bases is the Frequently Asked Questions (FAQs) file. The use of FAQs evolved in USENET newsgroups where certain questions came up over and over. These questions and their answers were put into FAQ files where new participants could then look up answers without tying up network resources [16]. Although these systems do use questions as part of their representations, the questions serve more as a finding aid for the answer than a representation of the knowledge itself although the form of the question incorporates cues (e.g., "how do I…?" or "what is a…?") as to the nature of the information contained in the answer. As implied in the name, this information has been identified as relevant based on frequency of requests and is aimed at solving common or routine problems, rather than more innovative application.

The following sections describe two knowledge systems built at the Jet Propulsion Laboratory (JPL), a US national laboratory whose mission of planetary exploration is to "do what no one has done before." Work is inherently innovative and technologically challenging and there is increasing recognition that more-effective use of existing knowledge is critical to the success of future efforts. The sheer volume of knowledge that is potentially applicable to a given task is enormous, so getting the right information into the hands of the person who needs it depends on attracting attention and making it as easy as possible for that person to assess what is relevant.

Both the Technical Questions Database and JPL 101 knowledge resources are based on the concept of encoding knowledge in the form of questions. These systems, however, differ significantly in the type of knowledge they convey, the goals of the organization in creating them, and the way questions are employed. The use of "questions" is a non-threatening way of engaging users, and adds value by initiating thinking processes. The following sections

describe these knowledge resources, goals for organizational learning, and the results from system deployment. The paper concludes with a discussion on the use of questions for knowledge representation.

3. Technical Questions Database

The Technical Questions Database (TQDB) is a web-accessible database containing sets of questions in technical areas employed at JPL to build and operate space missions. The questions are of the type expected at a peer review, where a skilled person evaluates the user's design and development approach in domains such as thermal modeling, electronics design, materials properties, and deep space navigation. The knowledge consists of a set of questions in a given discipline, background information on why a given question is important, a point of contact, and the organization responsible for that discipline. There are currently over 700 questions in over 70 technical disciplines. Figure 1 provides an example of the type of question contained in the database.

Technical Discipline Area:
Mechanisms
Point of Contact: [Person's name]
Organization: [Section]
Subdomain: Lubricants
Question:
If you are using a dry-film lubricant, how do you handle the differences between air and vacuum?
Background:
Recall that graphite is an excellent lubricant in air, but becomes abrasive in vacuum.

Figure 1. Sample TQDB Entry

The knowledge delivery system consists of a web front-end to the database that stores the questions. It enables users to browse, sort, search, view, select, and publish a report of questions in the represented technical disciplines. Additional information on how to make the best use of the system, how to contribute questions, and related resources is also available.

The motivating factor for this work was the realization by executive management that there weren't sufficient domain experts to support all peer reviews, a critical part of the design process. As a result, problems that should have been caught at a peer level were being caught later in the development cycle when they were much more difficult to correct. While the database isn't a replacement for the involved presence of experts or skilled peers, it does serve to provide some of their insights to development teams.

The TQDB impacts design and review activities through the thought processes of the individual users. Users are encouraged to access the system during the course of their regular design activities to identify items they need to consider. In preparation for a review, the TQDB serves as an "open book test" for the types of questions the designers can expect from their reviewers. It is also intended to help reviewers prepare by reminding them of the types of questions that are appropriate. Both organization and individual points of contact are listed with the questions, providing the ability to link users with deeper sources of knowledge.

The critical first step is "thinking" about the subsystem or instrument under development to identify salient characteristics, while the final step is "thinking" about how the issues raised through the questions should be addressed. By design, the questions aren't a test with right or wrong answers, but "mind ticklers" to help developers. One of the most significant choices made in implementing the system was to *not* include answers. The context-uniqueness of the systems under development, rapidly changing technology, and an organizational culture recognizing the importance of individual judgment in innovation made answers a liability.

The TQDB is an example of a system that operates as an advisor. The functionality is relatively simple, but use of the system demands the attention of the user to evaluate applicability and relevance, and to think about if and how to answer the questions relative to his/her design. The system is modeled on the relationship of peers and experts that attend reviews, therefore, the system approximates their behavior by "asking questions." In this sense, the knowledge representation is user natural, since this is the way the contributors (knowledge sources) and users would interact. The organization of the questions is also natural, based on the functional organization of the Laboratory. Users gain valuable information from seeing which part of the organization contributed the questions.

The quality of the questions is ensured by having the functional organizations contribute and maintain questions in their areas. This also addresses the credibility issue, since the domain expertise in a given area is generally housed in

the functional part of the matrix organization. General relevance is assured because the questions are updated by those actively participating in the field. We have also maintained editorial control over the content to ensure that questions are truly technical in nature and representative of the discipline, so that all questions in the database are of potential value. Figure 2 presents the guidelines provided to contributors who generate the questions. Enforcing these guidelines ensures that the technical value of the resource doesn't become diluted by marginal questions.

- **Are they technical** (vs. administrative, programmatic, etc.)?
- **Are they specific to a technical discipline**, or are they general in nature?
- **Are they valuable at the peer review level**? For example, do they: Lead to insights for a better design/implementation; Prevent previously identified problems from occurring ; Improve understanding of the impact of design/implementation decision ; Identify other design/implementation options; Identify "gotcha's" or subtle design issues
- **Do they conform to the format of the database**? Is all pertinent information included? Is the question readable by someone not familiar with that discipline (e.g., explained all the acronyms)?
- **Are they duplicates of another questions**?
- **Does including this question provide enough value to justify increasing the size of the database.** Note: the larger the database, the more overwhelming it will be for people to use. We've set a goal of only including "excellent" questions in order to increase the value of the resource and make sure that users don't have to wade through a pile of mediocre information to get to valuable parts.

Figure 2. TQDB Content Guidelines

One design concern was how to help the user narrow down contents to those areas relevant to their specific problem, since the full spectrum of technical disciplines couldn't apply to all efforts. We've found that by arranging the questions into sets based on technical discipline area and functional organization, users find it easy to browse through a list of domains to roughly identify those that are pertinent. We've also made use of white space, boxed text, and headings to make it visually easier to scan the list, and have grouped related questions to reduce the number of "questions" to scan.

3.1. Results

The Technical Questions Database has been operational for several years and has just completed a 6 month evaluation summarized in Table 1. Through user feedback obtained through an on-line survey (based on Davis's perceived usefulness and usability [10]), direct contact with users, and monitoring of usage statistics, the system has received a positive evaluation from the targeted user communities, attained steady-state usage consistent with its intended purpose, received high marks as being both useful and usable, and has been integrated into training processes.

In addition to meeting the needs of individual designers and cognizant engineers, the TQDB has also been useful as a mechanism for group knowledge sharing activities (in creating and evaluating sets of questions), as a checklist for domain experts, as a resource for review board members, and as a mechanism for identifying potential review board members. Although developers have identified a number of potential system improvements, user response has clearly indicated that the basic functionality of the system meets their needs and that future efforts should go into expanding the content and increasing connectivity to related resources.

The evaluation activities answered the pragmatic question "is this resource useful enough to continue to support it?" While obviously not a robust, academic assessment, it does provide evidence from multiple users through a variety of sources that this is a valuable resource. The use of the "questions" format is regularly mentioned by respondents as contributing to their positive assessment.

The system has high perceived value because it meets the goal of helping to cover items that may otherwise be missed. The primary use of a browse (vs. search) paradigm requires users to identify categories that may be applicable to their domain, and then review individual questions in those areas. This approach enables users to find questions in their areas that they *weren't* looking for -- the purpose of the resource.

4. JPL 101

JPL 101 is a web-accessible database of general organizational knowledge, formulated as a question-and-answer quiz. The questions are

in the form of multiple choice, true/false, and matching. The answers identify the correct choice and provide references to resources, additional information, and links to other sites for both the right and wrong answers. The questions cover the gamut from pure trivia to items that every employee should know in the areas of: JPL History and Culture, Flight Projects and Missions, Science, Technology, JPL Organization and Structure, Stakeholders, and JPL General Information. Figure 3 provides a sample question-answer-links set.

Where is the Carl Sagan Memorial Station?

a) Ares Vallis, Mars
b) JPL mall wall
c) Aboard Voyager spacecraft
d) 65 N. Catalina Avenue, Pasadena

Correct Answer: a) Ares Vallis, Mars

The Pathfinder Lander was formally named the "Carl Sagan Memorial Station" following the successful touchdown in the Ares Vallis region on Mars - refer to this JPL Universe article (7/11/97) or the Mars Pathfinder Web site for more information.

Other answers are also associated with Carl Sagan:

- *The JPL mall wall, located northeast of the fountain in the JPL mall, was dedicated to Dr. Sagan.*
- *The Voyager spacecraft carries with it a gold disk containing greetings from the people of Earth that Dr. Sagan was instrumental in developing. To see and hear the content of the disk, visit the Voyager display in von Kármán Auditorium, or the Voyager Web site*
- *This is the address of The Planetary Society (TPS), which was co-founded by Dr. Sagan. Be sure to visit The Planetary Society's Web site to view their tribute to him.*

Figure 3. Sample JPL 101 Question

The content categories were carefully chosen to emphasize areas important to the Laboratory. History and Culture, obviously, addresses the history and culture of the Laboratory with the goal of aiding in socialization of newcomers. Missions and Flight Projects, such as Voyager, Galileo, and Mars Pathfinder are the reason the Laboratory exists, and knowledge of key missions is important, especially when representing the Laboratory to the public. The Science and Technology categories cover basic knowledge and how-to information on the core value-adding processes of the Laboratory: scientific investigation, technology research, and spacecraft development. JPL Organization and Structure looks at the internal structure, how work is organized, and the location and relationship of service and support functions. Since JPL is a National Laboratory operated for NASA by the California Institute of Technology, there is a wide spectrum of stakeholders who influence the operations of the Laboratory. Understanding the nature of these stakeholder relationships and the various legal, contractual, and public trust concerns of the Laboratory is important for efficient operation. Finally, JPL General Information covers the day-to-day business of getting work done.

JPL 101 was created to serve as an educational resource for Laboratory personnel, and to provide a way to assist them in exploring the abundance of electronic and other resources available to them. The name was chosen as a tongue-in-cheek reference to beginners classes in college to emphasize the educational nature of the resource, and to convey that much of the content is basic material that employees should know. The questions serve as an excuse to present additional knowledge in the answers. For example, a question about the identity of a raccoon that caused a power outage on the Laboratory is used as an entry point to warn employees about the dangers of indigenous fauna such as mountain lions and rattlesnakes.

The orienting question that guided the development of JPL 101 was "how do you help people to understand the 'big picture' given that direct work-related exposure may be minimal (or non-existent)?" The "quiz" metaphor was chosen because it seemed like a natural approach in an organization that values education as highly as JPL does. The information to be conveyed can be quite dry, so the use of colorfully phrased questions and the juxtaposition of unlikely objects were used to keep the quiz portion interesting. "Fun" was an explicit goal.

The content was developed by first identifying knowledge goals, then devising questions and right/wrong answers to support those goals. For example, a knowledge goal could be to create greater awareness of a new test facility, let after-hours personnel know about restaurants available for take-out, provide background information on why a new regulation was imposed, highlight an especially exciting technology, or acknowledge a well-executed mission event. Questions and answers are then formulated to provide the entry point for discussion of the knowledge goal material.

For their premiere, the questions are organized into quizzes containing 5 - 10 questions each from across the categories and at varying levels of difficulty. Since the user base

for this tool is all employees, across multiple disciplines, professional areas, levels of tenure, and organizations, it was important to make sure that there is something relevant to every individual user in each quiz. Also, the goal is not to "stump" users, so questions are kept at a reasonable level of difficulty and truly arcane information is not part of the question (though it can be incorporated into the answers).

In addition to the active quiz, past quiz questions and answers are available for access. While similar to a Frequently Asked Questions (FAQ) type resource, JPL 101 differs because these questions fall more into the infrequently asked domain. Also, unlike an FAQ where a question is created based on frequency of occurrence, the questions in JPL 101 are formulated because they contain information that people should know, but might not ask about.

4.1. Results

User response to pilot activities has been enthusiastic and positive across a broad range of the potential user population. There is significant interest in both accessing the information and contributing to it. Beta-testing was used to determine the size of the quiz, appropriate mix of questions, level of difficulty of questions, and span of the categories. Based on preliminary responses, a "submit a question" function was added to the user interface. The operational system is in the process of being deployed and is expected to reach 100's of users per day, and will be evaluated during a 12 week initial operating period (see Table 1).

Given the nature of this resource, a critical issue is validating the correctness of questions and answers. Beta-testing of content led to standards for structuring a "good" question and guidelines for a reasonable amount of material to include in the answer. The practical solutions of either triangulating an answer (two-sources to confirm) or verification through an unimpeachable source to ensure correctness have been adopted.

The level of acceptance of this resource has been surprising. With very few exceptions, the personnel who have been involved with the pilot version have been anxious to share the information with their colleagues, contribute questions and answers, and considered it both valuable and fun. Everyone, including people who have been with the organization for multiple decades, indicated that they learned something either through the questions or the supporting information given in the answers.

5. Discussion

The development and deployment of the two knowledge resources presented in this paper indicate that questions can be a valuable way to encode knowledge. Based on practioner experience, they also indicate several potential areas for further research:

5.1 Under what conditions are questions a valuable way to encode knowledge?

We had explored declarative representations of knowledge and found that either approach could be used to capture equivalent information. The main difference appeared to be the psychological effects of using questions. First, they mimic the natural way the information would be conveyed if an information system wasn't mediating the exchange (particularly for the TQDB). Second, questions provide a cue in conversational discourse that indicates that a subject is open to discussion or interpretation, while flat declarative statements convey a sense of finality. Finally, in an environment where adaptation or contextualization of the knowledge is essential for it to be useful, the question serves as a starting point for the thinking process. As one reviewer questioned, would context specificity make questions more or less useful as a form of knowledge representation?

The major structural difference between TQDB and JPL 101 is in the use of *answers*. For JPL 101, the knowledge is encoded in both the questions (at the scanning level) and the answers (at deeper levels). This is possible because the nature of the knowledge is not context dependent and is relatively static. Therefore, it was possible to incorporate the declarative knowledge without incurring a significant maintenance overhead. The opposite is true for TQDB, where relevance is highly context-dependent and could change fairly rapidly as technology changes.

5.2. How does knowledge representation impact the ease and effectiveness of knowledge solicitation?

As compared to previous knowledge capture activities at JPL, asking for questions was much more productive than asking for knowledge.

Whether the proposed form was rules of thumbs, if-then-else statements, facts, or procedural knowledge, the sources tend to put a lot of effort into making sure their statements were correct, precise, and addressed all possible combinations of events. Sources appeared much more comfortable creating questions, and were willing to accept a "good enough" formulation of the question. The process was relatively fast and required significantly less hand-holding than previous attempts at populating knowledge bases. As a point of reference, the initial population of the TQDB, which provided roughly half of the current content, took approximately 3 calendar weeks and was accomplished via an email solicitation from upper management. While not all knowledge translates well into a question format, for those cases where it does, this could serve as a useful method for eliciting knowledge.

5.3. What is the value of spanning multiple disciplines in a single resource?

Both TQDB and JPL 101 provide content that crosses functional and organizational boundaries. Even at relatively higher levels of abstraction (e.g., the listing of the technical discipline area, independent of specific questions), the juxtaposition of information from such varied sources increases the awareness that these areas exist (akin to Roger's [26] "awareness knowledge"). More detailed content, while not sufficient to educate a person in a particular domain, does serve to educate a person about that domain. The questions in the TQDB provide basic information about what types of activities occur in a particular domain, the types of things that are of special interest, and what are the areas where things could go wrong. This type of information can help in bridging thought worlds [11] by increasing the sensitivity of members from one functional area to the concerns of another area. In turn this leads to reduced conflict and improved performance in cross-functional teams [12,24].

5.4. To what extent can knowledge representation and system functionality be traded off in system design?

The implementation of both TQDB and JPL 101 are relatively simple, with a minimal amount of user functions. Although as developers we can identify a significant number of changes that would improve functionality, user feedback has indicated that more "bells & whistles" aren't needed, nor are they wanted. A minimalist approach has a significant effect on maintenance costs, and user training and support. This suggests that there may be a system trade between the representation of the knowledge and the complexity of the delivery system.

This does not, however, reduce the value of an aesthetically pleasing interface. Practitioners in usability engineering are moving toward concepts such as "joy of use" [14] and hedonic quality [17] to describe the need for systems to meet the affective needs of the users. A system that is fun -- or at least not annoying -- contributes to the overall value to the user. Additionally researchers have called for information system designers to strive for user delight rather than simply satisfaction [15] and user seduction [20] when users may not be initially inclined to believe that a system may be of value.

5.5 What are the organizational communication implications of knowledge representations and resources?

The types of questions that are asked are indicative of what's important to an organization. In JPL 101, for example, the inclusion of questions on stakeholder relationships indicates that at an organizational level, these relationships are important to the operation of the Laboratory and that the average employee should know something about them. The inclusion of a question that leads to a list of local restaurants that are open after normal work hours sends a message to employees acknowledging that the institution is aware of and appreciates the times people need to put in extra effort. Similarly, the inclusion of questions on a given technical discipline area in TQDB acknowledges that the specific discipline contributes to the overall mission and concerns in that area should be addressed. While we're not advocating using either of these tools for propaganda purposes, the investment in the content sends a clear message that the organization perceives a given area to be valuable. An open research issue is how the use of questions (e.g., as a knowledge representation, a strategy, or a form of message) impacts organizational communications processes (e.g., [30]).

5.6 How do knowledge resources contribute to organizational discussions and social exchange?

User and test groups for both JPL 101 and TQDB indicated that these resources would be useful in a group setting. One functional organization described how they projected the TQDB website at a staff meeting and systematically went through the areas related to their domain to identify relationships, gaps in content, and items that were regarded as important across the different groups in their organizations. Beta testers for JPL 101 wanted to use the content as a part of a team building exercise and starting point for discussion. The Human Resources department intends to incorporate it into their orientation program, and executive management is considering using the content for a Lab-wide contest in support of JPL's anniversary celebration. Given the benefits of discussion in learning processes (e.g., [18,27,31]), the potential for knowledge resources to support group interaction is an important consideration in implementation.

6. Conclusion

The choice of knowledge representation is a key component in the overall design of any knowledge resource. While design trades often consider the architectural implications of these decisions (e.g., inference engine interface, database schema), this paper argues that the representation choice also impacts system usability and usefulness. Two case studies were used to illustrate how the unusual choice of questions as the knowledge representation affected the implementation and use of these resources. While the use of questions may not be appropriate in all circumstances, there were benefits in the form of user engagement, easier knowledge solicitation, reduced maintenance effort, and the adaptability of the knowledge for the systems discussed here.

Since the end goal of knowledge capture is the successful reuse of the codified knowledge, developers need to consider content representations that engage the users and support group interaction. The practical experiences gained in implementing these systems lead to a number of questions that have both research and practical implications. Answering these questions could lead to improvements in the implementation, and use of organizational knowledge resources.

7. Acknowledgements

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Special thanks to: members of the Knowledge Capture Team, Teresa Bailey, Rebecca Nash, and Tu-Anh Phan; the Knowledge Management Program, Roger Lee, Edward Ng, and Jeanne Holm; Thomas Gavin, Associate Director, Flight Projects and Mission Success; and the anonymous reviewers.

8. References

[1] Alavi, M. and Leidner, D. E., Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues *MIS Quarterly*, vol. 25, pp. 105-136, 2001.

[2] Allen, T.J., *Managing the flow of technology: Technology transfer and the dissemination of technological information within the R&D organization*, Cambridge, MA: MIT Press, 1977.

[3] Appleyard, M. M., How does knowledge flow? Interfirm patterns in the semiconductor industry *Strategic Management Journal*, vol. 17, pp. 137-154, 1996.

[4] Argote, L. *Organizational Learning: Creating, Retaining, and Transferring Knowledge*, Norwell, MA: Kluwer, 1999.

[5] Argote, L. and Ingram, P., Knowledge transfer: A basis for competitive advantage in firms *Organizational Behavior and Human Decision Processes*, vol. 82, pp. 150-169, 2000.

[6] Armbrecht, F. M. R., Chapas, R. B., Chappelow, C. C., Farris, G. F., Friga, P. N., Hartz, C. A., McIlvaine, M. E., Postle, S. R., and Whitwell, G. E., Knowledge management in research and development *Research-Technology Management*, vol. 44, pp. 28-48, 2001.

[7] Boose, J. H., A survey of knowledge acquisition techniques and tools *Knowledge Acquisition* , vol. 1, pp. 3-37, 1989.

[8] Clark, H. *Using Language*, Cambridge: Cambridge University Press, 1996.

[9] Cohen, W. M. and Levinthal, D. A., Absorptive capacity: A new perspective on learning and

innovation *Administrative Science Quarterly*, vol. 35, pp. 128-152, 1990.

[10] Davis, F. D., Perceived usefulness, ease of use, and user acceptance of IT *MISQ*, vol. pp. 319-340, 1989.

[11] Dougherty D., Interpretative barriers to successful product innovation in large firms. *Organization Science*, vol. 3, pp. 179-202, 1992.

[12] Dyer, B. and Song, X. M., Innovation strategy and sanctioned conflict: A new edge in innovation? *Journal of Product Innovation Management*, vol. 15, pp. 505-519, 1998.

[13] Dyer, J. H. and Noveoka, K., Creating and managing a high-performing knowledge-sharing network *Strategic Management Journal*, vol. 21, pp. 345-367, 2000.

[14] Glass, R. The looking glass. On#Sun.com Magazine (October), 6. 97. Sun Microsystems.

[15] Grudin, J., Interactive systems: Bridging the gaps between developers and users *IEEE Computer*, vol. 24, pp. 59-69, 1991.

[16] Hammond, K., Burke, R., Martin, C., and Lytinen, S., "FAQ Finder: A case-based approach to knowledge navigation," *Proceedings of the 11th Conference on Artificial Intelligence for Applications,* Los Angeles, CA, pp. 80-86, 1995.

[17] Hassenzahl, M., Beu, A., and Burmester, M., Engineering Joy *IEEE Software*, vol. pp. 70-76, 2001.

[18] Kim, P. H., When What You Know Can Hurt You: a Study of Experiential Effects on Group Discussion and Performance *Organizational Behavior and Human Decision Processes*, vol. 69, pp. 165-177, Feb, 1997.

[19] Kogut, B. and Zander, U., Knowledge of the firm, combinative capabilities, and the replication of technology *Organization Science*, vol. 3, pp. 383-397, 1992.

[20] Markus, M. L., Majchrzak, A., and Gasser, L. A design theory for systems that support emergent knowledge processes. In: *Redefining the Organizational Roles of Information Technology*, eds. Segars, A., Sampler, J., and Zmud, R. University of Minnesota Press, 2001.

[21] Moreland, R. L. and Myaskovsky, L., Exploring the performance benefits of group training: Transactive memory of improved communication? *Organizational Behavior and Human Decision Processes*, vol. 82, pp. 117-133, 2000.

[22] Nahapiet, J. and Ghoshal, S., Social capital, intellectual capital, and the organizational advantage *Academy of Management Review*, vol. 23, pp. 242-266, 1988.

[23] Nonaka, I., A dynamic theory of organizational knowledge creation *Organization Science*, vol. 5, pp. 14-37, 1994.

[24] Pelled, L. H., Demographic diversity, conflict, and work group outcomes: an intervening process theory *Organization Science*, vol. 7, pp. 615-631, Nov, 1996-Dec 31, 1996.

[25] Rice, R. E. and Rogers, E., Reinvention in the innovation process *Knowledge, Creation, Diffusion, Utilization*, vol. 1, pp. 499-514, 1980.

[26] Rogers, E. *Diffusion of Innovations*, New York: The Free Press, 1983.

[27] Sniezek, J. A., Groups under uncertainty: An examination of confidence in group decision making *Organizational Behavior and Human Decision Processes*, vol. 52, pp. 124-155, 1992.

[28] Star, S. L. and Griesemer, J. R., Institutional ecology, 'translations', and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907-39 *Social Studies of Science*, vol. 19, pp. 387-420, 1989.

[29] Szulanski, G., The process of knowledge transfer: A diachronic analysis of stickiness *Organizational Behavior and Human Decision Processes*, vol. 82, pp. 9-27, 2000.

[30] Te'eni, D., Review: A cognitive-affective model of organizational communication for designing IT *MIS Quarterly*, vol. 25, pp. 251-312, 2001.

[31] Tjosvold, D. Cooperation theory, constructive controversy, and effectiveness: Learning from crisis. In: *Team effectiveness and decision making in organizations*, eds. Guzzo, R. A., Salas, E., and Associates. San Francisco: Jossey-Bass, 1995.pp. 79-112.

[32] Yin, R. K. *Case Study Research: Design and Methods*, Newbury Park: Sage, 1994.

Table 1. Evaluation Summary for TQDB and JPL 101

	TQDB	JPL 101
Target users	JPL technical personnel working in disciplines relating to space systems	JPL personnel across all categories
Relevance Window	Primarly during preparation for system and subsystem design reviews. More generally throughout the design process	Ongoing
Status	Operational for 3 years	About to go operational

TQDB Evaluation			
Evaluation Method	Description	Indication	Other
Usage statistics (Users)	Obtained from server logs. Average 20-30 users/month, consistent with target users and relevance window	Positive for usefulness for target users.	Interpreted as a need to publicize rather than change the system
On-Line Survey (Users)	Accessible from TQDB website, based on Davis [10]to measure perceived usefulness and usability. Very low response rate (<10%)	Positive for both usefulness and usability	
Email-based feedback form (Users)	Available from TQDB website. Open ended comments with low (10-20%) number of users	Strong positive feedback on usability and usefulness. Requests to increase content to cover additional domains	Many respondents indicated they "didn't have time to take the survey – so they sent the email instead"
Executive Advocacy (Management)	Executive level support in obtaining maintenance funding and reaffirming importance of contributing content	Positive indication of overall perceived value	
External Requests (future users)	Requests from NASA employees external to JPL for access to content	Positive indication of perceived usefulness	
JPL 101 Evaluation			
Beta-Test	20 subjects taking paper version of quiz. Used to evaluate characteristics of the questions and obtain feedback on length of quiz, mix of questions, potential value of resource	Feedback on design of content incorporated into operational system. Generally positive feedback on concept, with some negative	
Informal user sessions	Informal meetings held with groups of 2-5 people to get feedback on overall concept and perceived value	Extremely enthusiastic response indicating high perceived value and multiple offers of advocacy	Routinely received offer to submit questions (content) for future versions
Usage statistics and quiz results	Data not yet available	Will be collected during 12 week initial operations period	
On-line survey			
Email Feedback			
Voluntary contribution of questions			

The power of a question: A case study of two organizational knowledge capture systems

Lynne P. Cooper
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109
lynne.p.cooper@jpl.nasa.gov

Abstract

Designers have many options for how to encode knowledge, although most are based on declarative representations. This paper explores the use of questions to represent knowledge. Practioner experiences implementing two knowledge resources using a question-based representation are described. In both resources, the use of "questions" was chosen as both a non-threatening way of engaging users and for its value in initiating thinking processes. Both systems have succeeded in capturing the interest of users and serve as valuable components of the organization's knowledge capture program. This paper describes the systems, the underlying design approach, and results from system evaluation. Since the goal of any knowledge resource is to facilitate the reuse of knowledge, it is important to understand the impact that different knowledge representations could have on system acceptance. This study raises several research issues based on experiences using the unusual representation of "questions" in knowledge resources.

1. Introduction

Knowledge transfer is the process through which knowledge acquired in one situation is applied to another [5]. Knowledge transfer can generally be subdivided into knowledge sharing (the process by which an entity's knowledge is captured [3]) and knowledge reuse (the process by which an entity is able to locate and use shared knowledge [1]). The goal of knowledge capture efforts is to codify knowledge and make it available for use by a larger community. There is, however, a significant difference between codifying knowledge and engaging personnel to actually make use of this knowledge.

The likelihood of knowledge being reused is affected by characteristics of the knowledge itself, and characteristics of the participants in a knowledge exchange such as the ability to absorb new knowledge [9], the use of broad search strategies [2,6], the source's willingness to share knowledge [22,29], and the closeness of the relationship between the source and recipient, [4,13,23].

In innovative contexts, knowledge reuse will involve adaptation as previous knowledge and capabilities are applied in novel and creative ways to new situations. Rice and Rogers [25] proposed the concept of "reinvention" to describe how practices are often changed as they are adopted and implemented. Clark [8] and Star and Griesemer [28] have suggested the importance of shared artifacts to facilitate knowledge sharing with tacit, ambiguous knowledge, such as that required to support innovation. Third parties who can convey the credibility of knowledge when the sources are unknown to users can also aid in reuse [21]. The ability of a company to generate new combinations of existing knowledge is referred to as combinative capabilities [19]. This capability has been posited to be a strategically significant resource to a competitive organization.

Building useful knowledge systems to support innovative work environments therefore requires careful attention to characteristics of the content, of the source of the content, and of the intended end user. Since the knowledge system acts as an intermediary between the original source and potential recipients, users may benefit from a representation that approximates the relationship that would exist during a more direct

transfer of knowledge. Questions are an intrinsic part of exchanges between sources and recipients, and therefore could serve as a useful representation for knowledge transfer. The following revelatory case study [32] describes two systems built upon the central representation of knowledge as questions.

2. Design Approach

The design approach for the systems discussed in this paper evolved pragmatically from the need to support the adaptive application of knowledge in the innovative context of an R&D organization. The goals were to build systems that would (a) ensure content quality, (b) support scanning as well as deeper access, and (c) engage the user. There was also a desire to minimize maintenance and knowledge acquisition efforts.

Content quality refers to having material that is credible, relevant to the target user, up-to-date, and accurate. The user needs to immediately recognize that the resource as a whole is valuable, and that it has a high probability of containing information applicable to his or her current knowledge needs.

Since the environment is one of innovation, it is reasonable to assume that any knowledge gained through the system will need to be adapted in some way to meet the context of the user. Therefore, the entry point must support rapid evaluation by the user for *potential* relevance, with deeper access to the information to determine *actual* relevance. Finally the presentation of the material needs to engage the user. From a user interface standpoint, this leads to a desire for simple, intuitive interactions, an attractive presentation, ease of access, and an organization of the content that appears natural.

From a content perspective, however, the actual representation of the information also serves as a form of engagement. There are multiple options for how to codify potentially reusable knowledge. Boose [7] identifies a variety of methods to represent expertise (e.g., cognitive maps, decision tables, rules, scripts) and different knowledge types (e.g., causal knowledge, terminology, constraints, example cases, procedures, relations, facts, uncertainties). Most representations use declarative methods, where the knowledge is presented as a statement or fact for the user (e.g., document management systems, experts directories, how-to manuals) or embedded as factual data in the system (e.g., decision support systems).

Taking a cue from classical Socratic method, questions are a natural form, particularly in a science and engineering organization, and especially appropriate when the goal is learning. The choice of questions as the knowledge representation was inspired by the initial framing of an organizational problem as "getting the right questions asked" as compared to "getting the right answers."

One highly visible use of questions in knowledge bases is the Frequently Asked Questions (FAQs) file. The use of FAQs evolved in USENET newsgroups where certain questions came up over and over. These questions and their answers were put into FAQ files where new participants could then look up answers without tying up network resources [16]. Although these systems do use questions as part of their representations, the questions serve more as a finding aid for the answer than a representation of the knowledge itself although the form of the question incorporates cues (e.g., "how do I...?" or "what is a...?") as to the nature of the information contained in the answer. As implied in the name, this information has been identified as relevant based on frequency of requests and is aimed at solving common or routine problems, rather than more innovative application.

The following sections describe two knowledge systems built at the Jet Propulsion Laboratory (JPL), a US national laboratory whose mission of planetary exploration is to "do what no one has done before." Work is inherently innovative and technologically challenging and there is increasing recognition that more-effective use of existing knowledge is critical to the success of future efforts. The sheer volume of knowledge that is potentially applicable to a given task is enormous, so getting the right information into the hands of the person who needs it depends on attracting attention and making it as easy as possible for that person to assess what is relevant.

Both the Technical Questions Database and JPL 101 knowledge resources are based on the concept of encoding knowledge in the form of questions. These systems, however, differ significantly in the type of knowledge they convey, the goals of the organization in creating them, and the way questions are employed. The use of "questions" is a non-threatening way of engaging users, and adds value by initiating thinking processes. The following sections

describe these knowledge resources, goals for organizational learning, and the results from system deployment. The paper concludes with a discussion on the use of questions for knowledge representation.

3. Technical Questions Database

The Technical Questions Database (TQDB) is a web-accessible database containing sets of questions in technical areas employed at JPL to build and operate space missions. The questions are of the type expected at a peer review, where a skilled person evaluates the user's design and development approach in domains such as thermal modeling, electronics design, materials properties, and deep space navigation. The knowledge consists of a set of questions in a given discipline, background information on why a given question is important, a point of contact, and the organization responsible for that discipline. There are currently over 700 questions in over 70 technical disciplines. Figure 1 provides an example of the type of question contained in the database.

Technical Discipline Area:
Mechanisms
Point of Contact: [Person's name]
Organization: [Section]
Subdomain: Lubricants
Question:
If you are using a dry-film lubricant, how do you handle the differences between air and vacuum?
Background:
Recall that graphite is an excellent lubricant in air, but becomes abrasive in vacuum.

Figure 1. Sample TQDB Entry

The knowledge delivery system consists of a web front-end to the database that stores the questions. It enables users to browse, sort, search, view, select, and publish a report of questions in the represented technical disciplines. Additional information on how to make the best use of the system, how to contribute questions, and related resources is also available.

The motivating factor for this work was the realization by executive management that there weren't sufficient domain experts to support all peer reviews, a critical part of the design process. As a result, problems that should have been caught at a peer level were being caught later in the development cycle when they were much more difficult to correct. While the database isn't a replacement for the involved presence of experts or skilled peers, it does serve to provide some of their insights to development teams.

The TQDB impacts design and review activities through the thought processes of the individual users. Users are encouraged to access the system during the course of their regular design activities to identify items they need to consider. In preparation for a review, the TQDB serves as an "open book test" for the types of questions the designers can expect from their reviewers. It is also intended to help reviewers prepare by reminding them of the types of questions that are appropriate. Both organization and individual points of contact are listed with the questions, providing the ability to link users with deeper sources of knowledge.

The critical first step is "thinking" about the subsystem or instrument under development to identify salient characteristics, while the final step is "thinking" about how the issues raised through the questions should be addressed. By design, the questions aren't a test with right or wrong answers, but "mind ticklers" to help developers. One of the most significant choices made in implementing the system was to *not* include answers. The context-uniqueness of the systems under development, rapidly changing technology, and an organizational culture recognizing the importance of individual judgment in innovation made answers a liability.

The TQDB is an example of a system that operates as an advisor. The functionality is relatively simple, but use of the system demands the attention of the user to evaluate applicability and relevance, and to think about if and how to answer the questions relative to his/her design. The system is modeled on the relationship of peers and experts that attend reviews, therefore, the system approximates their behavior by "asking questions." In this sense, the knowledge representation is user natural, since this is the way the contributors (knowledge sources) and users would interact. The organization of the questions is also natural, based on the functional organization of the Laboratory. Users gain valuable information from seeing which part of the organization contributed the questions.

The quality of the questions is ensured by having the functional organizations contribute and maintain questions in their areas. This also addresses the credibility issue, since the domain expertise in a given area is generally housed in

the functional part of the matrix organization. General relevance is assured because the questions are updated by those actively participating in the field. We have also maintained editorial control over the content to ensure that questions are truly technical in nature and representative of the discipline, so that all questions in the database are of potential value. Figure 2 presents the guidelines provided to contributors who generate the questions. Enforcing these guidelines ensures that the technical value of the resource doesn't become diluted by marginal questions.

- **Are they technical** (vs. administrative, programmatic, etc.)?
- **Are they specific to a technical discipline**, or are they general in nature?
- **Are they valuable at the peer review level**? For example, do they: Lead to insights for a better design/implementation; Prevent previously identified problems from occurring ; Improve understanding of the impact of design/implementation decision ; Identify other design/implementation options; Identify "gotcha's" or subtle design issues
- **Do they conform to the format of the database**? Is all pertinent information included? Is the question readable by someone not familiar with that discipline (e.g., explained all the acronyms)?
- **Are they duplicates of another questions**?
- **Does including this question provide enough value to justify increasing the size of the database**. Note: the larger the database, the more overwhelming it will be for people to use. We've set a goal of only including "excellent" questions in order to increase the value of the resource and make sure that users don't have to wade through a pile of mediocre information to get to valuable parts.

Figure 2. TQDB Content Guidelines

One design concern was how to help the user narrow down contents to those areas relevant to their specific problem, since the full spectrum of technical disciplines couldn't apply to all efforts. We've found that by arranging the questions into sets based on technical discipline area and functional organization, users find it easy to browse through a list of domains to roughly identify those that are pertinent. We've also made use of white space, boxed text, and headings to make it visually easier to scan the list, and have grouped related questions to reduce the number of "questions" to scan.

3.1. Results

The Technical Questions Database has been operational for several years and has just completed a 6 month evaluation summarized in Table 1. Through user feedback obtained through an on-line survey (based on Davis's perceived usefulness and usability [10]), direct contact with users, and monitoring of usage statistics, the system has received a positive evaluation from the targeted user communities, attained steady-state usage consistent with its intended purpose, received high marks as being both useful and usable, and has been integrated into training processes.

In addition to meeting the needs of individual designers and cognizant engineers, the TQDB has also been useful as a mechanism for group knowledge sharing activities (in creating and evaluating sets of questions), as a checklist for domain experts, as a resource for review board members, and as a mechanism for identifying potential review board members. Although developers have identified a number of potential system improvements, user response has clearly indicated that the basic functionality of the system meets their needs and that future efforts should go into expanding the content and increasing connectivity to related resources.

The evaluation activities answered the pragmatic question "is this resource useful enough to continue to support it?" While obviously not a robust, academic assessment, it does provide evidence from multiple users through a variety of sources that this is a valuable resource. The use of the "questions" format is regularly mentioned by respondents as contributing to their positive assessment.

The system has high perceived value because it meets the goal of helping to cover items that may otherwise be missed. The primary use of a browse (vs. search) paradigm requires users to identify categories that may be applicable to their domain, and then review individual questions in those areas. This approach enables users to find questions in their areas that they *weren't* looking for -- the purpose of the resource.

4. JPL 101

JPL 101 is a web-accessible database of general organizational knowledge, formulated as a question-and-answer quiz. The questions are

in the form of multiple choice, true/false, and matching. The answers identify the correct choice and provide references to resources, additional information, and links to other sites for both the right and wrong answers. The questions cover the gamut from pure trivia to items that every employee should know in the areas of: JPL History and Culture, Flight Projects and Missions, Science, Technology, JPL Organization and Structure, Stakeholders, and JPL General Information. Figure 3 provides a sample question-answer-links set.

Where is the Carl Sagan Memorial Station?

a) Ares Vallis, Mars
b) JPL mall wall
c) Aboard Voyager spacecraft
d) 65 N. Catalina Avenue, Pasadena

Correct Answer: a) Ares Vallis, Mars

The Pathfinder Lander was formally named the "Carl Sagan Memorial Station" following the successful touchdown in the Ares Vallis region on Mars - refer to this JPL Universe article (7/11/97) or the Mars Pathfinder Web site for more information.

Other answers are also associated with Carl Sagan:

- *The JPL mall wall, located northeast of the fountain in the JPL mall, was dedicated to Dr. Sagan.*
- *The Voyager spacecraft carries with it a gold disk containing greetings from the people of Earth that Dr. Sagan was instrumental in developing. To see and hear the content of the disk, visit the Voyager display in von Kármán Auditorium, or the Voyager Web site*
- *This is the address of The Planetary Society (TPS), which was co-founded by Dr. Sagan. Be sure to visit The Planetary Society's Web site to view their tribute to him.*

Figure 3. Sample JPL 101 Question

The content categories were carefully chosen to emphasize areas important to the Laboratory. History and Culture, obviously, addresses the history and culture of the Laboratory with the goal of aiding in socialization of newcomers. Missions and Flight Projects, such as Voyager, Galileo, and Mars Pathfinder are the reason the Laboratory exists, and knowledge of key missions is important, especially when representing the Laboratory to the public. The Science and Technology categories cover basic knowledge and how-to information on the core value-adding processes of the Laboratory: scientific investigation, technology research, and spacecraft development. JPL Organization and Structure looks at the internal structure, how work is organized, and the location and relationship of service and support functions. Since JPL is a National Laboratory operated for NASA by the California Institute of Technology, there is a wide spectrum of stakeholders who influence the operations of the Laboratory. Understanding the nature of these stakeholder relationships and the various legal, contractual, and public trust concerns of the Laboratory is important for efficient operation. Finally, JPL General Information covers the day-to-day business of getting work done.

JPL 101 was created to serve as an educational resource for Laboratory personnel, and to provide a way to assist them in exploring the abundance of electronic and other resources available to them. The name was chosen as a tongue-in-cheek reference to beginners classes in college to emphasize the educational nature of the resource, and to convey that much of the content is basic material that employees should know. The questions serve as an excuse to present additional knowledge in the answers. For example, a question about the identity of a raccoon that caused a power outage on the Laboratory is used as an entry point to warn employees about the dangers of indigenous fauna such as mountain lions and rattlesnakes.

The orienting question that guided the development of JPL 101 was "how do you help people to understand the 'big picture' given that direct work-related exposure may be minimal (or non-existent)?" The "quiz" metaphor was chosen because it seemed like a natural approach in an organization that values education as highly as JPL does. The information to be conveyed can be quite dry, so the use of colorfully phrased questions and the juxtaposition of unlikely objects were used to keep the quiz portion interesting. "Fun" was an explicit goal.

The content was developed by first identifying knowledge goals, then devising questions and right/wrong answers to support those goals. For example, a knowledge goal could be to create greater awareness of a new test facility, let after-hours personnel know about restaurants available for take-out, provide background information on why a new regulation was imposed, highlight an especially exciting technology, or acknowledge a well-executed mission event. Questions and answers are then formulated to provide the entry point for discussion of the knowledge goal material.

For their premiere, the questions are organized into quizzes containing 5 - 10 questions each from across the categories and at varying levels of difficulty. Since the user base

for this tool is all employees, across multiple disciplines, professional areas, levels of tenure, and organizations, it was important to make sure that there is something relevant to every individual user in each quiz. Also, the goal is not to "stump" users, so questions are kept at a reasonable level of difficulty and truly arcane information is not part of the question (though it can be incorporated into the answers).

In addition to the active quiz, past quiz questions and answers are available for access. While similar to a Frequently Asked Questions (FAQ) type resource, JPL 101 differs because these questions fall more into the infrequently asked domain. Also, unlike an FAQ where a question is created based on frequency of occurrence, the questions in JPL 101 are formulated because they contain information that people should know, but might not ask about.

4.1. Results

User response to pilot activities has been enthusiastic and positive across a broad range of the potential user population. There is significant interest in both accessing the information and contributing to it. Beta-testing was used to determine the size of the quiz, appropriate mix of questions, level of difficulty of questions, and span of the categories. Based on preliminary responses, a "submit a question" function was added to the user interface. The operational system is in the process of being deployed and is expected to reach 100's of users per day, and will be evaluated during a 12 week initial operating period (see Table 1).

Given the nature of this resource, a critical issue is validating the correctness of questions and answers. Beta-testing of content led to standards for structuring a "good" question and guidelines for a reasonable amount of material to include in the answer. The practical solutions of either triangulating an answer (two-sources to confirm) or verification through an unimpeachable source to ensure correctness have been adopted.

The level of acceptance of this resource has been surprising. With very few exceptions, the personnel who have been involved with the pilot version have been anxious to share the information with their colleagues, contribute questions and answers, and considered it both valuable and fun. Everyone, including people who have been with the organization for multiple decades, indicated that they learned something either through the questions or the supporting information given in the answers.

5. Discussion

The development and deployment of the two knowledge resources presented in this paper indicate that questions can be a valuable way to encode knowledge. Based on practioner experience, they also indicate several potential areas for further research:

5.1 Under what conditions are questions a valuable way to encode knowledge?

We had explored declarative representations of knowledge and found that either approach could be used to capture equivalent information. The main difference appeared to be the psychological effects of using questions. First, they mimic the natural way the information would be conveyed if an information system wasn't mediating the exchange (particularly for the TQDB). Second, questions provide a cue in conversational discourse that indicates that a subject is open to discussion or interpretation, while flat declarative statements convey a sense of finality. Finally, in an environment where adaptation or contextualization of the knowledge is essential for it to be useful, the question serves as a starting point for the thinking process. As one reviewer questioned, would context specificity make questions more or less useful as a form of knowledge representation?

The major structural difference between TQDB and JPL 101 is in the use of *answers*. For JPL 101, the knowledge is encoded in both the questions (at the scanning level) and the answers (at deeper levels). This is possible because the nature of the knowledge is not context dependent and is relatively static. Therefore, it was possible to incorporate the declarative knowledge without incurring a significant maintenance overhead. The opposite is true for TQDB, where relevance is highly context-dependent and could change fairly rapidly as technology changes.

5.2. How does knowledge representation impact the ease and effectiveness of knowledge solicitation?

As compared to previous knowledge capture activities at JPL, asking for questions was much more productive than asking for knowledge.

Whether the proposed form was rules of thumbs, if-then-else statements, facts, or procedural knowledge, the sources tend to put a lot of effort into making sure their statements were correct, precise, and addressed all possible combinations of events. Sources appeared much more comfortable creating questions, and were willing to accept a "good enough" formulation of the question. The process was relatively fast and required significantly less hand-holding than previous attempts at populating knowledge bases. As a point of reference, the initial population of the TQDB, which provided roughly half of the current content, took approximately 3 calendar weeks and was accomplished via an email solicitation from upper management. While not all knowledge translates well into a question format, for those cases where it does, this could serve as a useful method for eliciting knowledge.

5.3. What is the value of spanning multiple disciplines in a single resource?

Both TQDB and JPL 101 provide content that crosses functional and organizational boundaries. Even at relatively higher levels of abstraction (e.g., the listing of the technical discipline area, independent of specific questions), the juxtaposition of information from such varied sources increases the awareness that these areas exist (akin to Roger's [26] "awareness knowledge"). More detailed content, while not sufficient to educate a person in a particular domain, does serve to educate a person about that domain. The questions in the TQDB provide basic information about what types of activities occur in a particular domain, the types of things that are of special interest, and what are the areas where things could go wrong. This type of information can help in bridging thought worlds [11] by increasing the sensitivity of members from one functional area to the concerns of another area. In turn this leads to reduced conflict and improved performance in cross-functional teams [12,24].

5.4. To what extent can knowledge representation and system functionality be traded off in system design?

The implementation of both TQDB and JPL 101 are relatively simple, with a minimal amount of user functions. Although as developers we can identify a significant number of changes that would improve functionality, user feedback has indicated that more "bells & whistles" aren't needed, nor are they wanted. A minimalist approach has a significant effect on maintenance costs, and user training and support. This suggests that there may be a system trade between the representation of the knowledge and the complexity of the delivery system.

This does not, however, reduce the value of an aesthetically pleasing interface. Practitioners in usability engineering are moving toward concepts such as "joy of use" [14] and hedonic quality [17] to describe the need for systems to meet the affective needs of the users. A system that is fun -- or at least not annoying -- contributes to the overall value to the user. Additionally researchers have called for information system designers to strive for user delight rather than simply satisfaction [15] and user seduction [20] when users may not be initially inclined to believe that a system may be of value.

5.5 What are the organizational communication implications of knowledge representations and resources?

The types of questions that are asked are indicative of what's important to an organization. In JPL 101, for example, the inclusion of questions on stakeholder relationships indicates that at an organizational level, these relationships are important to the operation of the Laboratory and that the average employee should know something about them. The inclusion of a question that leads to a list of local restaurants that are open after normal work hours sends a message to employees acknowledging that the institution is aware of and appreciates the times people need to put in extra effort. Similarly, the inclusion of questions on a given technical discipline area in TQDB acknowledges that the specific discipline contributes to the overall mission and concerns in that area should be addressed. While we're not advocating using either of these tools for propaganda purposes, the investment in the content sends a clear message that the organization perceives a given area to be valuable. An open research issue is how the use of questions (e.g., as a knowledge representation, a strategy, or a form of message) impacts organizational communications processes (e.g., [30]).

5.6 How do knowledge resources contribute to organizational discussions and social exchange?

User and test groups for both JPL 101 and TQDB indicated that these resources would be useful in a group setting. One functional organization described how they projected the TQDB website at a staff meeting and systematically went through the areas related to their domain to identify relationships, gaps in content, and items that were regarded as important across the different groups in their organizations. Beta testers for JPL 101 wanted to use the content as a part of a team building exercise and starting point for discussion. The Human Resources department intends to incorporate it into their orientation program, and executive management is considering using the content for a Lab-wide contest in support of JPL's anniversary celebration. Given the benefits of discussion in learning processes (e.g., [18,27,31]), the potential for knowledge resources to support group interaction is an important consideration in implementation.

6. Conclusion

The choice of knowledge representation is a key component in the overall design of any knowledge resource. While design trades often consider the architectural implications of these decisions (e.g., inference engine interface, database schema), this paper argues that the representation choice also impacts system usability and usefulness. Two case studies were used to illustrate how the unusual choice of questions as the knowledge representation affected the implementation and use of these resources. While the use of questions may not be appropriate in all circumstances, there were benefits in the form of user engagement, easier knowledge solicitation, reduced maintenance effort, and the adaptability of the knowledge for the systems discussed here.

Since the end goal of knowledge capture is the successful reuse of the codified knowledge, developers need to consider content representations that engage the users and support group interaction. The practical experiences gained in implementing these systems lead to a number of questions that have both research and practical implications. Answering these questions could lead to improvements in the implementation, and use of organizational knowledge resources.

7. Acknowledgements

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Special thanks to: members of the Knowledge Capture Team, Teresa Bailey, Rebecca Nash, and Tu-Anh Phan; the Knowledge Management Program, Roger Lee, Edward Ng, and Jeanne Holm; Thomas Gavin, Associate Director, Flight Projects and Mission Success; and the anonymous reviewers.

8. References

[1] Alavi, M. and Leidner, D. E., Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues *MIS Quarterly*, vol. 25, pp. 105-136, 2001.

[2] Allen, T.J., *Managing the flow of technology: Technology transfer and the dissemination of technological information within the R&D organization*, Cambridge, MA: MIT Press, 1977.

[3] Appleyard, M. M., How does knowledge flow? Interfirm patterns in the semiconductor industry *Strategic Management Journal*, vol. 17, pp. 137-154, 1996.

[4] Argote, L. *Organizational Learning: Creating, Retaining, and Transferring Knowledge*, Norwell, MA: Kluwer, 1999.

[5] Argote, L. and Ingram, P., Knowledge transfer: A basis for competitive advantage in firms *Organizational Behavior and Human Decision Processes*, vol. 82, pp. 150-169, 2000.

[6] Armbrecht, F. M. R., Chapas, R. B., Chappelow, C. C., Farris, G. F., Friga, P. N., Hartz, C. A., McIlvaine, M. E., Postle, S. R., and Whitwell, G. E., Knowledge management in research and development *Research-Technology Management*, vol. 44, pp. 28-48, 2001.

[7] Boose, J. H., A survey of knowledge acquisition techniques and tools *Knowledge Acquisition* , vol. 1, pp. 3-37, 1989.

[8] Clark, H. *Using Language*, Cambridge: Cambridge University Press, 1996.

[9] Cohen, W. M. and Levinthal, D. A., Absorptive capacity: A new perspective on learning and

innovation *Administrative Science Quarterly*, vol. 35, pp. 128-152, 1990.

[10] Davis, F. D., Perceived usefulness, ease of use, and user acceptance of IT *MISQ*, vol. pp. 319-340, 1989.

[11] Dougherty D., Interpretative barriers to successful product innovation in large firms. *Organization Science*, vol. 3, pp. 179-202, 1992.

[12] Dyer, B. and Song, X. M., Innovation strategy and sanctioned conflict: A new edge in innovation? *Journal of Product Innovation Management*, vol. 15, pp. 505-519, 1998.

[13] Dyer, J. H. and Noveoka, K., Creating and managing a high-performing knowledge-sharing network *Strategic Management Journal*, vol. 21, pp. 345-367, 2000.

[14] Glass, R. The looking glass. On#Sun.com Magazine (October), 6. 97. Sun Microsystems.

[15] Grudin, J., Interactive systems: Bridging the gaps between developers and users *IEEE Computer*, vol. 24, pp. 59-69, 1991.

[16] Hammond, K., Burke, R., Martin, C., and Lytinen, S., "FAQ Finder: A case-based approach to knowledge navigation," *Proceedings of the 11th Conference on Artificial Intelligence for Applications,* Los Angeles, CA, pp. 80-86, 1995.

[17] Hassenzahl, M., Beu, A., and Burmester, M., Engineering Joy *IEEE Software*, vol. pp. 70-76, 2001.

[18] Kim, P. H., When What You Know Can Hurt You: a Study of Experiential Effects on Group Discussion and Performance *Organizational Behavior and Human Decision Processes*, vol. 69, pp. 165-177, Feb, 1997.

[19] Kogut, B. and Zander, U., Knowledge of the firm, combinative capabilities, and the replication of technology *Organization Science*, vol. 3, pp. 383-397, 1992.

[20] Markus, M. L., Majchrzak, A., and Gasser, L. A design theory for systems that support emergent knowledge processes. In: *Redefining the Organizational Roles of Information Technology*, eds. Segars, A., Sampler, J., and Zmud, R. University of Minnesota Press, 2001.

[21] Moreland, R. L. and Myaskovsky, L., Exploring the performance benefits of group training: Transactive memory of improved communication? *Organizational Behavior and Human Decision Processes,* vol. 82, pp. 117-133, 2000.

[22] Nahapiet, J. and Ghoshal, S., Social capital, intellectual capital, and the organizational advantage *Academy of Management Review*, vol. 23, pp. 242-266, 1988.

[23] Nonaka, I., A dynamic theory of organizational knowledge creation *Organization Science*, vol. 5, pp. 14-37, 1994.

[24] Pelled, L. H., Demographic diversity, conflict, and work group outcomes: an intervening process theory *Organization Science*, vol. 7, pp. 615-631, Nov, 1996-Dec 31, 1996.

[25] Rice, R. E. and Rogers, E., Reinvention in the innovation process *Knowledge, Creation, Diffusion, Utilization*, vol. 1, pp. 499-514, 1980.

[26] Rogers, E. *Diffusion of Innovations*, New York: The Free Press, 1983.

[27] Sniezek, J. A., Groups under uncertainty: An examination of confidence in group decision making *Organizational Behavior and Human Decision Processes*, vol. 52, pp. 124-155, 1992.

[28] Star, S. L. and Griesemer, J. R., Institutional ecology, 'translations', and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907-39 *Social Studies of Science*, vol. 19, pp. 387-420, 1989.

[29] Szulanski, G., The process of knowledge transfer: A diachronic analysis of stickiness *Organizational Behavior and Human Decision Processes*, vol. 82, pp. 9-27, 2000.

[30] Te'eni, D., Review: A cognitive-affective model of organizational communication for designing IT *MIS Quarterly*, vol. 25, pp. 251-312, 2001.

[31] Tjosvold, D. Cooperation theory, constructive controversy, and effectiveness: Learning from crisis. In: *Team effectiveness and decision making in organizations*, eds. Guzzo, R. A., Salas, E., and Associates. San Francisco: Jossey-Bass, 1995.pp. 79-112.

[32] Yin, R. K. *Case Study Research: Design and Methods*, Newbury Park: Sage, 1994.

Table 1. Evaluation Summary for TQDB and JPL 101

	TQDB		JPL 101
Target users	JPL technical personnel working in disciplines relating to space systems		JPL personnel across all categories
Relevance Window	Primarly during preparation for system and subsystem design reviews. More generally throughout the design process		Ongoing
Status	Operational for 3 years		About to go operational
TQDB Evaluation			
Evaluation Method	Description	Indication	Other
Usage statistics (Users)	Obtained from server logs. Average 20-30 users/month, consistent with target users and relevance window	Positive for usefulness for target users.	Interpreted as a need to publicize rather than change the system
On-Line Survey (Users)	Accessible from TQDB website, based on Davis [10]to measure perceived usefulness and usability. Very low response rate (<10%)	Positive for both usefulness and usability	
Email-based feedback form (Users)	Available from TQDB website. Open ended comments with low (10-20%) number of users	Strong positive feedback on usability and usefulness. Requests to increase content to cover additional domains	Many respondents indicated they "didn't have time to take the survey – so they sent the email instead"
Executive Advocacy (Management)	Executive level support in obtaining maintenance funding and reaffirming importance of contributing content	Positive indication of overall perceived value	
External Requests (future users)	Requests from NASA employees external to JPL for access to content	Positive indication of perceived usefulness	
JPL 101 Evaluation			
Beta-Test	20 subjects taking paper version of quiz. Used to evaluate characteristics of the questions and obtain feedback on length of quiz, mix of questions, potential value of resource	Feedback on design of content incorporated into operational system. Generally positive feedback on concept, with some negative	
Informal user sessions	Informal meetings held with groups of 2-5 people to get feedback on overall concept and perceived value	Extremely enthusiastic response indicating high perceived value and multiple offers of advocacy	Routinely received offer to submit questions (content) for future versions
Usage statistics and quiz results	Data not yet available	Will be collected during 12 week initial operations period	
On-line survey			
Email Feedback			
Voluntary contribution of questions			