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Using Knowledge-Based Systems to Support Learning of Organizational Knowledge: A Case Study

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Abstract

This paper describes the deployment of a knowledge system to support learning of organizational knowledge at the Jet Propulsion Laboratory (JPL), a US national research laboratory whose mission is planetary exploration and to "do what no one has done before." Data collected over 19 weeks of operation were used to assess system performance with respect to design considerations, participation, effectiveness of communication mechanisms, and individual-based learning. These results are discussed in the context of organizational learning research and implications for practice.

1. Introduction

Organizations can be viewed as having two streams of work: *value-adding processes*, which are those that directly create the value delivered to external customers, and *enabling processes*, which are internally focused processes that create no direct value for customers but support or enable processes that do [8: pp. 219, 316]. In an organization such as the Jet Propulsion Laboratory, a US national research laboratory whose mission is planetary exploration and to "do what no one has done before," large numbers of technical and professional disciplines must be integrated to support innovation (the value-adding process). In addition, infrastructure and support services are required to perform routine organizational functions (the enabling processes). While cross-functional project teams have become a common approach to integrating multi-disciplinary knowledge in support of product development [3], less attention has been paid to bridging gaps between value-adding and enabling processes.

In established firms, emergent knowledge processes (EKPs) [14] such as product development take place within the context of the organization's bureaucracy. The clash between those tasked with operating the bureaucracy and those who must work within it can be viewed as another flavor of "thought world." Dougherty [7] describes thought world differences between members from the marketing, engineering, and manufacturing functions in new product development teams. Areas such as human resources, contracting, accounting, and information technology also draw from different professional disciplines, focus on different critical issues, and use different approaches to define and solve problems. While cross-

functional teams work to create a shared vision of a successful, marketable product, which helps to bridge their thought worlds, there are few resources (e.g., mission statements) that are effective at providing the same sort of actionable focus for the organization as a whole.

Thought-world related problems, such as conflict and miscommunication, can be mitigated by helping people to learn about the other domains and to recognize and exploit differences [7]. Knowledge management systems (KMS) have the potential to support this type of learning. Knowledge-based approaches have been used to support transfer of best practices [13], knowledge reuse for innovation [12], identifying experts, and a variety of business processes) [6].

Alternatively, person-to-person approaches can be employed. Mentoring programs, social networks [15] and storytelling [2, 17] are common mechanisms by which organization members share information about their disciplines and their tacit understanding of how their organizations really function.

While KMSs are perceived to have a positive impact on the performance of the organization, empirical evidence is often difficult to come by [4]. Person-to-person contact is viewed as highly effective, but may not be available to the full membership of the organization.

This paper presents a descriptive case study [18] of a KMS developed to support the sharing of knowledge about the organization at the Jet Propulsion Laboratory (JPL). JPL has a rich organizational culture and a history of stunning successes such as the Voyager and Mars Pathfinder missions. JPL projects require the collected efforts of multi-disciplinary teams in a broad range of scientific, technical, professional, business, and support areas. The ability of people from such broad areas to work together effectively is highly dependent upon them having a shared appreciation for the different disciplines involved and the constraints under which they operate. This paper first describes the JPL 101 system, then presents results from 19 weeks of operation, and finally discusses the implications for research and practice.

2. System Description

JPL 101 is a web-accessible database of general organizational knowledge. Knowledge is encoded as questions, answers, and connections to related information and resources (see [[5] for a detailed discussion of the use of the "quiz" interface). The system is organized into quizzes containing 5-10 multiple choice and matching questions each. The deployment of the system took place over 12 weeks, after which it entered steady-state operation. During each of the first 12 weeks a new quiz was added. Following the 12-week initial deployment of the content, the system provided access to the full set of past quizzes.

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 orienting question that guided the development of the JPL 101 content was "how do you help people to understand the 'big picture' given that direct work-related exposure may be minimal (or non-existent)?"

2.1 Content

The heart of JPL 101 is the content. The content categories were carefully chosen to emphasize areas important to the Laboratory, essentially representing the different thought worlds. Table 1 provides a description of the different categories, the rationale for including them, and an example of each.

Over the course of the 12 weeks, a total of 66 questions were presented. Each question went through a rigorous quality check to ensure accuracy and that it met the standards for a well-formulated question. The distribution of questions across categories is also provided in Table 1.

Two areas received special attention in developing the questions: JPL Basics and Stakeholders. The 21 questions in the Basics category covered material ranging from how to get help with computer problems, information on new institutional resources and local restaurants available after hours. This is the type of information that generally doesn't get high visibility, but contributes to the overall work environment.

The Stakeholder category consisted of 10 questions that covered the multiple constituencies to which JPL is responsible.

Area	Description	Rationale	Example
Basics (n=22)	General knowledge about how JPL operates at and below the level of published procedures	Make it easier for employees to learn about things that make it easier to get their job done (and correct misconceptions)	What is the number to call if you're having computer hardware or software-related problems? (A: x4-HELP)
History (n=6)	Knowledge of key accomplishments and of individuals who contributed greatly to the Lab	Establish a connection to the past and share accomplishments that contribute to a sense of pride. Share the excitement of space exploration, which is the reason for existence for the Lab	Who was the director of GALCIT, and co-founder of JPL? (A: Theodore von Karman)
Missions (n=10)	Knowledge about missions, which are the primary product of the Laboratory and the focus of our work		What is the name of the rover that explored the surface of Mars in 1997? (A: Sojourner)
Product Development (n=9)	Knowledge about how the Laboratory builds and operates space missions and instruments	The three JPL core processes represent the reason the Lab exists: our mission of space exploration. All work at the Laboratory contributes either directly to one of these three areas, or is responsible for supporting these processes.	Where could you go at JPL to evaluate your spacecraft under environmental conditions that are similar to those found in space? (A: 25-foot Space Simulator)
Science (n=5)	Knowledge about key scientific principles of importance in space exploration		What is the most active volcanic body currently known in the solar system? (A: Jupiter's moon, Io)
Technology (n=4)	Knowledge about the development of technology of importance in space exploration		What is the name of the substance nicknamed "frozen smoke"? (A: Aerogel)
Stakeholders (n=10)	Knowledge about external entities that impact or are impacted by JPL.	JPL is answerable to multiple constituencies and is often highly constrained in the way it can operate. It is critical for JPL personnel to understand these factors and how they impact their work.	Who is the President of Caltech? (A: Dr. David Baltimore)

Table 1 JPL 101 Question Categories

Because 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.

2.2 Design considerations

JPL 101 was designed based on the assumptions that the general JPL population had access to a computer, were able to effectively use a web interface, and would find the use of a quiz-based model for the information acceptable. The first two are reasonable given the proliferation of web-based institutional applications for general exchange of information, support of business and administrative functions, and organizational communications. The third assumption was validated during preliminary beta-testing of the concept.

Based on our assessment of the organization and with guidance from ethics, human resources, and internal communications offices, we

incorporated several constraints into our design process. First, we needed to make the overall set of quizzes representative of concerns across the wide range of disciplines on Lab so that no group would feel "ignored" in the process and to ensure that we address the thought-world issues. Second, in order to avoid potential problems with time-keeping rules, we needed to keep the quizzes short. Third, we had to ensure that people could participate at their convenience, and that pragmatics, such as individuals being on travel, would not limit participation. Fourth, participation would be voluntary, therefore we had to motivate people to use the system. Fifth, the goal of the system was learning, therefore it was critical that we have mechanisms for assessing whether people actually benefited from the system. Finally, it was important that people not feel that they were being graded or assessed in any way. Therefore, we needed to ensure that participants could take the quizzes without fear of violating their privacy. This limited the type of performance and participation data we could collect.

3. Data Collection

We used two primary methods for collecting performance, participation, and user data: background collection of usage statistics and quiz answers, and user participation in the form of email feedback, an on-line survey, and an on-line form to submit comments. The background data collection was done using a commercial monitoring package associated with the web server. It provided information such as hit rates, IP addresses, number of unique visitors, amount of time spent on site, and time distributions of users. In addition, the quiz database recorded the answers submitted each time someone took a quiz.

Our on-line survey was used to collect basic organizational demographics (tenure, organizational unit, job category, and whether a manager or not) and responses to two questions: "Did you learn anything from the questions?" and, "Did you learn anything from the answers?" Taking the survey was voluntary, as was responding to the demographic questions. Our second anonymous response method was an on-line feedback form. Users could submit comments, problems, feedback, and candidate questions for the system. While most users decided to remain anonymous, some made the effort to include their names and contact information. Finally, the e-mail based feedback form was available for people to contact the development team directly. This was not anonymous and was the least used form of feedback.

4. Results

JPL101 premiered on January 13, 2003 and ran for 12 weeks ending its initial deployment on April 6th. It remains in operation, although new content is not currently being developed. Based on analysis of the data collected during the initial 12 weeks, and extending through week 19 of operations, we present results relative to the following: design considerations, usage, motivation for use, learning results, and general reaction.

4.1 Design Considerations

Background usage and database data were used to assess how well we met our design considerations. Background usage data indicated that we succeeded in meeting the participation time goals of the system. The average time spent in the system each work day ranged from 2:01 minutes to 8:21 minutes, with the grand average being 3:53, which are within the limits recommended by JPL Ethics and Human Resources offices.

A second consideration was that we did not want to make the quizzes too hard, but did want them to be somewhat challenging. Figure 1 shows the average quiz scores for the 12 quizzes, based on data from the entire operational period. With the exceptions of weeks 5 and 8, the average quiz grades stayed between 70-90% which was our goal.

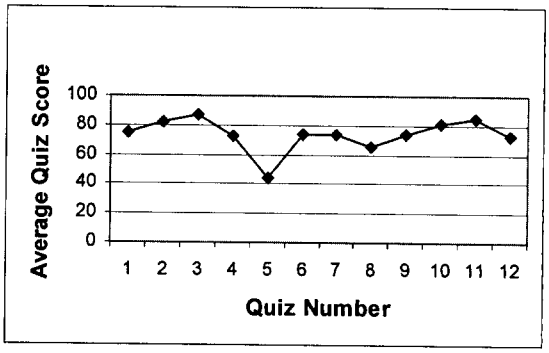

Figure 1. Average scores for each quiz

In addition, we were concerned about question quality. Because the JPL culture is such that participants would readily point out

any errors in the questions, we chose to evaluate question quality based on the number of corrections required. We received two inputs regarding the accuracy of questions, one of which resulted in a minor change (attributing an additional source for information in an answer). Given the volume of material in 65 questions plus all the associated ancillary information, two minor comments are well within the range for acceptable performance.

4.2 Participation

Ultimately, the success of any system is the number of people who use it. Given that this is a voluntary-use resource, and not required for anyone's job, participation statistics are critical for gauging overall success. Background usage statistics were collected including hit rates and unique visitors based on IP addresses, modified to filter out members of the development team and automated web crawlers. During the 19 weeks of operation covered in this study, a total of 2144 employees participated, or roughly 42% of the Laboratory population. Figure 2 shows the usage statistics over time for the 19 weeks.

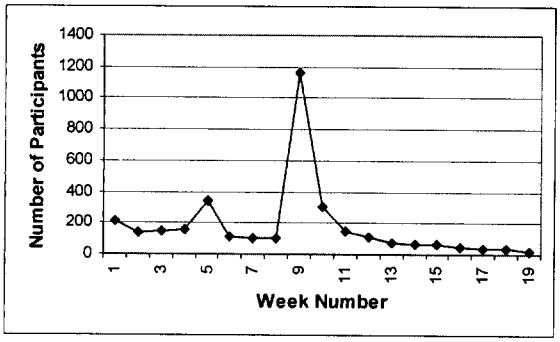

Figure 2. Usage statistics over time

In addition to reaching a large audience, our goal was to reach a broad audience. Although privacy and user-burden concerns prevented us from collecting organizational demographics on general participants, we were able to collect that type of data via our voluntary survey instrument. We received 533 surveys over the course of 19 weeks, representing a participation rate of just under 25%. The organizational tenure for participants ranged from brand new (0 years) to a maximum of 47 years, with an average of 15.3 years and a standard deviation of 10.5 years. Users spanned the entire Laboratory, with participation concentrated most heavily in the Technical and Administrative divisions, where the majority of Laboratory personnel are assigned. Participants were distributed across technical, administrative, and science disciplines, and included both managers and non-managers. Taken in total, the data collected via the on-line survey indicates that we reached a broad and substantial audience.

4.3 Impact of Communication Mechanisms

Because JPL 101 is a voluntary-use system, providing general rather than job-specific knowledge, we employed a number of institutional communication mechanisms in order to let people know this resource existed. These mechanisms were:

- JPL Universe: a traditional, bi-weekly organizational "news paper" distributed to personnel through interoffice mail. There was a multi-column story about JPL 101 plus a sample quiz.
- Cafeteria Monitors: closed circuit television screens in the cafeterias that broadcast announcements. Consisted of "teaser" questions -- shorter versions of quiz questions, plus the url for the site
- Daily Planet: electronic daily "news paper" for JPL personnel. Accessible via intranet. Icon refers to a small graphic posted on the sidebar of the page that linked to JPL 101. Article refers to a short blurb placed in center column "news item" area.
- Inside JPL Portal: web portal that provides central access to JPL webspace for internal users. Link to JPL 101 included in sections for new employees and institutional knowledge management
- This Week: electronically distributed (email announcement with link to web page) weekly newsletter that highlights personnel announcements, organizational changes, upcoming talks and events. Article refers to one paragraph blurb about JPL 101 plus access information.
- All.Personnel email: tightly controlled list that sends email to entire Laboratory population.

We began publicity for JPL 101 the week prior to its roll-out. Pre-release publicity included an article in the JPL Universe and announcements on the JPL monitors. In partnership with our Internal Communications office, the primary entry point for JPL 101 was the Daily Planet. Unfortunately due to higher priority events, we were limited to a sidebar icon during our initial weeks. This icon remained until the end of the initial 12-week run. Later during the first week, we were added to the Inside JPL portal. These links continued throughout the entire period. Complete information on communication mechanisms is provided in Table 2.

The impact of each of these devices can be seen in the usage statistics shown in Figure 2. The first spike in the graph occurs during Week 5 and corresponds to the publication of the Daily Planet article. A smaller increase, not visible in the weekly statistics, but present in the daily statistics, occurred when links were added to the Inside JPL portal. The most prominent feature of the graph, however, is the gigantic spike that occurs during Week 9. This corresponds to the sending of the all.personnel email publicizing JPL 101. This spike is due almost entirely to the day that the email was sent.

4.4 Learning Results

The primary goal of the system was individual learning. We assessed our success in attaining this goal in two ways. The first, and most direct way, was to use our survey to simply ask participants if they learned anything. Just under 90% of the survey respondents indicated that they had learned something from either the questions, the answers, or both. Preliminary analysis found small but significant negative correlations ($p<.01$) between tenure and learning, and being a manager and learning. No other relationships were found.

Our second approach to evaluating learning was to look at the quiz response data. Figure 1 shows the average grades for each of the 12 quizzes. These data indicate that on average, people missed 1-2 questions per quiz, indicating a learning opportunity existed. Detailed analysis of individual questions shows that the number of respondents getting a specific question right varied from a low of 33% to one question where everyone who answered got it right.

We were also interested in how well people performed across the different categories of questions. Because this is a voluntary-use, no-attribution resource, we also felt it would be valuable to look at what questions people skipped. Table 3 provides a summary of the performance in each of the categories. Inspection of Table 3 data indicates that JPLers performed well on questions relating to the three value-adding processes, slightly below average on Basics, History, and Missions, and significantly below average on Stakeholder questions. While JPL 101 is not intended as a diagnostic system for organizational knowledge, these results suggest a gap in knowledge about stakeholders that should be remedied. Inspection of the data on questions that were skipped clearly showed that matching-type questions were skipped more often than multiple choice, with all five matching questions placing within the bottom six response rates.

Week(s)	Pre	1	2	3-4	5	6-8	9	10-11	12	13- 17	18-19
Universe Article	x										
Cafeteria Monitors	p	p									
Daily Planet Icon		x	x	x	x	x	x	x	x		
Inside JPL Portal		p	x	x	x	x	x	x	x	x	x
This Week Announcement			p						p		
Daily Planet Article					x						
All.personnel email							p				

Table 2. Use of institutional communication mechanisms
x indicates used for whole week, p indicates partial week

4.4 Other

Feedback via email and through the on-line form was overwhelmingly positive. (The sole negative comment received via any of the feedback mechanisms was a complaint about the use of the all.personnel email.) For example one respondent wrote "This is great and I love it! I learned more about JPL in the past few weeks just by taking these quizzes then the 3 years I have been here. Thank you." Several constructive comments were made about how to improve the system. Respondents were pleased with the quiz-type presentation and one suggested that "JPL 101 is the paradigm that should be used for all training and knowledge dissemination at JPL."

One area in which we were disappointed was the lack of suggestions for questions. During beta-testing for JPL 101, one of the most surprising results was the level of excitement individuals had over the idea of the quiz, and their desire to contribute questions and make suggestions for material. Because of this response, we included the feedback form in the system, with a field specifically for submitting potential questions. We only received three suggestions, from which we were able to use two to construct questions.

4.5 Summary

In summary, the variety of data collected during the 19 weeks of operation for JPL 101 have provided us with valuable information on this system which we can hopefully apply to future efforts. Although we weren't able to collect everything we had originally hoped for, the data we did collect represents a pragmatic approach that is reasonable for practitioner analysis. The following section discusses these results and the potential learning to be gained from them.

5. Discussion

As a case study of the deployment of a single knowledge resource, in a single organization, this work has obvious limitations with regard to generalizability [18]. It does, however, offer a high degree of ecological validity [10] and provides examples of the types of issues that are important in practice.

5.1 Practitioner Perspective

From a practitioner perspective, there are a number of lessons of value for the organization. First, fun works. The use of humor and clever construction of questions and answers did not diminish the fundamental value of the content, but instead added to the probability that the resource would be used.

Second, there were remarkable differences in the effectiveness of different institutional communications channels, as evidenced by the usage data. While one must be cautious about extrapolating from a small number of experiences, the data for JPL 101 imply that specific channels are more effective in motivating participation than others. In this case, the all.personnel email (which was short and clearly indicated that participation would take a small time investment with high potential for payoff) resulted in orders of magnitude increases in participation.

Third, the differences in successful response rates for different question categories does provide a level of diagnostic information regarding gaps in individual knowledge about the organization. Our concern about general awareness of stakeholder issues was reinforced by the particularly low scores in the stakeholder category. This information could be used to modify communication and training activities to place special emphasis on areas with sub-par performance.

Finally, the feedback responses were overwhelmingly positive, particularly with respect to the quiz interface. Given the JPL culture, we felt this was a good approach [5], but we were surprised at the level of enthusiasm, and with the degree of frustration expressed

	Basics	History	Missions	Prod Dev	Science	Stake holders	Technology	Total/Avg
Number of Q's	22	6	10	9	5	10	4	66
Avg%Skipped	2.1	1.7	1.4	0.8	0.8	1.5	0.6	1.3
Avg%Right	73.2	70.9	75.6	83.5	85.2	66.0	85.1	77.1

Table 3. Summary of performance across question categories

regarding other on-line training interfaces. This result indicates that modifications to existing training approaches may be warranted.

5.2 Research Perspective

JPL 101 is first and foremost a system for *individual* learning. If one adopts the perspective of Huber [9] that an organization learns if "any of its units acquires knowledge that it recognizes as potentially useful to the organization" (p.89), then JPL 101 can also be seen as supporting organizational learning. Using the framework of Senge, et al. [16], JPL 101 supports organizational learning by:

(1) *Mental Models:* Contributing to the development and maintenance of mental models of how the organization operates and why it operates that way. For JPL, the nature of the work and of the institution both drive and constrain the work environment in many different ways. Mental models that accurately predict the behavior of this complex environment will contribute to improvements in the peoples' ability to work more effectively. JPL 101 attempted to contribute to mental model development, for example, by providing information about how JPL's special status as an FFRDC impacts operations. A number of policies that might not make sense under a for-profit business model appear much more logical with a fuller understanding of FFRDC status.

(2) *Personal mastery*: JPL 101 provides a mechanism for both validating the personal knowledge of individuals who are well-informed about how the Lab operates, and for guiding less experienced personnel to important material. The privacy afforded by the quiz interface allows individuals to assess their own knowledge in a non-threatening environment. There are no penalties for getting answers wrong. By structuring JPL 101 for self-learning, and by keeping the general tone light and fun, individuals were encouraged to "test themselves" strictly for their own information.

(3) *Shared vision*: JPL 101 served to provide insights into the culture as shaped by past accomplishments and an understanding of important components of current projects. Simply asking a question in a given area sends the message that this area is important [5]. JPL 101 was intended to help bridge boundaries between different groups at the Laboratory. By highlighting critical issues associated with different disciplines, JPL 101 served to expose participants to areas outside of their normal working environment.

(4) *Team Learning*: JPL 101 is an individual learning tool that can also be used in a shared mode. For example, there were instances where versions of the quizzes were used as an activity during group meetings. One common approach was to print out a quiz and complete it as an exercise at a group meeting. Members would share their own insights to the answers presented in the quiz with each other, debate answers, and describe their personal experiences relative to a topic covered in the quiz. We received several requests to generate longer versions of the quizzes with special groupings of questions to support larger organizational meetings.

(5) *Systems thinking:* JPL 101 contributes to systems thinking by providing insights into the internal structure, processes, and players, as well as external influences. All of the areas covered in the quiz contribute to JPL's overall mission. A better understanding of the competing constraints, differing perspectives, and the coupling between different functions leads to a better ability to make sense of the organization.

The practitioner nature of this work, however, places it firmly in the realm of a *learning organization* as compared to the research field of *organizational learning* [1]. As noted by Kuchinke [11] "organizations have in fact little control over *whether* learning takes place, but they do have potentially substantial amounts of control over the *kind* of learning that occurs within their bounds" (p. 309). In this respect, JPL 101 provides a learning opportunity where the content, by its mere presence, indicates a degree of organizational importance. The system serves as an intervention aimed at reducing thought world differences between personnel. In that regard, the work falls victim to a common problem in both organizational learning [11] and KMSs [4] which is measuring the impact on performance. While the JPL 101 results clearly indicate that learning took place, there isn't a clear connection between individual and organizational learning, nor is there a connection between either type of learning and organizational performance.

5.3 Research Implications

The work reported in this paper contributes to the on-going research in both knowledge management and organizational learning through the questions it raises.

(1) JPL 101 was designed to support boundary spanning between different technical and administrative disciplines, and to promote sharing of cultural information. While the literature on cross-functional teams has looked at the benefits of integrating technical disciplines for new product development, the cross-organizational integration of knowledge attempted by JPL 101 represents an under-explored boundary.

(2) The relationship between individual and organizational learning is the subject of debate in the organizational learning literature [1]. How does learning about the organization, as supported by JPL 101 relate to organizational learning?

(3) There are obvious connections between learning and knowledge management systems. JPL 101 is a KMS explicitly created to provide a learning opportunity. It collects knowledge and codifies it in a way to make it appealing to a broad audience. It also provides a starting point for deeper exploration of the topics presented in the quizzes. Based on the JPL 101 experience, the use of a quiz interface provides a mechanism to transform a KMS into a tool for learning. While this proved true at JPL, additional research is needed to identify general approaches to merging KMSs with learning support.

(4) The JPL 101 experience clearly demonstrated that different communication media have different results with respect to increasing participation. The huge increase in participation following the all.personnel email indicates that, at JPL, this is powerful tool for instigating initial attention. However, in our environment, we were allowed to use broadcast email only once during the 12 weeks of primary operations due to internal communications policies. Questions remain regarding how effective email would be if employed on subsequent occasions, how to increase long-term participation (e.g., vs. the significant fall-off in participation in weeks after the email "blip"), and theories for how to predict which communication mechanism would be most effective in general.

(5) How should these types of systems be instrumented to collect data that can support both research and practice? Our data collection was constrained by resources, policy, privacy issues, and the level of burden we felt we could place on our users. But even without these constraints, there's a lack of resources for determining what types of data should be collected to enable cross-comparison of efforts. From a practitioner perspective, we're concerned about addressing our immediate problems, but given the opportunity, we'd like to contribute a case to a broader course of study. Additional guidance could be provided in the form of meta-analyses of KMS and organizational learning systems which would indicate the type of data needed to support cross-study comparisons.

6. Conclusion

In summary, this work contributes to the on-going discussion of knowledge management and organizational learning in multiple ways. First, it provides a detailed description of the deployment and operation of a organizational knowledge-based resource specifically targeted to support general learning. Second, it connects this work to streams of research in organizational learning and learning organizations. Finally, it discusses the research implications of this practice-oriented case study.

A clear goal for knowledge management systems is to expand the knowledge base of the organization -- in other words, learning. The work presented in this paper describes one instance of the deployment of such a knowledge management system. It is our hope that this effort contributes to the on-going body of work in knowledge management and organizational learning.

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