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Report to the Subcommittee on Space and Aeronautics, Committee on Science, House of Representatives

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NASA

Better Mechanisms Needed for Sharing Lessons Learned

GAO Accountability * Integrity * Reliability

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The Honorable Dana Rohrabacher
Chairman, Subcommittee on Space
and Aeronautics
Committee on Science
House of Representatives

The Honorable Bart Gordon
Ranking Minority Member, Subcommittee
on Space and Aeronautics
Committee on Science
House of Representatives

In response to your request, this report discusses the mechanisms that the National Aeronautics and Space Administration (NASA) has in place to capture, disseminate, and apply past lessons learned towards future mission success. We found that NASA's processes, procedures, and systems do not effectively capture and share lessons learned and therefore, NASA has no assurance that lessons are being applied towards future missions. We include recommendations to the NASA administrator on ways to strengthen the agency's lessons learning processes and systems.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 3 days from its issue date. At that time we will send copies of this report to the NASA administrator and interested congressional committees. We will also provide copies to others on request. If you or your staffs have any questions regarding this report, please contact me at (202) 512-4841, or John Oppenheim, assistant director, at (202) 512-3111. Key contributors are listed in appendix II.

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Executive Summary

Purpose

In the early 1990s, the National Aeronautics and Space Administration (NASA) administrator challenged the agency to complete projects faster, better, and cheaper. The intent was to reduce costs, become more efficient, and increase scientific results by conducting more and smaller missions in less time. Although NASA maintained a high success rate under the faster, better, and cheaper strategy, a few significant mission failures also occurred—particularly the loss of the Mars Polar Lander and Climate Orbiter spacecraft. NASA investigations of these failures, as well as its review of other programs, raised concern that lessons from past experiences were not being applied to current programs and projects.

At the request of the Chairman and Ranking Minority Member, Subcommittee on Space and Aeronautics, House Committee on Science, GAO assessed whether NASA has adequate mechanisms in place to ensure that past lessons learned from mission failures are being applied. Specifically, GAO (1) identified the policies, procedures, and systems NASA has in place for lessons learning, (2) assessed how effectively these policies, procedures, and systems facilitate lessons learning, and (3) determined whether further efforts are needed to improve lessons learning.

Background

NASA's procedures and guidelines require that program and project managers review and apply lessons learned from the past throughout a program's or project's life cycle and to document and submit any significant lessons to the agency's Lessons Learned Information System (LLIS) in a timely manner. NASA defines a lesson learned as knowledge or understanding gained by experience. The experience may be positive, such as a successful test or mission, or negative, such as a mishap or failure. A lesson must be significant in that it has a real or assumed impact on operations; valid in that it is factually correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result.

Results in Brief

NASA recognizes the importance of learning from the past to ensure future mission success and uses several mechanisms to capture and disseminate lessons learned. The principal source NASA has established for the agency-wide collection and sharing of lessons is the LLIS, a Web-based lessons database that managers are required to review on an ongoing basis. In addition, NASA uses training, program reviews, and periodic revisions to agency policies and guidelines to communicate lessons. Several NASA centers and key programs also maintain lessons learned systems that are geared toward their own staff. Recently, NASA has taken steps to improve the way it captures and shares information by developing a business strategy called knowledge management. Knowledge management can be defined as the way that organizations create, capture, and reuse knowledge to achieve their objectives. According to NASA officials, knowledge management has the potential to link agency staff with the knowledge and resources they need to complete tasks faster, better, and cheaper. In pursuit of knowledge management, NASA has developed a strategic plan, established a management team to coordinate knowledge management activities at NASA's centers, and initiated several information technology pilot projects.

Despite the processes and procedures in place to capture and share lessons learned, there is no assurance that lessons are being applied toward future missions success. A GAO survey of NASA program and project managers revealed weaknesses in the collection and sharing of lessons learned agency-wide. While some lessons learning does take place, our survey found that lessons are not routinely identified, collected, or shared by programs and project managers. Respondents reported that they are unfamiliar with lessons generated by other centers and programs. In addition, many respondents indicated that they are dissatisfied with NASA's lessons learned processes and systems. Managers also identified challenges or cultural barriers to the sharing of lessons learned, such as the lack of time to capture or submit lessons and a perception of intolerance for mistakes. They further offered suggestions for areas of improvement, including enhancements to LLIS and implementing mentoring and "storytelling," or after-action reviews, as additional mechanisms for lessons learning.

While NASA's current knowledge management efforts should lead to some improvement in the sharing of agency lessons and knowledge, they lack ingredients that have been shown to be critical to the success of knowledge management at leading organizations. Cultural resistance to sharing knowledge and the lack of strong support from agency leaders often make it difficult to implement an effective lessons learning and knowledge sharing environment. We found that successful industry and government organizations have overcome barriers by making a strong management commitment to knowledge sharing, developing a well-defined business plan for implementing knowledge management, providing incentives to encourage knowledge sharing, and building technology systems to facilitate easier access to information. The application of these principles could increase opportunities for NASA to perform its basic mission of exploring space faster, better, and cheaper more successfully.

Principal Findings

NASA's Policies and Procedures for Lessons Learning

NASA uses various mechanisms to communicate lessons garnered from past programs and projects. Policies and guidelines, programmatic and technical reviews, mentoring and training programs, the Academy of Program and Project Leadership, and LLIS are the mechanisms employed by NASA for capturing and sharing lessons learned. LLIS is the "official" agency-wide repository for such lessons. Lessons entered in the LLIS database are screened for relevance and to ensure that they do not contain sensitive or proprietary information. Initial reviews of lessons are usually conducted by the centers,[1] with a final review by the Office of Safety and Mission Assurance. After a lesson is entered into the system, it remains in the database indefinitely and is not reviewed for currency or relevance. Currently, the system contains over 900 lessons on topics ranging from program management to technical cause of failure.

In response to the Mars Program failures and the recommendations of agency reviews of program and project execution, NASA has recently taken action to improve its policies and practices for capturing and sharing knowledge by developing a business strategy referred to as knowledge management. Implementation of knowledge management can lead to increased productivity, collaboration, and innovation in the workplace. To coordinate and guide its efforts, NASA recently formed a knowledge management team, which developed a strategic plan that laid out broad goals and objectives for knowledge management. In addition, several pilot projects are underway at various NASA centers to enhance knowledge sharing.

[1] NASA consists of NASA headquarters, nine centers, the Jet Propulsion Laboratory (operated under contract to NASA by the California Institute of Technology), and several ancillary installations and offices in the United States and abroad. The implementation of NASA programs and aeronautical and space/earth science research occurs primarily at the centers.

Fundamental Weaknesses Exist in the Collection and Sharing of Lessons Learned

A survey we conducted of all NASA program and project managers revealed fundamental weaknesses in the collection and sharing of lessons learned agency-wide. Although NASA's processes and procedures require that program and project managers review and apply lessons learned throughout a program's or project's life cycle, our survey found that managers do not routinely identify, collect, or share lessons. Respondents indicated that LLIS, NASA's primary method for disseminating lessons learned agency-wide, is not the primary source for lessons learning. Instead, managers identified program reviews and informal discussions with colleagues as their principal sources for lessons learned. One reason LLIS is not widely used, according to one center official, is because its lessons cover so many topics that it is difficult to search for an applicable lesson. Another respondent indicated that it is difficult to weed through all the irrelevant lessons to get to the few "jewels" that you need to find.

Respondents also identified challenges or cultural barriers to the sharing of lessons learned as well as areas of improvement. Managers noted that there is a reluctance to share negative lessons for fear that they might not be viewed as good project managers, and there is a lack of time for lessons learning to take place. One manager stated, "Until we can adopt a culture that admits frankly to what really worked and didn't work, I find many of these tools to be suspect." Managers suggested that NASA could improve lessons learning by implementing mentoring and "storytelling" activities, and it could enhance LLIS by increasing its search functions, including more positive lessons, and developing a mechanism to disseminate key lessons to users.

In discussions with NASA officials, we found there was general agreement with the results of our survey as well as suggested improvements for lessons learning. Officials indicated that lessons learning has taken on greater importance in recent years due to the implementation of more programs and projects under the faster, better, cheaper strategy and the continuing loss of agency expertise due to attrition. They acknowledge that LLIS has not been an effective mechanism for agency-wide sharing of lessons. Although the system is viewed as providing a useful repository for storing lessons, officials agreed with managers' concerns about the difficulties involved in searching the system and finding relevant lessons, the inconsistent quality of information contained in the system, and the lack of lessons about positive project experiences. However, while program and project managers' suggested improvements would help increase the usability of LLIS, they have not targeted some of the more fundamental problems hampering NASA's ability to share lessons, such as persistent cultural barriers.

Creating an Environment for Lessons Learning through Knowledge Management

Leading organizations are discovering that actively managing knowledge creates value by increasing productivity and fostering innovation. Likewise, NASA's paramount concern should be about capturing and sharing organizational knowledge and using it to perform its basic mission of exploring space faster, better, and cheaper. Although NASA has recently taken action to improve the way in which the agency captures, organizes, and shares knowledge, these efforts do not fully address the fundamental weaknesses in lessons learning identified by our survey: namely, cultural resistance to sharing knowledge and the lack of an effective strategic framework and management attention for overcoming such resistance.

NASA has made a reasonable start by developing a strategic plan for knowledge management, but the agency has not made a good business case for how it will implement and use knowledge management within the organization. In addition, while successful industry and government organizations have made a firm commitment to making knowledge management practices work, NASA has not provided the leadership, support, and resources needed for effective knowledge management to take place. Furthermore, knowledge management organizations have employed incentives, processes, and systems designed to address cultural barriers to continuous lessons learning and knowledge sharing. For example, organizations that value knowledge sharing have encouraged employees to spend time sharing knowledge, helped facilitate communities of practice based around common interests, and provided rewards when knowledge has been shared and applied. NASA has not done so on an agency-wide basis.

Recommendations

NASA needs to strengthen its lessons learning in the context of its overall efforts to develop and implement an effective knowledge management program. Improvement of NASA's lessons learning processes and systems can help to ensure that knowledge is gained from past experiences and applied to future missions.

We recommend that the NASA administrator strengthen the agency's lessons learning processes and systems by

- articulating the relationship between lessons learning and knowledge management through an implementation plan for knowledge management;
- designating a lessons learned manager to lead and coordinate all agency lessons learning efforts;

- establishing functional and technical linkages among the various center-level and program-level lessons learning systems;
- developing ways to broaden and implement mentoring and "storytelling" as additional mechanisms for lessons learning;
- identifying incentives to encourage more collection and sharing of lessons among employees and teams, such as links to performance evaluations and awards;
- enhancing LLIS by coding information and developing an easier search capability to allow users to identify relevant lessons, including more positive lessons, providing a means to disseminate key lessons to users; and soliciting user input on an ongoing basis; and
- tracking and reporting on the effectiveness of the agency's lessons learning efforts using objective performance metrics.

Agency Comments and Our Evaluation

In written comments on a draft of this report, NASA generally concurred with our recommendations for improving the agency's lessons learned processes and systems. NASA stated that it must do a better job of communicating the various lessons learned sources to employees, improving mechanisms to link these sources, and ensuring appropriate training for employees in order to maximize lessons learning.

Chapter 1: Introduction

The 1990’s was a decade of significant challenge for the National Aeronautics and Space Administration (NASA) brought about, in part, by decreased budgets, a reduced work force, and technological innovation. To adapt to this changing environment, the NASA administrator challenged agency personnel to do projects faster, better, and cheaper (FBC) by streamlining practices and becoming more efficient. The goal was to shorten program development times, reduce cost, and increase scientific return by flying more and smaller missions in less time. However, the failure of the Mars Polar Lander and Climate Orbiter spacecraft raised concerns that lessons learned from past experiences were not being passed along and applied toward future mission success. To ensure that individuals learn from past experiences, effective processes and systems must be in place to collect, store, and disseminate lessons learned.

Faster, Better, Cheaper: A Management Philosophy

In 1992 NASA adopted the FBC philosophy as a way of managing programs and projects. An important element of this approach was a reduction in NASA headquarters management and moving more program responsibility to NASA’s centers. This philosophy also increased the demand for program and project managers at a time when NASA was experiencing a significant reduction in staff due to retirements, downsizing, and departures to industry. Prior to FBC, there were fewer missions, and program and project managers accumulated significant first-hand experience before managing a program. Under FBC, with a threefold increase in projects and fewer staff, this was not always the case. Relatively unseasoned managers who were challenged to be more efficient and innovative and to take greater risks in designing and implementing missions led many projects.

NASA’s record in designing, developing, and operating smaller spacecraft under the FBC concept, while mostly successful, has experienced a few notable failures. A number of projects including Clementine, Near Asteroid Rendezvous, Mars Pathfinders, and Mars Global Surveyor proved successful within the schedule and fiscal constraints imposed under the FBC concept. However, for other programs, including the Mars Polar Lander and Climate Orbiter, the challenge was too great, resulting in undue risk-taking and failure. After-action reports commissioned by NASA found that the Mars Program failures resulted from cost and schedule constraints and a lack of rigorous attention to sound process and practices.

Mars Surveyor Program

In 1993 NASA initiated the Mars Surveyor Program with the objective of conducting an on-going series of missions to explore Mars. NASA's Jet Propulsion Laboratory (JPL) was selected as the lead center for this program and was responsible for mission design, spacecraft and payload development, as well as integration, testing, and launch of the proposed spacecraft.

The first Mars Surveyor Program spacecraft, the Mars Global Surveyor and the Mars Pathfinder, were launched in 1996 and both were highly successful. After completing its primary mission of acquiring knowledge of the climate, subsurface resources, and topography of Mars, the Mars Global Surveyor is conducting reconnaissance of future Mars landing sites. The Mars Pathfinder and Sojourner Rover were a demonstration of a way to use technology to deliver an instrumented lander and a free-ranging robotic rover to the surface of Mars. Two additional Mars Surveyor Program spacecraft were launched in late 1998 and early 1999, respectively, to explore and collect additional scientific data on Mars.

The Mars Climate Orbiter, which cost $75 million to develop, was launched December 11, 1998, and was intended to observe Mars' seasonal climate and daily weather from a low orbit around the planet. Nine and a half months after launch, in September 1999, the spacecraft was supposed to fire its main engine to achieve an elliptical orbit around Mars and then pass through its upper atmosphere for several weeks before moving into a low circular orbit around the planet. On September 23, 1999, the Orbiter spacecraft was destroyed when it entered the Martian atmosphere on a lower than expected trajectory, causing the spacecraft to burn up. A NASA mishap investigation team determined that the loss was due to the mistaken use of English rather than metric units in the navigation software. As a result, an incorrect trajectory was computed and the spacecraft was lost.

The Mars Polar Lander was launched January 3, 1999, and cost $113 million to develop. The Lander was a robotic spacecraft designed to land softly near the South Pole of Mars to study the planet's layered polar terrain. Attached to the Lander was the Deep Space 2 mission—two small probes designed to separate from the Lander about 5 minutes prior to touchdown and penetrate at high speed into the Martian soil to search for traces of vaporized water ice. The Deep Space 2 probes cost $29.6 million to develop. Unfortunately, the Lander was lost December 3, 1999, while attempting to land. The two small probes also were lost. NASA's mishap investigation team concluded that the premature shutdown of the Lander's descent engines was the most probable cause for the loss of the spacecraft.

Mishap Investigations Raised Concern That NASA Did Not Heed Lessons Learned

The failure of the Mars Polar Lander and Climate Orbiter spacecraft raised concern that lessons learned from past mishaps and programs were not being applied effectively toward future mission success. Support for this comes from reports commissioned by NASA that reviewed spacecraft failures in the Mars Program, Shuttle wiring problems, and an assessment of the agency's approach in executing "Faster, Better, Cheaper" projects.[1] These reports identified the root and contributing causes for failure as well as making broader recommendations on ways NASA might improve its general approach to executing programs and projects.

NASA's decision to leave critical information-gathering mechanisms off the Mars Polar Lander is a case in point. The importance of downlink telemetry[2] during critical mission events was a lesson learned from the failure of NASA's 1992 Mars Observer mission that was not heeded during design of the Mars Polar Lander seven years later. The design of Lander precluded transmission of critical communications or telemetry data during entry, descent, and landing on Mars. A Special Review Board determined that the probable cause of the loss of the spacecraft was due to a premature shutdown of the descent engines due to spurious signals generated when the Lander's legs deployed. The spurious signals gave a false indication that the spacecraft had landed. The board also determined that the spurious signals resulted from inadequate software design and systems testing.

Concern that NASA had not heeded past lessons learned was also confirmed in a recent study[3] conducted by RAND's National Security

[1] Mars Program Independent Assessment, chaired by Mr. A. Thomas Young (retired), Lockheed Martin; Mars Climate Orbiter (MCO) Mishap Investigation, chaired by Mr. Arthur Stephenson, director, Marshall Space Flight Center; NASA Faster, Better, Cheaper Task Force, chaired by Mr. Anthony Spear (retired), Jet Propulsion Laboratory; and Shuttle Independent Assessment, chaired by Dr. Henry McDonald, director, Ames Research Center.

[2] Telemetry is information on the condition of the spacecraft and its subsystems, such as the temperature and voltage of spacecraft batteries, that is transmitted to spacecraft operators on the ground.

[3] Sarsfield, Liam. *The Application of Best Practices to Unmanned Spacecraft Development: An Exploration of Success and Failure in Recent Missions.* (Santa Monica, CA: RAND, 2000).

Research Division. The purpose of the study was to provide guidance on practices that reduce risk and improve the performance of next-generation spacecraft by including an examination of NASA's successes and failures in building spacecraft both before and after implementing the faster, better, cheaper approach. The RAND study identified the top ten sources of failures in NASA programs and reported that a significant source of error has been the failure of NASA to incorporate lessons previously learned and consistently apply them. As shown in the following table, the reasons for failure of the Mars Polar Lander and Climate Orbiter are not new; they have been identified as areas of concern by major program reviews and have occurred during the development of several other space systems.

Table 1: Reasons for Spacecraft Failures

Reasons for Failure	Major Program Reviews			Major Mishap Reviews							
	Broad Area Review	Lockheed Martin Independent Assessment Team	Faster, Better, Cheaper Task Force	WIRE[a]	Mars Climate Orbiter	Mars Polar Lander	Lewis	SOHO[b]	Mars Observer	DC-X[c]	Challenger
Cost and Schedule Constraints	•			•			•		•		•
Insufficient Risk Assessment and Planning		•	•		•	•	•	•	•	•	•
Underestimation of Complexity and Technology Maturity	•		•				•	•	•		
Insufficient Testing			•	•	•		•		•	•	•
Poor Team Communication	•	•	•	•	•	•	•	•			•
Inattention to Quality and Safety	•	•	•		•						•
Inadequate Review Process	•	•	•	•	•	•	•	•		•	•
Design Errors	•			•	•	•			•	•	•
Inadequate System Engineering	•	•	•	•	•	•	•	•	•		
Inadequate or Under Trained Staff	•	•			•	•		•	•	•	•

[a]WIRE: Wide-Field Infrared Explorer
[b]SOHO: Solar and Heliospheric Observatory
[c]DC-X: Delta Clipper-Experimental

Source: RAND, used with permission.

NASA Efforts to Apply Lessons Learned from Mars Mishaps

In December 2000, NASA issued a report, *Enhancing Mission Success*, which identified specific actions the agency planned to take to apply prior mishap findings and recommendations broadly in order to improve its approach to executing programs and projects.[4] The development of this report was driven principally by the multiple mission failures associated with the Mars Program. As part of its assessment, NASA reviewed a total of 165 recommendations originating from the Mars mishaps reports, the Shuttle Independent Assessment, and the agency-wide assessment of faster, better, cheaper projects. As a result, NASA recommended 17 actions that are integrated into five broad themes: people, technology, risk management, program and project management, and communications.

One of the 17 recommended actions, which deals with improving communications, concerns knowledge management[5] and the recognition that NASA needs to do better in capturing, disseminating, and utilizing knowledge. This includes improving the capture and application of lessons learned from programs, projects, and missions, with the goal of ensuring that NASA does not have to keep "relearning" the lessons of the past–relearning evidenced by the reoccurrence of similar causes to mission failures or difficulties. The report also indicated a lack of access to and process for lessons learned. The recommended action further stated that the continuous capture and application of project knowledge and lessons learned must become a core business process within the agency's program and project management environment.

Lessons Learning: A Mechanism to Learn from Successes As Well As Mistakes

Use of lessons learned is a principal component of an organizational culture committed to continuous improvement. Lessons learned mechanisms serve to communicate acquired knowledge more effectively and to ensure that beneficial information is factored into planning, work processes, and activities. Lessons learned provide a powerful method of sharing good ideas for improving work processes, facility or equipment design and operation, quality, safety, and cost-effectiveness.

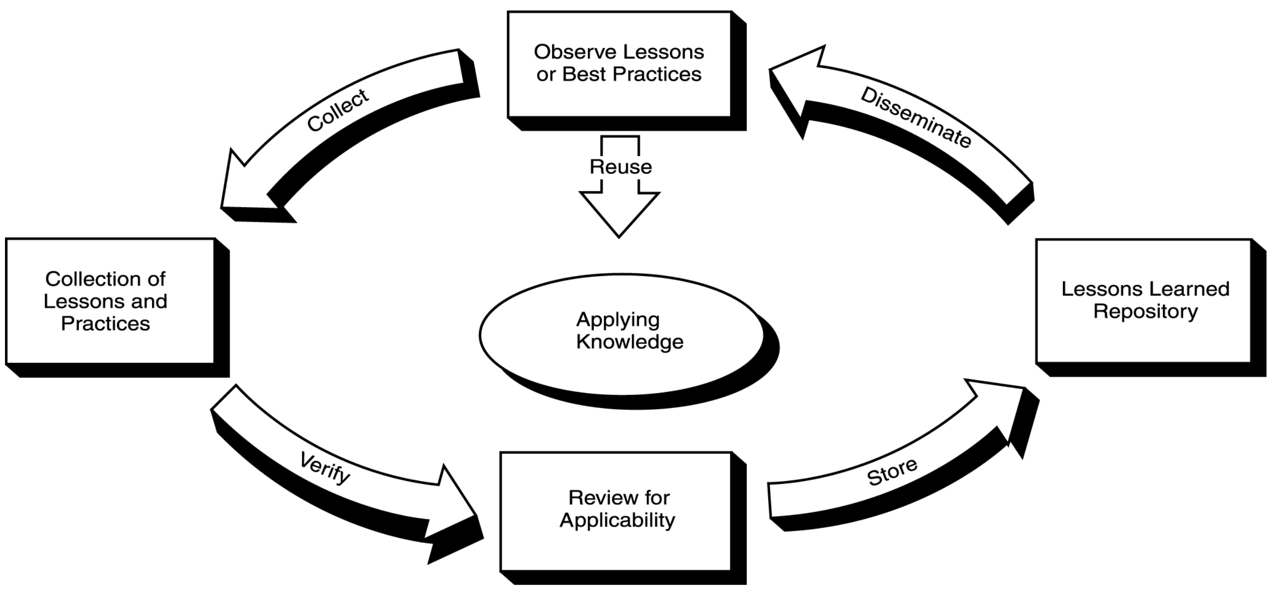
[4] National Aeronautics and Space Administration. *Enhancing Mission Success – A Framework for the Future.* A Report by the NASA Chief Engineer and the NASA Integrated Action Team, December 21, 2000.

[5] Knowledge management can be defined as the way that organizations create, capture, and re-use knowledge to achieve organizational objectives.

Elements of the Lessons Learned Process

The mechanisms or processes used to collect, share, and disseminate lessons learned may vary, but in general such a process is comprised of four main elements: collection, verification, storage, and dissemination. Figure 1 is a generic representation of the lessons learned process.

Figure 1: Generic Lessons Learned Process



Source: Based on Weber, R., Aha, D., and Becerra-Fernanadez, I. Categorizing Intelligent Lessons Learned Systems. *Intelligent Lessons Learned Systems: Papers from the AAAI Workshop* (Technical Report AIC-00-005). Aha, D.W. and Weber, R. (Eds.) pp. 63-67. Washington, DC: Naval Research Laboratory, Navy Center for Applied Research in Artificial Intelligence, 2000.

- The collection process involves the capture of information through structured and unstructured processes such as mishap or accident reporting, project critiques, written forms, and meetings. The collection of lessons may come from as many sources as an organization is willing to solicit. Lessons learned can be based upon positive experiences that prevent accidents or save money or on negative experiences that result in undesirable outcomes. However, if an organization focuses only on failures, its overall program's effectiveness will be reduced and it will miss opportunities to improve all its processes.

- The verification process serves to verify the correctness and applicability of lessons submitted. Domain or subject matter experts may be involved in coordinating and conducting reviews to determine whether or not a lesson is relevant across many other projects, is unique to a particular department or project, or applies globally to the organization as a whole.

- The storage aspect of lessons learned usually involves incorporating lessons into an electronic database for the dissemination and sharing of information. Information should be stored in a manner that allows users to identify applicable information searches. In addition, each program should include a keyword and functional category search capability to facilitate information retrieval.

- The final element, and the most important, is the dissemination of lessons learned, since lessons are of little benefit unless they are distributed and used by people who will benefit from them. Dissemination can include the revision of a work process, training, and routine distribution via a variety of communication media. Lessons can be "pushed," or automatically delivered to a user, or "pulled" in situations where a user must manually search for them. Lessons can also be disseminated with an assigned priority descriptor, which denotes the risk, immediacy, and urgency of the lessons learned content.

Objectives, Scope, and Methodology

The Chairman and the Ranking Minority Member, Subcommittee on Space and Aeronautics, House Committee on Science, requested that we examine whether NASA has sufficient mechanisms in place to ensure that past lessons learned are applied effectively towards future mission success. Specifically, we (1) identified what policies, procedures, and systems NASA has in place for lessons learning, (2) assessed how effectively these policies, procedures, and systems facilitate lessons learning, and (3) determined whether further efforts are needed to improve lessons learning.

We reviewed NASA policies and procedures and interviewed agency staff to determine how they captured, processed, and used lessons learned in their programs and projects. We also obtained briefings and documents on the different mechanisms used by NASA to capture and disseminate lessons learned. In addition, we conducted site visits at NASA headquarters, Washington, D.C.; Goddard Space Flight Center, Greenbelt, Maryland; Kennedy Space Center, Florida; Langley Research Center, Hampton, Virginia; and the Jet Propulsion Laboratory, Pasadena, California.[6]

To assess how effectively NASA's policies and procedures facilitate lessons learning, we conducted a survey of NASA program and project managers. We issued an interim report in September 2001 on the results of our survey.[7] NASA officials generally agreed with the survey results and indicated that the agency must do a better job of communicating various lessons learning resources to employees, improving linkages among the sources, and encouraging training to increase lessons learning. We build on the findings and results of our survey in this report. The methodology we employed in conducting this survey included the following steps:

- To obtain the views of NASA program and project managers on lessons learned processes and systems at NASA, we conducted a survey in June and July 2001 using a self-administered electronic questionnaire posted on the World Wide Web. The survey contained four groups of questions on (1) how NASA personnel collect, access, and use lessons learned; (2) the strengths and weaknesses of current NASA lessons learned processes, procedures and systems, including the Lessons Learned Information System; (3) potential challenges or barriers to sharing lessons learned within NASA; and (4) ways to improve the lessons learned processes and systems at NASA.

- In designing the questionnaire, we interviewed NASA officials and program and project managers, as well as other government and industry officials who had insight into lessons learned processes and systems. We also obtained and reviewed NASA documents and guidance pertinent to lessons learned. To further guide the development of appropriate questions, we reviewed current literature on lessons learned and knowledge management. To validate the content and structure of the questionnaire, we submitted it to officials at NASA headquarters and others for review and comment. To verify the clarity, length of time of administration, and suitability of the questions, we also pre-tested the questionnaire with selected program and project managers at Goddard Space Flight Center.

[6] The Jet Propulsion Laboratory is a federally funded research and development center. In our report, we treat the Jet Propulsion Laboratory as a NASA center in our discussions.

[7] U.S. General Accounting Office, *Survey of NASA's Lessons Learned Process*, GAO-01-1015R (Washington, D.C.: 2001).

- NASA officials provided us with a list of the e-mail addresses of all NASA program and project managers as of April 2001. On June 5, 2001, we sent e-mail messages to each of the 199 NASA managers in this survey population, notifying them of the survey and asking them to complete the questionnaire. Subsequently, we discovered one additional NASA manager who was eligible for our survey, and removed seven managers who were ineligible for the survey because they were not project or program managers at the time of the survey. We also eliminated one duplicate listing, resulting in a final survey population of 192.
- Over the following several weeks, until closing the survey on July 13, 2001, we received a total of 115 useable responses, for an overall response rate of 60 percent. All of the responses had been submitted using the Web questionnaire, although one participant had asked to submit a paper version of the survey, due to problems in accessing the Web survey. Of the 77 non-respondents, 9 provided partial questionnaire responses but had not indicated that they were finished with the questionnaire. Partial responses were not included in our survey results.

While we believe that our survey results are generalizable to the population of NASA program and project managers as described above, the practical difficulties of conducting any survey may introduce errors into estimates made from surveys. Although we administered questionnaires to all known members of the population, and thus our results are not subject to sampling error, non-response to the entire survey or individual questions can introduce a similar type of variability or bias into our results to the extent that those not responding differ from those who do respond in how they would have answered our survey questions. In addition, population coverage errors can occur if some members of the population are excluded from the survey. Measurement errors can arise from how questions are interpreted by respondents and mistakes made by respondents. Data processing errors can arise during the handling or analysis of responses. We took steps in the design, data collection, and analysis phases of our survey to minimize such errors, such as pre-testing questionnaires before the survey, following up with those not reachable at original e-mail addresses or otherwise not immediately responding, and checking for errors in computer programming used to analyze survey results. In addition, the distribution of respondents across NASA enterprise areas generally reflected the actual distribution of the entire population, which was consistent with our belief that non-response error was not significant.

To identify practices for improving NASA's lessons learning processes and systems, we reviewed existing literature on lessons learning and knowledge management practices. In addition, we identified a selected number of commercial and government organizations that are practitioners of knowledge management and obtained information related to their experience. In making our selections, we reviewed literature and spoke with industry and academic experts to find organizations recognized for their ability to share lessons learned or effectively manage knowledge. We identified the following organizations: World Bank, United States Department of Energy, Ford Motor Company, TRW, Boeing Space and Communications, Northrop Grumman, and Lockheed Martin.

We discussed with representatives from each organization the processes they used for sharing information, emphasizing those practices that were critical for successful lessons learning. During our discussions with the organizations, we compared and contrasted their practices with those of NASA. This allowed us to identify practices that NASA could use to improve its processes and systems. For each organization, we interviewed key managers and obtained documentation to determine (1) the processes and tools used to enhance information sharing and (2) the extent to which these processes and tools affected the organizations' ability to share information.

Our work was performed from October 2000 through September 2001 in accordance with generally accepted government auditing standards.

Chapter 2: NASA Policies, Processes, and Systems for Lessons Learning and Knowledge Sharing

NASA uses various mechanisms to communicate lessons garnered from past programs and projects. Policies and guidelines, programmatic and technical reviews, mentoring and training programs, the Academy of Program and Project Leadership, and the Lessons Learned Information System (LLIS) are all mechanisms employed by NASA for capturing and sharing lessons learned. While not the only means available for capturing and disseminating lessons learned, LLIS is the “official” agency-wide repository for such lessons. In addition to agency-wide mechanisms for collecting and sharing lessons learned, several NASA centers also operated lessons learned systems configured to support specific programs, such as the International Space Station.

To improve the way the agency captures and shares information and lessons learned, NASA has recently formed a knowledge management team. Knowledge management is a business strategy used by many organizations that strive to make more effective use of the experience and expertise of employees within an organization. Organizations believe that by developing new ways to capture and share knowledge, they can increase productivity, collaboration, and innovation.

NASA’s Policies and Procedures Require Lessons Learning

NASA’s policies and procedures require the continuous capture, dissemination, and utilization of lessons learned. NASA defines a lesson learned as knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has a real or assumed impact on operations; valid in that it is factually correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result.

Program and Project Managers Are Directed to Review Lessons Learned

To ensure that lessons learned from previous experiences are used as a resource, NASA Procedures and Guidelines for Program and Project Management Processes and Requirements (NPG 7120.5A) directs each program and project manager to review and apply significant lessons learned from the past throughout the program or project life cycle. Managers are also directed to consult LLIS prior to major milestones to gain lessons from past programs and projects that are documented and collected as a benefit to future programs and projects. Program and project managers are also directed to document and submit to the LLIS in a timely manner any significant lessons learned throughout the life of a project or program. One of the objectives of the agency’s guidance is to protect against the recurrence of past mistakes and provide a mechanism for sharing best practices.

NASA Mishap Reporting and Investigating Policy (NPD 8621.1G) and NASA Procedures and Guidelines for Mishap Reporting, Investigating, and Recordkeeping (NPG 8621.1) also require the development of lessons learned from the mishaps for possible application to existing or future programs.[1] In addition, NASA is supposed to exchange lessons learned and other pertinent safety information of common interest with other federal agencies, international partners, and NASA contractors. Since NASA uses contractors to produce many of its systems, NASA's Procedures and Guidelines for Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts (NPG 8735.2) requires that lessons learned during the contract surveillance activities be captured and submitted to LLIS.

NASA Uses Numerous Methods for Lessons Learning

Lessons learned mechanisms are used by many commercial and government organizations to share and use knowledge derived from experience to (1) promote the recurrence of desirable outcomes, or (2) preclude the recurrence of undesirable outcomes. Policies and guidelines, programmatic and technical reviews, training programs, and the LLIS are all mechanisms employed by NASA for capturing and sharing lessons learned. While not the only means available for capturing and disseminating lessons learned, LLIS is NASA's only agency-wide repository for such lessons.

LLIS is NASA's Principal Mechanism for Sharing Lessons Learned

The purpose of LLIS is to capture and share lessons learned from programs, projects, and missions and to help ensure that NASA does not have to keep "relearning" the lessons of the past. LLIS was created in 1995 and subsequently updated to include a Web interface. Program and project managers are directed to use LLIS to identify and share lessons learned, thus facilitating the early incorporation of safety, reliability, maintainability, and quality into the design of flight and ground support hardware, software, facilities, and procedures. Currently, the system

[1] NASA defines a mishap as "an unplanned event that results in injury to non-NASA personnel caused by NASA operations; damage to public or private property (including foreign property) caused by NASA operations; occupational injury or occupational illness to NASA personnel; damage to NASA property caused by NASA operations; or mission failure."

contains over 900 lessons learned on the development and design of aeronautics and space systems.

Lessons entered in the LLIS database are screened for relevance and to ensure that they do not contain sensitive or proprietary information. Initial reviews of lessons are usually conducted by the centers with a final review conducted by the Office of Safety and Mission Assurance. After a lesson is entered into the system, it is not reviewed for currency or relevance. In other words, once lessons are entered, they remain in the database indefinitely. The Office of Safety and Mission Assurance monitors the system to determine the number of times it is accessed, a search is conducted, and/or search results are obtained, but does not collect information on the number of times lessons are applied to a program or project.

Administrator for Safety and Mission Assurance is Responsible for LLIS

NASA's Quality Management System Policy (NPD 8730.3) establishes the Quality Management Systems used by the agency to identify and control processes to assure the quality of hardware, software, and services provided.[2] According to this policy, the Associate Administrator for Safety and Mission Assurance is responsible for ensuring that the LLIS database is maintained and accessible. Furthermore, the policy states that the associate deputy administrator and the center directors are responsible for ensuring that LLIS is used to ensure quality and document, investigate, and apply lessons learned for all programs and projects.

Center and Program Based Systems Used to Collect and Disseminate Lessons Learned

While NASA's LLIS is supposed to be the NASA-wide system, several NASA centers maintain their own electronic lessons learned systems. For example, the Goddard Space Flight Center uses the Flights Programs and Projects Directorate Lessons Learned Database to collect lessons learned for each flight project. Once a lesson is approved, it is passed along to the center data manager for review and eventual submission to LLIS, thereby ensuring that what has been learned at the Goddard Space Flight Center is accessible to other facilities. One lesson that was passed along from the Goddard Space Flight Center system is the benefit of testing deployable devices, such as the Landsat 7 solar array, early in satellite development. Testing devices early is a cost-effective tactic for developing complex and critical mechanism subsystems. By testing the Landsat 7 solar array early,

[2] NASA's Quality Management System is implemented in accordance with the International Organization for Standardization's ISO 9000 Quality Management System Standards.

program officials were able to discover problems that could have resulted in a program delay and increased costs. Another lesson in the Flights Programs and Projects Directorate Lessons Learned Database makes a recommendation on minimizing the effects associated with ongoing construction at mission-critical facilities. Specifically, NASA officials learned the importance of developing a strategy to minimize conflicts between the construction schedule and project requirements. One of the recommendations for future projects is that construction activities in mission-specific support areas of a mission-critical facility should be suspended 30 days prior to launch to ensure that the facility is ready to support mission operations.

In addition, program-based lessons learned databases have been established for key NASA programs. For example, the International Space Station and Phase 1 Lessons Learned Database documents historical lessons learned from the Phase 1 Program, U.S./Russian Program Office of the International Space Station Program; the top ten lessons learned during the Skylab program; and current lessons learned from the International Space Station Program.[3] The International Space Station and Phase 1 Lessons Learned Database is the official system for submitting new lessons learned in the International Space Station program. The lessons learned collected in that Lessons Learned Database are intended to be used as tools for the improvement of International Space Station operations. NASA officials are deliberating the feasibility of transferring the lessons learned from the International Space Station database to the NASA-wide LLIS.

NASA Uses Training for Capturing and Sharing Lessons

Another mechanism used by NASA to share lessons is training. NASA's Academy of Program and Project Leadership (APPL) provides numerous courses throughout the year.[4] Many of the classes employ case studies to learn from successes and failures. According to an academy official, lessons learned are incorporated into the different courses. Lessons incorporated into the curriculum are generic and can be applied to all programs (i.e., better communications) rather than technical issues unique to a particular program. About 4,000 program management employees

[3] Skylab was the United States' first experimental space station. The Skylab program's objectives were to prove that humans could live and work in space for extended periods, and to expand our knowledge of solar astronomy.

[4] The Academy of Program and Project Leadership is the NASA education organization responsible for training program and project managers.

have attended academy courses, and thus they contribute to sharing information within the organization.

In addition to formal training, APPL engages in development activities, which play a role in diffusing knowledge throughout NASA. For example, it hosts a series of forums on “hot topics” to gather and disseminate information. Another activity involves capturing and sharing the experiences of program managers. Once a year, APPL sponsors two sessions in which project managers considered the “best” by their centers are sent to discuss project management. At these sessions, two or three project managers from each center share what works and the types of tools that they need to accomplish their jobs.

Another activity used by APPL is encouraging senior program managers to share their knowledge through a series of short stories made available through its Web site. Each story discusses a topic that will help program managers succeed. One recently completed story dealt with the importance of saying no. According to a NASA official, many developing project and program managers are driven by NASA’s “can do” attitude and have a hard time knowing when to say “no” during a project. NASA is also identifying capable individuals to mentor new project and program managers. In addition, managers are provided several online tools and training resources, such as project management tools that can be used to effectively manage a project.

Changes to Policy Also Reflect Lessons Learned

According to NASA officials, periodic revisions to agency policies and procedures are another way that the agency shares lessons learned. For example, NASA is currently revising its Program and Project Management Processes and Requirements (NPG 7120.5A) and will incorporate some of the issues raised by the Mars Climate Orbiter and Polar Lander mishaps. This document is intended to provide the basic processes, requirements, and responsibilities for managing NASA programs and projects.

Additional Steps Taken by NASA to Facilitate Lessons Learning

In response to the Mars Program failures and the recommendations of the NASA Integrated Action Team, NASA has taken steps to promote the capture and sharing of knowledge within the agency by developing new policies, processes, and practices for program and project management. Foremost among these is the development of a business strategy commonly referred to as knowledge management. According to NASA officials, knowledge management has the potential to link people with the information and resources they need to complete tasks faster, better, and cheaper. Knowledge management can be defined as the way that organizations create, capture, and re-use knowledge to achieve organizational objectives. Organizations that manage knowledge effectively claim higher performance, innovation, and collaboration among employees. Lesson learning in the context of knowledge management is defined as “knowledge, both positive and negative, gained through experience, which if shared, would benefit the work of others.”

NASA Created a Knowledge Management Team to Coordinate Knowledge Sharing Activities

NASA has recently created a knowledge management team, composed of headquarters and center officials, to advise the agency’s chief information officer (CIO). The team does not act as a central authority for knowledge management, but rather as a focal point for coordinating knowledge management activities conducted throughout the agency. Its goal is to connect the various knowledge management activities ongoing in the agency and avoid duplication. The team is currently working on efforts to baseline knowledge management in NASA, gather requirements, and define opportunities for applying knowledge management.

Knowledge Management Projects Conducted by Selected Centers

Several centers have initiated knowledge management projects in the past few years. For example, the Ames Research Center is designing and developing a comprehensive information technology program called Design for Safety/Engineering for Complex Systems to help programs and projects agency-wide manage risk and capture and disseminate knowledge and lessons learned. The Johnson Space Center is piloting a Quality Assurance database, and the Jet Propulsion Laboratory is developing an “experts” directory as well as a Technical Questions database. In addition, the Kennedy Space Center has created a category of knowledge managers in each of its directorates who are responsible for identifying and recognizing core knowledge management competencies. Furthermore, the Langley Research Center has initiated a process to reward scientists if knowledge they have shared is used by others. The re-use of the knowledge must be documented in order for the scientist to receive the reward.

CIO-Sponsored Knowledge Management Pilot Projects

NASA’s CIO supports agency knowledge management efforts by investing in information technology projects to facilitate knowledge sharing. The NASA Knowledge Management Team advises the CIO on projects submitted by the centers for funding. In fiscal year 2000, the CIO funded three knowledge management pilot projects totaling $567,000. For fiscal year 2002, the CIO has a budget of $3 million that can be used to fund selected knowledge management initiatives. Because knowledge management projects are not centrally managed or funded, there is no visibility over how much the various NASA centers spend on them.

One of the projects being funded is to develop an agency-wide Web portal to bring together NASA's online information resources,[5] which are currently dispersed across different agency functional areas, centers, and programs. The portal will integrate existing resources and provide users with more direct access to information from across the agency. A second project is intended to develop a directory of agency expertise, which will allow NASA personnel to quickly locate others working in a related field or on a particular project and thus enhance collaboration among distributed groups. When complete, the directory will be integrated into the NASA Web portal.

The third CIO-funded project will improve the capture and re-use of lessons learned by augmenting the agency's current LLIS. The pilot project was a collaborative effort involving the Jet Propulsion Laboratory, Langley Research Center, and the Air Force Research Laboratory. The Jet Propulsion Laboratory team was responsible for defining the processes used to create and capture lessons learned, as well as the functional and system requirements for the system's redesign. The Langley Center was responsible for developing the digital library technology for the system. The Air Force Research Laboratory role was to evaluate the system design.

After spending about $135,000 to develop a system requirements document and a new system software design, NASA terminated the pilot project. According to a NASA official, the Office of Safety and Mission Assurance considered the functional and system requirements document to be inadequate, and their office lacked the resources to implement the proposed prototype. However, since the termination of the pilot, the Goddard Space Flight Center has been tasked with determining ways to improve the LLIS. Officials there have proposed a subscription service that would enable users to receive lessons learned tailored to their interests. Other follow-on LLIS improvement efforts under consideration include an improved searching and storage capability and the ability to append to, update, and control lessons configuration over extended periods of time.

[5] A portal is a Web site that is a major starting site for users when they connect to the Internet or Intranet. A portal can include features such as a topical index, search engine, e-mail, news, and links to other online tools.

Strategic Plan for Knowledge Management

In March 2001, the Knowledge Management Team issued a Strategic Plan for Knowledge Management that provides a framework for addressing knowledge management in NASA in terms of people, process, and technology (see table 2). According to the plan, "people" are the most important component of knowledge management. It calls for recognizing and rewarding people for sharing knowledge as well as encouraging story telling and establishing communities of practice to promote knowledge sharing. The plan also advocates the development of policies and procedures for capturing and managing knowledge that must be published and understood by users. In addition, the plan emphasizes the need for better information technology to facilitate knowledge management. In the context of lessons learning, the plan suggests providing a subscription service that tailors specific lessons to user-defined interests and pushing positive lessons to users' desktops based upon project tasks or organizational characteristics.

Table 2: NASA's Framework for Knowledge Management

People	Process	Technology
Enable remote collaboration	Enhance knowledge capture	Enhance system integration and data mining
Support communities of practice	Manage information	Utilize intelligent agents
		Exploit expert systems
Reward and recognize knowledge sharing		
Encourage storytelling		

Source: Strategic Plan for Knowledge Management, March 2001.

Chapter 3: Lessons Learned Are Not Being Consistently Shared or Applied Toward Future Program Success

Although NASA recognizes it is more critical than ever to share knowledge and collect, store, and distribute lessons learned, the agency's current array of processes, systems, and culture do not facilitate such an environment. Importantly, our survey revealed that lessons are not routinely identified and shared by program and project managers, LLIS has not proven useful to these managers, and there is little incentive for managers to share. As a result, program and project managers are not maximizing opportunities to apply lessons learned toward its faster, better, and cheaper efforts.

Fundamental Weaknesses Exist in NASA's Processes, Procedures, and Systems for Lesson Learning

NASA's procedures and guidelines require that program and project managers review and apply lessons learned from the past throughout a program's or project's life cycle and document and submit any significant lessons learned in a timely manner. However, a survey we conducted of all NASA program and project managers revealed fundamental weaknesses agency-wide in the collection and sharing of lessons learned. While some lessons learning does take place, our survey identified that lessons are not routinely identified, collected, or shared by program and project managers. In addition, many respondents indicated that they are dissatisfied with NASA's lessons learned processes and systems. Respondents also identified challenges or cultural barriers to the sharing of lessons learned as well as areas of improvement. As a consequence, there is no assurance that lessons are being learned and applied to future mission success. We provided the basic results of our survey in a September 2001 report.[1] The following analysis builds on those results.

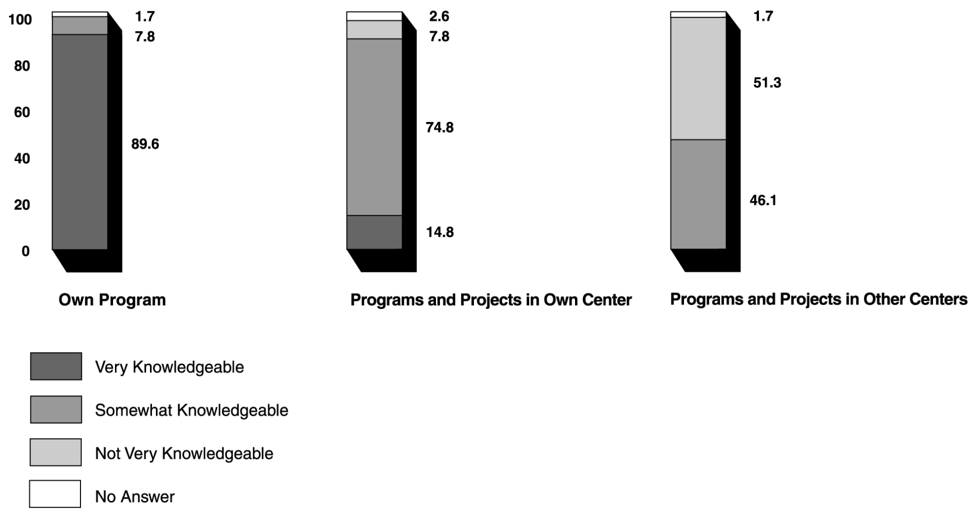
Limited Sharing of Lessons Learned Agency-Wide

To better understand the extent that lessons are being collected and shared within NASA, we asked program and project managers what they knew about lessons generated by their own programs and centers as well as by other centers. As shown in figure 2, program and project managers responded that while they are very or somewhat knowledgeable about lessons generated by their own programs and centers, they know less about lessons generated elsewhere. This fact was further substantiated by survey results which show that managers primarily identify lessons through program- or center-based activities such as project reviews or informal discussions with colleagues. For example, one project manager

[1] U.S. General Accounting Office, *Survey of NASA's Lessons Learned Process*, GAO-01-1015R (Washington, D.C.: 2001).

stated that monthly reviews with center management provided a way to capture and share lessons learned. The LLIS, NASA's primary method for disseminating lessons learned agency-wide, was not identified as a primary source for lessons learning.

Figure 2: Program and Project Managers Knowledge of Lessons Learned

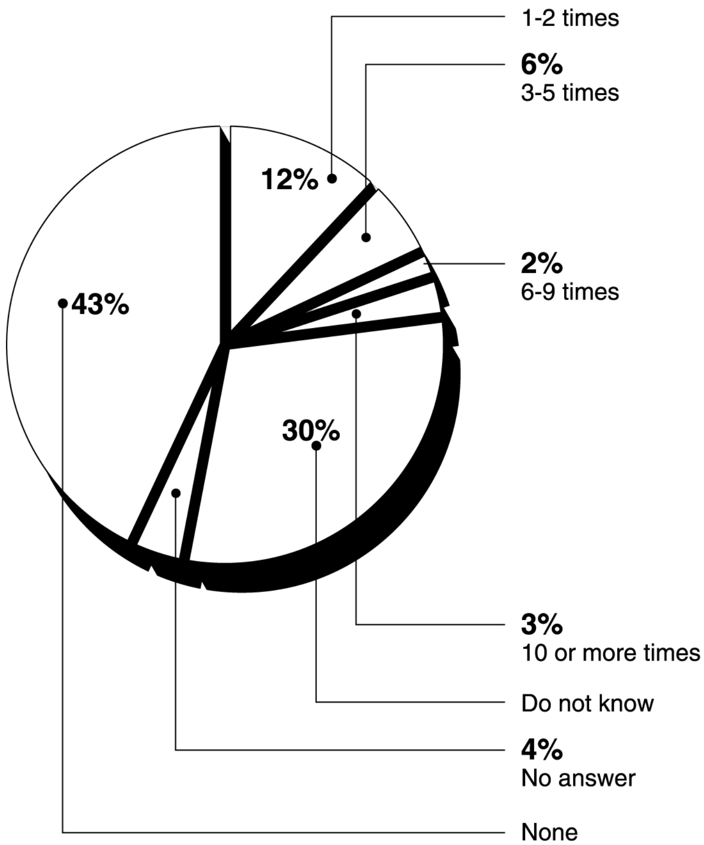


Respondents to our survey also indicated that their principal sources for identifying lessons learned were (1) system and engineering reviews, (2) program and project briefings, and (3) informal discussions with colleagues. According to NASA program officials, regular program and project meetings, reviews, and briefings provide an opportunity to share information, including lessons learned. For example, officials at Kennedy Space Center explained that after each space shuttle launch they gather to discuss what went well and what could be done better. Program and project managers also indicated that they maintain informal networks with colleagues where lessons learning take place.

Project reviews and informal discussions with colleagues are important mechanisms for lessons learning; however, they do not facilitate the systematic, agency-wide sharing of lessons. LLIS, which was established for such agency-wide sharing, is not widely used, according to survey respondents, even though NASA guidelines state that program and project managers should consult it prior to major milestones and submit any significant lessons learned in a timely manner. One reason the system is not widely used, according to one center official, is that its lessons cover so many topics that it is difficult to search for an applicable lesson. One of our survey respondents indicated that “It is difficult to weed through all the irrelevant lessons to get to the few ‘jewels’ that you need to find. There should be better categories to find relevant lessons.” Also, contractors, who perform much of NASA’s work, are unable to query the system easily. As shown in figure 3, in the past 2 years, 43 percent of program and project managers have not submitted a lesson to the LLIS compared to 23 percent of managers who have. The survey revealed there is also a low level of awareness of the system among managers; 27 percent of program and project managers were not aware of LLIS before our survey.

According to some project officials, accessing LLIS is time consuming and uses significant project resources. One official said it took about two weeks to review the lessons in the database. Another said that developing the process of assessing the applicability of lessons learned from the database for that project was very labor intensive and costly. For example, one project reviewed all the lessons learned in LLIS and attached the appropriate lessons learned as an appendix to the project’s Mission Assurance Plan. In contrast, another project developed a matrix containing all the lessons learned from LLIS categorized by functional area and technical discipline. Project teams organized by discipline then reviewed the lessons learned for applicability to the project. Further, while some projects formally reviewed lessons learned from the Mars Program failures, others did not. However, other projects reviewed the lessons learned from both LLIS and from the Mars Program failures.

Figure 3: Many Program and Project Managers Have Not Submitted Lessons to the Lessons Learned Information System

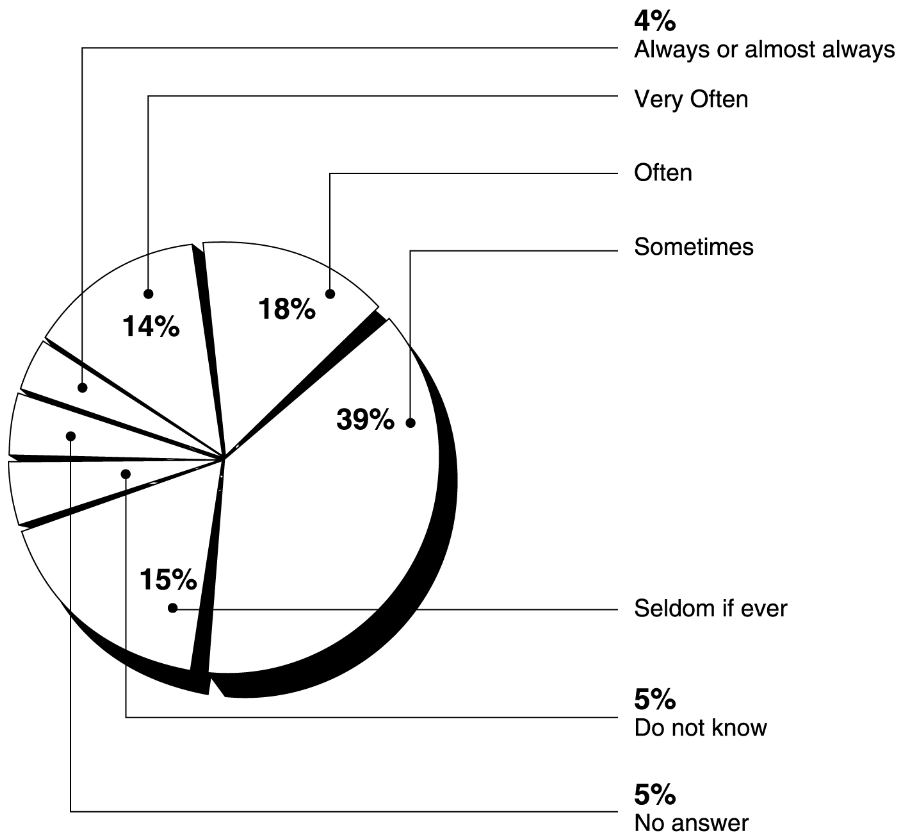


Dissatisfaction with Lessons Learned Processes and Systems

Our survey also determined that more managers are very or generally dissatisfied than are satisfied with NASA's lessons learned processes and systems, including LLIS. This level of dissatisfaction may stem from the fact that 58 percent of managers stated that current processes and systems do not allow them to retrieve the right lessons at the right time. As shown in figure 4, the level of dissatisfaction may also stem from the fact that 53 percent managers stated that they found lessons useful less than 25 percent of the time. One senior center official stated LLIS serves more as a repository of information that favors technical lessons, and is not effective for passing along such information.

Also, managers stated that it would be beneficial if more emphasis were placed on the reporting of positive lessons that are derived from successful program outcomes. For example, a positive lesson noted on the Jet Propulsion Laboratory's Deep Space 1 program was having the same program management team from the beginning through the end of the primary mission. One manager noted that positive lessons can be even more helpful to a project than negative ones because even if a project avoids negatives, without positives managers may not follow the most effective and efficient path to mission success.

Figure 4: Most Program and Project Managers Could Not Identify Helpful Lessons for Their Program or Project



Barriers Exist to Lessons Learning

If lessons learning is to succeed, it is important that the organizational culture fosters the value of sharing knowledge based on others' experiences. Our survey respondents identified several notable cultural barriers that affect lessons learning within NASA. These included:

- perception that there is no benefit from lessons learned;
- lack of time to share knowledge;
- lack of trust;
- intolerance for mistakes.

Our survey found that many program and project managers (39 percent) believe that implementing lessons learned contributes only some or little to improving mission effectiveness. This perception was highlighted by one manager who stated that “Until we can adopt a culture that admits frankly to what really worked and didn’t work, I find many of these tools to be suspect.”

Another critical barrier highlighted by the survey is the lack of time available for lessons learned. Managers reported that they and their project staff are very busy conducting assigned project tasks, and little, if any, time is allotted for lessons learning. One manager noted that “It is time consuming to agree on correct lessons learned for a project and accurately describe the issue…in a way that is helpful to a project.” Managers also noted that there is reluctance to share negative lessons for fear that they might not be viewed as good project managers. According to some respondents, this appears to stem from a culture that sees lessons learned as negative, i.e., an admission of failure. For example, one manager noted that “People are never rewarded for telling about how they screwed-up and caused a problem/mistake…. This will continue to be a problem until a way is found to allow and encourage people to talk about their mistakes without feeling that they are risking their careers.” The cultural barriers to lessons learning identified above present a serious challenge for NASA and the agency may well be missing fundamental opportunities to share and apply knowledge toward future mission success.

Suggested Improvements to Lessons Learning

While program and project managers identified a number of ways for improving lessons learning within NASA, mentoring was their first choice. One manager noted that the most effective lessons learned process results from the passing down of lessons from experienced people to those less experienced. We found that mentoring programs have been reinvigorated at a few centers in response to lessons learned from the faster, better, and cheaper changes as well as concerns that management expertise is being lost because of increasing retirements. Other suggestions for improvement included “storytelling” or “after-action reviews.” For example, NASA’s Academy of Program and Project Leadership asks senior program managers to share their knowledge through a series of short stories. Each story is 1 to 3 pages and discusses a topic that will help program mangers to succeed. A recently completed story deals with the importance of knowing when to say “no” in a project. However, most managers in our survey did not identify the academy as a principal source for lessons learning. Another notable suggestion was that senior management should be accountable for the infusion or engineering of lessons into a project with some kind of a matrix/metric to validate that the lessons were actually incorporated.

Managers also suggested a number of improvements regarding LLIS. As shown in table 3, suggested improvements were related to (1) developing a means to disseminate lessons from users, (2) improving the search capability, and (3) including more positive lessons. Currently with the LLIS, there is no automated dissemination of lessons, it is difficult to find relevant lessons, and there are few positive lessons included.

Table 3: Program and Project Manager Observations and Suggestions to Improve LLIS

Category	Specific Suggestion
Dissemination	• For non-NASA employees, it is extremely difficult to be granted access on a project basis. Team members on my project must apply for and be granted access on an individual basis. The process for access is tedious to say the least and this discourages routine use of the LLIS. • Send out lessons of the month. • Include a bulletin each week in the center newsletters about a lesson learned. • Send out alerts. • Tailor the dissemination or notification to target opportunities for benefit rather than blanket notification. Too much data inhibits information.
Searchability	• Have Mission Assurance Manager or Systems Engineer review LLIS on periodic basis & disseminate info where appropriate; this same individual could review failure/discrepancy reports for submission to LLIS. • Separate safety and mishap from program, technical, etc, lessons learned. Provide possible separate systems for each category: safety, technical, theoretical, Commercial product usage, contracting, project management, etc. • Better indexing - LLIS search usually does not return a high ratio of relevant information • Improved search engine. • Categorize the lessons into categories like the various technical disciplines and management disciplines, so that it would be easy to scan the ones you think are relevant to you.
More Positive Lessons	• Need more “positive” lessons learned. They can be even more helpful to a project than the “negative” ones. Even if a project avoids “negatives”, without “positives” they may not follow the most effective and efficient path to mission success. • When NASA has a failure, there are all sorts of reports on what went wrong from independent review panels (e.g. Mars Reports). It seems there would definitely be some benefit from similar type reports on projects that were successful, pointing out what these projects have done right. • Instead of focusing on the negative, focus on the positive things. There are some really well run projects. If people can look to great successes, instead of worrying about failures, I believe that they will try to emulate those successes. NASA has always been known as a risk taker because of what we do. We have no one else to look to, but within ourselves. I’m beginning to see something new at NASA - fear of taking a risk. As long as risks are calculated, and the project/program buys-in to taking that risk, it’s not a bad thing.

In discussions with NASA officials, we found there was general agreement with the problems and suggested improvements for lessons learning that were identified in our survey. Officials indicated that lessons learning has taken on greater importance in recent years due to the implementation of more programs and projects under the FBC strategy and the continuing loss of agency expertise due to attrition. They acknowledge that LLIS has not been an effective mechanism for agency-wide sharing of lessons. Although the system is viewed as providing a useful repository for storing lessons, officials agreed with managers’ concerns about the difficulties involved in searching the system and finding relevant lessons, the inconsistent quality of information contained in the system, and the lack of lessons about positive project experiences. However, while program and project managers’ suggested improvements would help increase the usability of LLIS, they do not target some of the more fundamental problems hampering NASA's ability to share lessons, such as the cultural barriers that persist.

Chapter 4: Creating an Environment for Lessons Learning through Knowledge Management

The limitations in NASA's ability to share lessons learned point toward two underlying problems: cultural resistance to sharing knowledge and the lack of an effective strategic framework and management attention for overcoming such resistance. The same problems often hamper organizations not only in sharing lessons learned, but also in broader efforts to use knowledge as a tool for increasing productivity and fostering innovation. We found that successful industry and government organizations have learned to overcome such barriers by developing strategic plans that provide a framework for how knowledge management will be implemented and by securing the management support and commitment needed to bring these plans to fruition. Moreover, they employ incentives, processes, and systems designed to overcome resistance and other cultural impediments to knowledge sharing. Just as employing these practices enables leading organizations to maintain a competitive edge, doing so can better position NASA to perform its basic mission of exploring space, faster, better, and cheaper.

Principles of Knowledge Management Could Help Mitigate Fundamental Weaknesses in Lessons Learning

We contacted practitioners of knowledge management in both government and industry to gain insight relative to how the application of knowledge management principles could mitigate the fundamental weakness in lessons learning identified by our survey. This effort included site visits and interviews of government and industry knowledge management practitioners, analysis of published case studies, and review of available literature. The outcome was the identification of common characteristics inherent in the design and implementation of knowledge management programs operated and maintained by government and commercial organizations. Literature searches and reviews of case studies also identified general principles deemed critical to the success of knowledge management.

Knowledge Management Must Be Linked to a Business Plan

According to practitioners of knowledge management, the first and perhaps most important element of knowledge management is to put in place a strategic plan that makes a business case for knowledge management. This involves translating the abstract concept of knowledge management into a vision, with goals and a roadmap for sharing and using knowledge within the organization. It also involves developing a collective vision that is long term and a commitment by senior management that they will see the plan through.

NASA has developed a strategic plan that identifies knowledge management goals and objectives the agency hopes to achieve. NASA, however, has not developed a business plan for achieving implementation of its vision and goals. Such a plan at a minimum should address the following:

- roles and responsibilities;
- knowledge needs and how they it relate to business processes;
- the role of information technology;
- a timetable for implementing for knowledge management;
- resources needed for implementing a knowledge strategy
- cultural barriers to learning;
- metrics needed for tracking and measuring results; and
- training.

Senior Management Support is Key to Knowledge Management's Success

While NASA senior management has shown its support for knowledge sharing and lessons learning, our survey nonetheless indicates that many program and project managers believe senior management support is lacking. Over one-third of survey respondents indicated that the effective utilization of lessons learning at NASA is inhibited because senior management lacks commitment to its use. One respondent stated that if management is serious about capturing and using lessons learned, then senior management must be seen and heard implementing the policy.

Of the organizations we observed, most had senior management who saw the strategic value in using knowledge and communicated to their employees that sharing knowledge is critical to their success.[1] At Ford Motor Company, the chief executive officer serves as a role model for knowledge sharing, personally writing weekly e-mails to employees with comments on his thoughts about and experiences of the past week.[2] Moreover, Ford executives provide sponsorship and support for

[1] Thomas Davenport and Laurence Prusak, *Working Knowledge: How Organizations Manage What They Know* (Boston: Harvard Business School Press,1998).

[2] Ford Motor Company 1999 Annual Report.

knowledge management. They encourage employee participation and recognize employees who share information.

An aerospace company believes that one of the best ways to disseminate lessons learned is to have management use them. This means that for the dissemination of lessons learned to be considered important by all the employees in the company, the executive team must understand and value them. This is accomplished by including as part of its executive training course items such as teaching managers how to file after action reports.

Management of Knowledge Sharing Activities

Although NASA's policies and procedures require continuous collection and sharing of lessons learned, NASA has not established a central management function to coordinate and direct its lessons learning processes and systems. Lessons learning activities are dispersed across several agency components. The Office of Safety and Mission Assurance has designated an administrator to maintain the LLIS; however, responsibility for LLIS is one of several assigned duties for the administrator. As a result, little effort is devoted to managing LLIS beyond keeping it operating. NASA has also established a team to coordinate recent knowledge management initiatives, but the team lacks authority to shape the direction or provide resources and tools to improve knowledge sharing.

Our research indicates that organizations that have implemented knowledge sharing programs often designate a knowledge management steward. For example, a recent article on knowledge management notes that ". . . a job title at Philip Morris is knowledge champion, Monsanto has a director of knowledge management, and Dow Chemical has a director of intellectual assets management."[3] Once such a position has been created, the steward is then responsible for identifying needs and opportunities for improvement, obtaining and distributing resources, applying and enforcing policies, and conducting daily operations. At Ford, a best practices coordinator manages the knowledge-sharing program. Similarly, at the World Bank, a Knowledge Management Office leads an organization-wide effort at knowledge sharing.

[3] Verna Allee, *Linking People, Learning and Performance -12 Principles of Knowledge Management*, American Society for Training and Development, (2001).

Investing in Knowledge Sharing Is Viewed as Important by Successful Organizations

NASA currently invests little in lessons learning. LLIS costs $50,000 to $100,000 annually to operate. And, according to NASA officials, funding is insufficient to upgrade LLIS in any significant way. Although there is no set answer as to the appropriate dollar amount that should be devoted to knowledge management, our review shows that those organizations that dedicate resources tend to be more successful at sharing knowledge effectively. Many of the organizations we contacted reported significant investments in knowledge management activities. For example, the World Bank invests about 3 percent of its total administrative budget in knowledge management. These resources are used for information technology systems, training, and dedicated staff to facilitate knowledge sharing.

A Corporate Culture That Encourages Knowledge Sharing Is a Key Element for Success

Although NASA acknowledges the importance of having an organizational culture that promotes teamwork and knowledge sharing, our survey indicated that significant cultural barriers within the agency inhibit an environment and culture that supports continuous learning. Our research indicates that practitioners of knowledge management foster an environment and culture that support continuous learning. Many knowledge management leaders agree that knowledge management is 90 percent culture and 10 percent technology.[4] A culture of knowledge sharing can be encouraged in many ways.

Effective Knowledge Sharing Requires Adequate Time

A common complaint among NASA survey respondents is the lack of time for sharing lessons learned. Consequently, knowledge-sharing activities at NASA are seen as simply an additional burden on an already tight schedule. Yet, if an organization values knowledge sharing it will allow time for knowledge sharing. Knowledge can only be shared when employees are given adequate time, as well as established places where they can actually transfer knowledge.

Formal And Informal Knowledge Sharing

Our survey indicated that much of the knowledge sharing at NASA is done on an informal basis. While talking informally with colleagues is one method of sharing information, it is not necessarily the most efficient way. Such informal exchanges do not allow the information to be further disseminated and do not necessarily allow the information to be validated.

[4] Directorate of eBusiness & Knowledge Management, Office of the Chief Information Officer, *DOD Knowledge Management Primer*, Department of Defense.

Information exchanges, however, are important because they allow people to discuss issues spontaneously. Many of the organizations that we examined instituted more formal arrangements for sharing information. Ford and the World Bank have established "communities of practice" as a method for sharing knowledge. They formed groups of employees who are bound together by shared expertise and a passion for joint enterprise.[5] These communities serve as knowledge transfer programs because employees can share information regarding a given issue. At the World Bank there are approximately 120 communities of practice—known as "thematic groups" arranged according to common interests, such as "urban poverty" or "urban services." The urban services group, for example, focuses on improving the living conditions in slums around the world by capturing and sharing past experiences and adapting them to today's experiences.

Incentives for Knowledge Sharing

Recently, some activities at NASA centers have sought to find ways to encourage knowledge sharing. For example, scientists at NASA's Langley Research Center are monetarily rewarded if knowledge they capture and share is re-used. Nevertheless, NASA has not developed a plan that details the principles, requirements, and architecture of how to implement its knowledge sharing strategy. While NASA realizes that rewards and recognition should be part of its initial priority area for knowledge management, the agency has not yet initiated any agency wide incentives for knowledge sharing.

Most of the organizations that we examined have developed incentives for knowledge sharing. Ford rewards employees who submit lessons learned that are adopted by the company. Managers are also encouraged to share because they are evaluated annually on the basis of knowledge sharing. Similarly, the World Bank has made learning and knowledge sharing part of core behaviors covered in each employee's performance evaluation.

Information Is Deemed Valuable

NASA is less successful at infusing lessons learned because the sharing of lessons learned is not highly valued by some program and project managers. Successful knowledge sharing organizations share knowledge because they view it as critical to their success. At Ford, for example, every plant is responsible for making a 5 percent productivity increase each year. Employees refer to this as "task." Ford's knowledge-sharing

[5] Wenger, Etienne and William M. Snyder. "Communities of Practice: The Organizational Frontier." *Harvard Business Review*. Jan/Feb. 2000:139-145.

database (Best Practice Replication system) provides managers with suggestions for improving efficiency, which in turn will enable managers to meet "task." Knowledge is shared because it meets a critical need. Moreover, managers at Ford use the lessons provided by the Best Practice Replication system because they trust the information, and experts within the organization have checked the best practice in the database for accuracy.[6] This is key to the Ford program.

Information Technology is Important, but Should Not Be the Only Mechanism for Knowledge Sharing

A pitfall of many knowledge management programs is the assumption that a database will automatically lead to knowledge sharing. Indeed, NASA's agency-wide effort at lessons learning is in practice limited to LLIS. At Ford, its electronic database is supplemented by other interactions. Not only do employees meet at community of practice meetings, but production engineers from the various plants also meet quarterly to discuss how each plant has implemented best practices. The World Bank not only uses a variety of databases to share information; employees also meet face-to-face at thematic group meetings and at knowledge fairs.

Well-designed information systems and databases, however, are important to facilitate knowledge sharing, especially for organizations such as NASA that have employees located at multiple centers across the country. Organizations with effective knowledge management have designed their database systems with heavy end-user involvement. The individuals who are intended to use the databases should be involved in the development and implementation of the system if it is to be successful. In addition, organizations often use dissemination mechanisms to "push" important and relevant information to the right people rather than have users to search for the information. NASA's LLIS requires users to search for possible useful lessons. In contrast, at the Department of Energy users receive automatic e-mail alerts regarding important lessons learned. Similarly, individuals at Ford receive new best practices every time they open the database system. Also, we found that organizations frequently dedicate "gatekeepers" to manage and monitor knowledge-sharing databases in order to keep the information up to date and relevant. At Ford, a "focal point" is assigned to manage the best practices system at each plant. The focal point is usually a production engineer appointed by the plant manager. They receive the pushed messages and also enter best

[6] Nancy M. Dixon, *Common Knowledge: How Companies Thrive by Sharing What They Know*, (Boston: Harvard Business School Press, 2000).

practices derived from their own plant. Similarly, at the Department of Energy a lessons learned coordinator maintains the lessons learned system at each site.

Chapter 5: Conclusions and Recommendations

The failures of the Mars Polar Lander and Climate Orbiter spacecraft raised concern that NASA was not learning from its past mistakes and applying lessons learned toward future mission success. Our survey of NASA program and project managers and subsequent analysis found that there are weaknesses in NASA's processes, procedures, and systems for lessons learning and knowledge sharing. Program and project managers indicate that current processes and systems do not allow them to retrieve the right lesson at the right time. Managers also report that they are not very knowledgeable about lessons generated from other centers and programs. This is partly due to the fact that NASA's LLIS is not widely used. As a result, there is no assurance that lessons learned from past mishaps or program successes are being applied to current programs and projects.

NASA has recognized that it must improve its lessons learning and knowledge sharing capabilities. The mandate to deliver leaner, more demanding, and increasingly more complex missions has resulted in a greater dependency on creating multi-disciplinary teams, building alliances with contractors, and being able to quickly link to and learn from other agency activities. Following a series of mission failures and mishaps, the NASA Integrated Action Team reported that the continuous capture and application of project knowledge and lessons learned must become a core business process within the agency's program and project management environment. More importantly, the team stated that program and project managers must regularly use knowledge management tools to apply previous lessons learned to their projects.

NASA has taken steps to promote the capture and sharing of lessons and other knowledge within the agency through knowledge management practices. According to NASA officials, knowledge management has the potential to rectify many of the weaknesses identified by our survey through more effective management of the agency's knowledge resources. Current knowledge management initiatives by NASA should lead to improvements in knowledge sharing, but the lack of a coordinated and well-supported effort will limit knowledge sharing agency-wide. Stronger commitment and efforts are needed to create an environment that encourages knowledge sharing. To achieve this environment, NASA must overcome communication barriers and create opportunities where open and candid communications are the norm and knowledge sharing is valued. In addition, time and resources must be dedicated in order for lessons learning and knowledge sharing to occur. Furthermore, improvements to information technology systems such as LLIS are needed to facilitate the collection, dissemination, and application of knowledge.

Recommendations for Executive Action

NASA needs to strengthen its lessons learning in the context of its overall efforts to develop and implement an effective knowledge management program. Improvement of NASA's lessons learning processes and systems can help to ensure that knowledge is gained from past experiences and applied to future missions.

We recommend that the NASA administrator strengthen the agency's lessons learning processes and systems by taking actions in the following areas:

Strategic Planning

- Articulate the relationship between lessons learning and knowledge management through development of an implementation plan for knowledge management.

Coordination

- Designate a lesson learned manager to lead and coordinate all agency lessons learning efforts.
- Establish functional and technical linkages among the various center-level and program-level lessons learning systems.

Culture

- Develop ways to broaden and implement mentoring and "storytelling" as additional mechanisms for lessons learning.
- Identify incentives to encourage more collection and sharing of lessons among employees and teams, such as links to performance evaluations and awards.

LLIS Enhancement

Enhance LLIS by

- coding information and developing an easier search capability to allow users to identify relevant lessons;
- including more positive lessons;
- providing a means to disseminate key lessons to users; and
- soliciting user input on an ongoing basis.

Performance Measurement

- Track and report on the effectiveness of the agency's lessons learning efforts using objective performance metrics.

Agency Comments and Our Evaluation

In written comments on a draft of this report, NASA generally concurred with our recommendations for improving the agency's lessons learned processes and systems. NASA stated that it must do a better job of communicating the various lessons learned sources to employees, improving mechanisms to link these sources, and ensuring appropriate training for employees in order to maximize lessons learning. NASA further indicated that it will develop plans to implement our report recommendations. NASA's comments are reprinted in appendix I.

Appendix I: Comments from the National Aeronautics and Space Administration

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

Mr. Allen Li
Director
Acquisition and Sourcing Management
U. S. General Accounting Office
Washington, DC 20548

JAN 14 2002

Dear Mr. Li:

We appreciate the opportunity to review and provide comments to the draft report, entitled, NASA: Better Mechanisms Needed for Sharing Lessons Learned. We have reviewed the report, and although may not agree with the conclusions that correlate Mars Mission failures with deficiencies in the application of lessons learned, we are essentially in agreement with the recommendations for improving our Lessons Learned Process. These recommendations are generally on the mark, and their intent will be implemented. There are several initiatives currently underway, and implementation plans are being developed.

We continue to evaluate NASA processes and will do the same for lessons learned. Major revisions to NASA Procedures and Guidelines (NPG) 7120.5, NASA Program and Project Management Processes and Requirements, are in the final stages and include more clarity in the use and scope of the Lessons Learned Information System (LLIS). Since NASA uses numerous sources for lessons learned, LLIS will no longer be referred to as the primary source, but one of many.

Programs and projects benefit from lessons learned day to day in many different forms. Some of these include status reporting, programmatic and technical reviews, and functional staff meetings. The more formal and widespread forms include technical standards and updating NPG's and other documentation. The various NASA training programs also incorporate lessons learned into their curricula, including "storytelling" by current and retired NASA program and project managers. One forum is designed specifically for sharing lessons learned and is titled Project Management Shared Experiences Program. The overall objective of this program is to provide a forum to understand key initiatives influencing NASA project management and for project people to share knowledge, experiences, and creative approaches to project management.

NASA must do a better job of communicating the various lessons learned sources, improving mechanisms by which these various sources are linked, and encouraging the proper training for employees in order to maximize the ability of current activities to draw upon the lessons of others. We plan continued improvement in these areas.

We appreciate the GAO assessment effort and subsequent recommendations on improving NASA's lessons learned system. This is a good example of agencies teaming for improvement.

At this time, we provide the following response, if the recommendations contained in the draft report are retained in the final report.

GAO Recommendation 1: Articulate the relationship between lessons learning and knowledge management through an implementation plan for knowledge management.

NASA Response: Concur. NASA has developed a "Strategic Plan for Knowledge Management" and "Near-Term Implementation Opportunities for Knowledge Management" which articulates the relationship between lessons learning and knowledge management. The Near-Term Implementation Opportunities plan will be revised to strengthen the linkage between knowledge management activities and processes for lessons learning. Some of the implementation activities are underway and others will be initiated as the overall implementation progresses.

GAO Recommendation 2: Designate a lessons learned manager to lead and coordinate all agency lessons learning efforts.

NASA Response: Concur. NASA is planning on designating a lessons learned manager.

GAO Recommendation 3: Establish functional and technical linkages among the various center-level and program-level lessons learning systems.

NASA Response: Concur. As NASA progresses in the implementation of knowledge management, methods to link the multiple lessons learning systems will be pursued and incorporated.

GAO Recommendation 4: Develop ways to broaden and implement mentoring and "storytelling" as additional mechanisms for lessons learning.

NASA Response: Concur. NASA will continue to hold several project management knowledge sharing forums, the annual publication of several issues of the online Academy Sharing Knowledge Journal, and the development of additional case studies and online knowledge sharing resources. Efforts are also underway to improve the systematic identification and utilization of NASA leaders as mentors and teachers, and processes and procedures will be completed in 2002.

3

GAO Recommendation 5: Identify incentives to encourage more collection and sharing of lessons among employees and teams, such as links to performance evaluations and awards.

NASA Response: Concur. In October 2001, the Agency began a new study--"Aligning Recognition and Awards with the Agency's Values and Expectations." A significant issue of this study scope is "What recognition practices in a technology-based organizational setting would drive and support particular initiatives in teaming, knowledge sharing, and organizational learning." Recommendations resulting from this study will be proposed by the end of this fiscal year.

GAO Recommendation 6: Enhance LLIS by coding information and developing an easier search capability to allow users to identify relevant lessons, including more positive lessons, providing a means to disseminate key lessons to users; and soliciting user input on an ongoing basis.

NASA Response: Concur. Since the inception of the LLIS in 1995 we have offered users an extremely easy-to-use "keyword" search capability for all data in the LLIS that functions in the same way as an Internet search browser such as "Yahoo" or "Lycos". Since 1999, we have also offered our users an advanced search capability. Currently, this advanced search capability allows users to search on several combinations of criteria (NASA Center/Facility, Enterprise, and Program/Project life-cycle stage), including keyword search. This collection of search combinations gives our users unparalleled searching flexibility.

Recent improvements now provide the capacity to disseminate key lessons to users with our new "push" capability. NASA will continue to study improvement possibilities for the LLIS to ease the system's use.

The LLIS web site offers several means by which users can presently contact us to provide comments or feedback on the system. We have a "submit a suggestion about the LLIS" link and a "comment on a lesson" link. We also have a hotline/help desk telephone number: 301-286-LLIS.

GAO Recommendation 7: Track and report on the effectiveness of the agency's lessons learning efforts using objective performance metrics.

NASA Response: Concur. Although challenging, NASA is pursuing the appropriate metrics to measure the effectiveness of our lessons learning efforts. We expect to have this in place later this year.

Thank you again for the opportunity to review this draft report. Should you have any questions, please call Keith Hudkins, Deputy Chief Engineer, at (202) 358-1823. The point of contact for this audit in the Office of the Chief Engineer is Gregory Robinson; he can be reached at (202) 358-2541.

Sincerely,

Michael D. Christensen

Michael D. Christensen
Associate Deputy Administrator for Institutions

cc:
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Appendix II: GAO Contacts and Staff Acknowledgments

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Acknowledgments

In addition to those named above, Christina Chaplain, Diana Dinkelacker, James Elgas, Jose Ramos, Carl Ramirez, and Lorene Sarne made key contributions to this report.

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