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DEVELOPMENT OF A NASA INTEGRATED TECHNICAL WORKFORCE CAREER DEVELOPMENT MODEL ENTITLED

REQUISITE OCCUPATION COMPETENCIES AND KNOWLEDGE—THE ROCK

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ABSTRACT

This paper shares the findings of NASA's Integrated Learning and Development Program (ILDP) in its effort to reinvigorate the HANDS-ON practice of space systems engineering and project/program management through focused coursework, training opportunities, on-the-job learning and special assignments. Prior to March 2005, NASA responsibility for technical workforce development (the program/project manager, systems engineering, discipline engineering and associated communities) was executed by two parallel organizations. In March 2005 these organizations merged. The resulting program—ILDP—was chartered to implement an integrated competency-based development model capable of enhancing NASA's technical workforce performance as they face the complex challenges of Earth science, space science, aeronautics and human spaceflight missions. Results developed in collaboration with NASA Field Centers are reported on. This work led to definition of the agency's first integrated technical workforce development model known as the Requisite Occupation Competencies and Knowledge (the ROCK). Critical processes and products are presented including: "validation" techniques to guide model development, the Design-A-CUrriculuM (DACUM) process, and creation of the agency's first systems engineering body-of-knowledge. Findings were validated via nine focus groups from industry and government, validated with over 17 space-related organizations, at an estimated cost exceeding $300,000 (US). Masters-level programs and training programs have evolved to address the needs of these practitioner communities based upon these results. The ROCK reintroduces rigor and depth to the practitioner's development in these critical disciplines enabling their ability to take mission concepts from imagination to reality.

FULL TEXT

INTRODUCTION

The tragic loss of the Space Shuttle Columbia on February 1, 2003 ushered in an era of significant organizational change and renewed workforce commitment at NASA. Guided by the recommendations codified in the final report of the Columbia Accident Investigation Board [CAIB, 2003][3] agency personnel at all levels sought ways in which the intent of those recommendations could be implemented in a manner that reduced the inherent risk associated with human and robotic space flight to the lowest level possible. No process, procedure or performing group was immune to the scrutiny stemming from the questions of "What are we currently doing?", "What can we be doing better?" and "How can we extend improvements across all activities?"

Career development of the technical workforce—the combined communities of project/program managers, systems engineers, discipline engineers, and associated professionals—was one of the areas reviewed for improvement during this period. Prior to the post-Columbia era, agency-wide development of the technical workforce at NASA was managed by two related but separate organizations, each with their own tailored programs. For program/project management and systems engineering these were the Academy for Program/Project Leadership (APPL) and NASA Engineering Training (NET), respectively. These organizations were located in the human resources organization and their programs were loosely coupled.

After the tragedy, reorganization activities within the agency focused upon the Office of the Chief Engineer (OCE). Led by the NASA Chief Engineer, the OCE ensures that missions are planned and conducted with sound engineering practices, as well as include proper controls and management approaches. The OCE accomplishes this through the issuance of policy, oversight and assessment of the engineering and project/program management communities. A survey of agency-related activities, including development activities, was conducted and resulted in the decision that all technical workforce "development" activities should be transferred to the OCE to complement the "execution" activities already associated with the office. This resulted in the organizational reassignment of APPL and NET to the OCE where they joined the NASA Engineering Services Center (NESC) Academy—the training program focusing on the development of discipline engineers.

It is important to note that while this action resulted in the co-location of the development programs for program/project management, systems engineering and discipline engineering it did not consolidate development of the entire technical workforce into the OCE. Development of the workforce responsible for mission assurance and safety remained within the Office of Safety and Mission Assurance. That said the integrated workforce development model discussed herein is believed to be fully extensible to this critical agency community.

With transfer of APPL and NET to the OCE complete, then NASA Chief Engineer R. D. Geveden recognized the potential duplication of effort and lost potential associated with having three parallel development programs to meet the needs of the technical workforce at NASA. If NASA was to fully realize its goal of meeting the challenges of the post-Columbia era then a new approach was required. This resulted in the immediate merger of APPL and NET into one, integrated program in March 2005.The new program was titled the "Integrated Learning and Development Program" (ILDP) and administratively placed under the oversight of then OCE Division Chief Christyl Johnson whose leadership facilitated the positive environment within which this activity was conducted. This paper presents the results of ILDP activities from March 2005 to February 2006.

From its inception, the ILDP team recognized the unique opportunity before it. The environment at NASA Headquarters and its Field Centers was uncommonly conducive to accepting a new integrated approach for the development of the agency's technical workforce. This opportunity was captured in the ILDP Vision Statement:

> *"Through a dedicated team, ILDP enables the NASA technical workforce to execute the agency's space flight mission requirements using the proficiency obtained through classroom, conference, and targeted work assignments."*

Table 1 presents the ILDP Need, Goals and Objectives.

The ILDP team was composed of NASA Civil Servants and support contractors, all of whom contributed to its success. The following list of personnel represents the key leadership assignments:

- Robert J. Menrad, ILDP Program Manager
- Anthony J. Maturo, ILDP Deputy Program Manager
- Dr. Wiley J. Larson, ILDP Deputy Program Manager for Curriculum Development
- Dr. Linda Morris, Area Lead, Program/Project Manager Development

TABLE 1. Integrated Learning and Development Program (ILDP) Need / Goals / Objectives. The ILDP scope reflects the post-Columbia environment intent to optimize career development of the NASA technical workforce—the community of program/project managers, systems engineers and discipline engineers.

Need: Implement an integrated technical workforce development model to consolidate training where possible, provide discipline-specific training tracks when necessary, and permit efficient transfer between development tracks to maximize development of the individual and benefit to the agency.

Goals	Objectives
Provide a unified technical work-force career development model for the agency.	Engage program/project, systems engineering and discipline engineering stakeholders from all NASA Centers and Headquarters.
	Model shall address all proficiency levels.
	The process to create the integrated model will employ strategies analogous to those used to "validate" readiness for space flight missions (i.e., validate vs. verify).
Integrate development requirements where possible.	Create or re-validate competency models.
	Identify common competencies and common proficiency levels for integration.
	Define "cross-over" points between development tracks to permit participant development in a new area with minimum redundancy and risk for missing content.
Define curriculum-based course work.	Offer focused course content in a manner that is immediately applicable to the participant's job.
Permit tailoring based upon participant post-course assessments and performance feedback from stakeholders.	Collect assessment data of job performance from participant and stakeholders.

- Dr. Gary Yale, Area Lead, Systems Engineer Development
- Dr. Kathleen VanScoyoc, Area Lead, Practitioner Assessment

The success of this effort was due in very large part to the collaborative environment in which it was executed. The ILDP Steering Committee was constituted by merging NET's "NASA Engineering Training Working Group" with project/program management development representatives from each NASA Field Center. Steering committee meetings were conducted quarterly, on average, and the level of interdependence and cohesion was higher than the authors had ever experienced; a testimony to the professional commitment and personal dedication each of these steering committee members brought to the ILDP initiative. Table 2 presents the membership of the ILDP Steering Committee.

TABLE 2. The Integrated Learning and Development Program Steering Committee. Representatives from all NASA Field Centers representing project/program management and systems engineering competencies participated in the ILDP Steering Committee. The success realized by the ILDP team could not have been possible without their active participation and dedicated efforts.

Name	NASA Affiliation
Ms. Junilla Applin	Langley Research Center
Mr. Al Bowers	Dryden Flight Research Center
Mr. David Coote	Stennis Space Center
Mr. Hector Delgado	Kennedy Space Center
Mr. Martin Forkosh	Glenn Research Center
Dr. Wiley Larson	Facilitator
Ms. Sally Ann Little	Marshall Space Flight Center
Mr. Anthony Maturo	Headquarters
Mr. Robert Menrad	Headquarters
Mr. Jerry Mulenburg	Ames Research Center
Dr. James Ortiz	Johnson Space Center
Ms. Barbara Pfarr	Goddard Space Flight Center
Mr. Jay Schmuecker	Jet Propulsion Laboratory
Ms. Susan White	Johnson Space Center

CREATING THE REQUISITE OCCUPATIONAL COMPETENCIES AND KNOWLEDGE (THE ROCK)

With its vision, need, goals and objectives defined the ILDP team turned its attention to the formulation of the integrated development model.

Definition of the Problem

It is well understood that combined skills and experiences necessary within a space mission project team are both diverse and detailed [APMSS, 2008][4]; no one competency set has all of the ingredients for mission success. Therefore, to be fully integrated any technical workforce development model would need to represent a significant set of skills and experiences. The ILDP team decided to focus initially on program/project management and systems engineering. There were several reasons for this selection:

- Program/project management was identified by the agency as a critical competency;
- NASA was already recognized as a world-class leader in the definition of space mission project management competencies and this represented a "control" against which results could be evaluated against a known and vetted baseline;
- Systems engineering was identified by the agency as the critical engineering competency;
- Both competencies represented senior-level positions that heavily influence the overall success of any space mission activity;
- By selecting only two competencies at the start the ILDP team was able to simplify the initial data to be ingested by an integrated workforce development model thereby mitigating complexity risk during the development of the model itself and avoid the potential need to descope the effort mid-stream;
- The ability to efficiently incorporate additional competencies in the future would represent validation of a key requirement of the model…to be a framework permitting future growth (scalability) and adaptation (extensibility) versus a model representing a point-solution.

A survey was conducted to identify competency sets already developed by each community which could serve as candidates for ILDP use. The survey results confirmed that this effort was to benefit significantly from the work already completed in competency definition for program/project management; a major input into the unified model. Both the Project Management Institute (PMI) developed Project Management Body of Knowledge (PMBOK) [PMI, 2004][5] and the NASA Academy of Program/Project Leadership (APPL) competency sets represented vetted products appropriate for benchmarking by the ILDP effort. Since the APPL product included the additional elements specific to space mission project management (e.g., mission assurance and safety) it was selected as the project/program input into the integration activity.

A similar survey for systems engineering competency sets was not as successful. In fact, the team was unable to identify a complete set with sufficient maturity, reviewed by the community or applicable to space mission projects in particular. Therefore, the ILDP management accepted the derived requirement to ensure that the integration model definition process captured a vetted "systems engineering" competency set as one of its products.

Formulation—The Paradigm and Preliminary Design

During formulation of the ROCK the underlying paradigm was defined in response to the requirements. The ILDP team condensed the conceptual design of any integrated workforce development model into three basic categories or phases:

- Global Community Development—the set of development goals that aim to address the need for universal "awareness". Such aspects treat the technical workforce as a single entity with a need for common information.

- Cross-Community Development—the set of development goals that two or more communities share in common that aim to address the need for "application" knowledge. Such aspects treat the involved communities as a single group for the purposes of delivering education and training opportunities.

- Focused Community Development—the set of development goals specific to one community and not shared by any other. Such aspects focus exclusively on that community and tailor the education and training environment to its specific needs.

Figure 1 illustrates the conceptual design of the integrated development model or "system" as developed by the ILDP team.

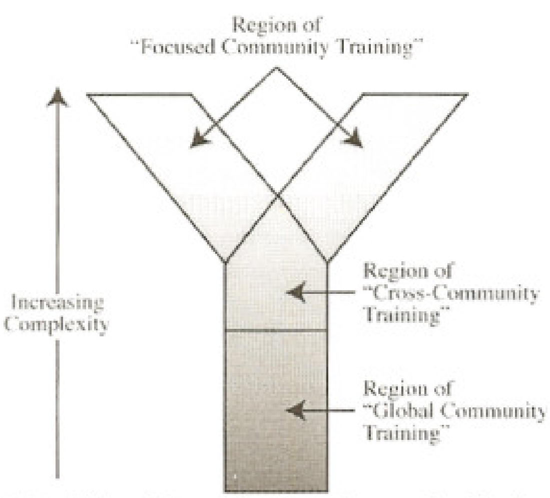

FIGURE 1. The Integrated Learning and Development Program's Integrated Development Model Conceptual Design. The ILDP model identifies three basic phases offered as essential to any multi-community integration effort: Global Community Training, Cross-Community Training and Focused Community Training.

A key component of the formulation process going forward was the objective to employ a tool that supported the principle of "mission validation" analogous to that applied by the agency to its human and robotic missions. This meant the tool would be required to:

- Elicit the accumulated experience of personnel recognized as performing at the highest level of proficiency;

- Prioritize the gross set of responsibility areas and specific tasks required of the individual performing at this level;

- Take into account the minor variances in experience and knowledge of any single individual despite the fact they were recognized experts in the field;

- Efficiently capture and integrate this aggregated knowledge in a generic and repeatable manner to permit cross-referencing across other disciplines with minimized opportunities for translation errors.

After a survey of available tools one stood out as unique in its proven ability to meet these requirements; the Design-A-CUrriculuM (DACUM) process. During its evaluation, the DACUM process was found to have a positive track record both inside and outside of NASA making it both a proven and repeatable technique for obtaining the very information from experts required by the ILDP team. In preparing for and executing the implementation phase of the integrated model's development, ILDP was most fortunate in obtaining the active participation of Mr. Mark Goldman, NASA Goddard Space Flight Center, an expert DACUM facilitator whose insight and experience proved exceptionally valuable for mitigating the inherent risks associated with any process of this kind.

Details about the DACUM process are available from multiple sources so will not be repeated here but the following is offered as a brief summary. The DACUM process is an occupational assessment tool comprised of three phases: needs assessment, data gathering workshop, and curriculum development. It is a controlled, repeatable process. During the facilitator-led workshop phase a group of experts in a specific occupation is assembled. By the completion of the workshop these experts have identified all the areas they are responsible for in the execution of their job (i.e., scope), the tasks they are responsible for within those areas (i.e., depth of responsibility), and when in their career they developed these skills (i.e., development timeframe). The captured information is expressed in behavioral terms for performing the occupation, not in career development terms. This is the key point; the experts always focus on the occupation they are experts in and not in the area of workforce development where they may have little or no experience. The translation of the workshop data into curriculum-development terms is completed by a second set of experts. As a result, it is the value of this expert-validated data efficiently passed between the appropriate expert groups which give the DACUM process its power.

The DACUM process is typically used to focus on a single, specific occupation. The ILDP team hypothesized that a modification to the *application* of the DACUM tool would make it an equally powerful tool in any effort to create an integrated development model *across* multiple occupations. This minor modification was implemented and proved to be a breakthrough for generating the results to follow. The catalyst for identifying this modification came from the conceptual design of the integrated workforce approach itself.

In defining its ILDP-unique execution plan the team identified the requirement to execute *three* DACUM workshops for the two occupations focused upon (i.e., project/program management and systems engineering). DACUM workshops 1 and 2 would focus exclusively upon one occupation each.

DACUM workshop 3, however, would be conducted with a single group of experts spanning *both* occupations. In this third workshop that the experts would focus on:

- Identifying the "common" areas of responsibility and associated tasks from the data collected in the first two DACUMs;
- Commonality in each occupation's traditional development paths for achieving the required level of proficiency;
- Collating each occupation's tasks into the development time-bins of: early-, mid- and late-career timeframes.

In effect, the ILDP team effectively treated the project/program and systems engineering domains as a single domain. With the occupation-specific information defined in the first two workshops, this third workshop defined the common threads for both occupations in terms of what proficiency levels are needed and when. The ILDP team recognized the opportunity with this third workshop to add new experts from both occupations. In this way "fresh eyes" vetted the inputs from the earlier workshops during its execution. The expert panel for the third workshop resulted in new observations that improved the overall quality of the earlier products but did not result in the identification of any gross errors thereby validating the quality of the original inputs.

Data Integration and Validation

The ILDP Systems Engineering DACUM was conducted June 1–2, 2005, in Potomac, Maryland, and was completed on schedule with no open actions. Table 3 presents the group of systems engineering experts who participated.

TABLE 3. The Integrated Learning and Development Program DACUM Systems Engineer Expert Group. The ILDP group of systems engineering experts was composed of individuals from inside and outside NASA in order to insure the broadest level of consensus.

System Engineer DACUM Representative	Affiliation
Mr. David Brown, Professor, Systems Engineering	Defense Acquisition University
Mr. Hector Delgado, Deputy Director, Independent Technical Authority and Systems Management Office	NASA - Kennedy Space Center
Mr. Dave Everett, Senior Systems Engineer	NASA - Goddard Space Flight Center
Mr. Richard Fullerton, International Space Station Systems Engineer	NASA - Headquarters, Space Operations Mission Directorate
Mr. John Huff, Systems Engineer	NASA - Headquarters, Exploration Systems Mission Directorate
Mr. Ross Jones, Systems and Software Assistant Division Manager for Systems Engineering	Jet Propulsion Laboratory
Mr. Jerry Lake, President	Systems Management International

TABLE 3. The Integrated Learning and Development Program DACUM Systems Engineer Expert Group. (Cont.) The ILDP group of systems engineering experts was composed of individuals from inside and outside NASA in order to insure the broadest level of consensus.

System Engineer DACUM Representative	Affiliation
Mr. Paul Lightsey, Systems Engineer	Ball Aerospace
Mr. Larry Martin, Systems Engineer	NASA - Marshall Space Flight Center
Mr. Al Motley, Senior Systems Engineer	NASA - Langley Research Center
Mr. Dennis Rohn, Senior Systems Engineer	NASA - Glenn Research Center
Ms. Jonette Stecklein, Systems Integrator, International Space Station	NASA - Johnson Space Center
Mr. Paul Wercinski, Senior Staff Scientist	NASA - Ames Research Center

The ILDP Project/Program Management DACUM was conducted June 23–24, 2005, in Colorado Springs, Colorado, and was completed on schedule with no open actions. Table 4 presents the group of project management experts who participated. After the workshop the ILDP team cross-checked the results against the APPL project/program competencies. No major changes were found; the set was considered re-validated. Table 5 presents the project/program competency set resulting from the first ILDP DACUM workshop.

TABLE 4. The Integrated Learning and Development Program DACUM Program/Project Manager Expert Group. The ILDP group of project/program experts was composed of individuals from inside and outside NASA in order to insure the broadest level of consensus.

Project Manager DACUM Representative	Affiliation
Mr. Kenneth Atkins, Project Manger	Jet Propulsion Laboratory
Ms. Elizabeth Citrin, Project Manager	NASA - Goddard Space Flight Center
Mr. David Collins, Project Manager	NASA - Kennedy Space Center
Mr. Lee Graham, Project Manager	NASA - Johnson Space Center
Mr. Ron Johnson, Project Manager	NASA - Ames Research Center
Mr. Robert Leroy, Project Manager	Lockheed Martin
Mr. John Rogers, Project Manager	SAIC
Mr. Thomas Sutliff, Project Manager	NASA - Glenn Research Center
Mr. R. Kern Witcher, Project Manager	NASA - Stennis Space Center

TABLE 5. The Integrated Learning and Development Program (ILDP) Project/Program Manager Competency Set. The ILDP group of experts re-validated the NASA competency set used to define the performance requirements for this critical position.

The Project Management Competencies[*]			
Competency Area 1: Project Conceptualization		**Competency Area 6: NASA Environment**	
1.1	Project Proposal	6.1	Agency Structure and Internal Goals
1.2	Requirement Development[†]	6.2	NASA PM Procedures and Guidelines
1.3	Acquisition Management	6.3	International Standards and Political Implications[†]
1.4	Project Planning[†]		
1.5	Cost-estimating[‡]		
1.6	Risk Management[†]		
Competency Area 2: Resource Management		**Competency Area 7: Human Capital Management**	
2.1	IT and MIS[**]	7.1	Position Management[**]
2.2	Budget and Full Cost Management[†]	7.2	Recruitment, Hiring and Retention[†]
2.3	Capital Management[**]	7.3	Team Dynamics and Management[†]
Competency Area 3: Project Implementation		**Competency Area 8: Safety and Mission Assurance**	
3.1	Systems Engineering[†]	8.1	Environment and Ecology[**]
3.2	Design and Development[†]	8.2	Workplace Safety
3.3	Contract Management[†]	8.3	Mission Assurance[†]
		8.4	Security
Competency Area 4: Delivery, Operation, and Closeout		**Competency Area 9: Professional and Leadership Development**	
4.1	Logistics Management[**]	9.1	Mentoring and Coaching
4.2	Stakeholder Management	9.2	Communication/Decision Making[†]
4.3	Technology Transfer and Communication	9.3	Leadership[†]
Proposed: Transition to Use, Project Delivery and Operations		9.4	Ethics[**]
Competency Area 5: Program Control and Evaluation		**Competency Area 10: Knowledge Management**	
5.1	Tracking/Trending of Project Performance	10.1	Knowledge Capture and Transfer
5.2	Project Control[†]	10.2	Knowledge Sharing
5.3	Project Review and Evaluation		

* Compiled via aligning APPL/PMDP Competency Model, NASA Center PM Competency Models (MSFC, ARC, JSC, JPL), NASA NPR 7120.5C PM Requirements (Generic Projects), PMI-PMBOK and ILDP DACUM Tasks.
† High Congruence: similarly represented in at least 6 of 8 sources.
‡ High Congruence: listed in 5 sources; added to the list.
** Low Congruence: listed by 2 or fewer resources and/or not detailed.

The ILDP team's survey for systems engineering competency sets for use in this integration process revealed none of suitable maturity nor were any vetted by the NASA systems engineering community. Using the outputs from the tailored DACUM process an activity was conducted to define a competency set for this critical position. Table 6 presents the systems engineering competency set created by ILDP team members Yale, Morris and VanScoyoc.

With the completion of the first two occupation-specific DACUM workshops the ILDP team had the inputs necessary to conduct the third *integrating* workshop…the first critical step towards realizing a truly integrated development model. To execute this workshop ILDP brought together a composite group of experts who spanned both project/program and systems engineering. While experts were drawn upon from both inside and outside NASA, a bias towards internal agency representation was employed in order to insure that the resulting products would have suitable buy-in later during the execution phase. Table 7 presents the group of project/program and systems engineering experts who participated.

ILDP conducted its combined PM/SE workshop in July 2005, in Boulder, Colorado, and was completed on schedule with no open actions. As designed, the workshop focused the gathered experts in a process to identify "common" project/program and systems engineering areas of responsibility, as well as common tasks. By definition those responsibilities and tasks that remained unpaired were not suitable candidates for integration and were categorized as Focused Training opportunities per the definition above.

The workshop then focused on the categorization of *when* in the career track of a systems engineer or project/program manager the individual needs to be able to execute the requisite tasks. This categorization was completed using three career timeframes: early-, mid- and late-career. The group of experts completed the workshop without the need to revisit the original process designed by the ILDP team affirming the validity of both the tailored DACUM tool and the integrated model conceptual design.

TABLE 6. The Integrated Learning and Development Program (ILDP) DACUM Systems Engineer Competency Set. The ILDP group of experts provided input into definition of this competency set—the first known product of its kind for the systems engineering occupation.

Systems Engineering Competencies*			
Competency Area: 1.0 Concepts and Architecture		**Competency Area: 6.0 NASA Internal and External Environments**	
1.1	Mission Needs Statement	6.1	Agency Structure, Mission, and Internal Goals
1.2	System Environments	6.2	NASA PM/SE Procedures and Guidelines
1.3	Trade Studies	6.3	External Relationships
1.4	System Architecture		
Competency Area: 2.0 System Design		**Competency Area: 7.0 Human Capital Management**	
2.1	Stakeholder Expectation Definition and Management	7.1	Technical Staffing and Performance
2.2	Technical Requirements Definition	7.2	Team Dynamics and Management
2.3	Logical Decomposition		
2.4	Design Solution Definition		
Competency Area: 3.0 Production, Product Transition, Operations		**Competency Area: 8.0 Security, Safety and Mission Assurance**	
3.1	Product Implementation	8.1	Security
3.2	Product Integration	8.2	Safety and Mission Assurance
3.3	Product Verification		
3.4	Product Validation		
3.5	Product Transition		
3.6	Operations		
Competency Area: 4.0 Technical Management		**Competency Area 9: Professional and Leadership Development**	
4.1	Technical Planning	9.1	Mentoring and Coaching
4.2	Requirements Management	9.2	Communication
4.3	Interface Management	9.3	Leadership
4.4	Technical Risk Management		
4.5	Configuration Management		
4.6	Technical Data Management		
4.7	Technical Assessment		
4.8	Technical Decision Analysis		
Competency Area: 5.0 Project Management and Control		**Competency Area: 10.0 Knowledge Management**	
5.1	Acquisition Strategies and Procurement	10.1	Knowledge Capture and Transfer
5.2	Resource Management		
5.3	Contract Management		
5.4	Systems Engineering Management		

* Compiled via aligning of SE Competencies/Processes/Function/Task from Centers (MSFC, GSFC, JSC, KSC, ARC), NASA (ILDP SE DACUM; OCE Systems Engineering NPR (Draft); APPL PMDP Competency Model; NESC), and other external SE Sources (DOD, INCOSE).

TABLE 7. The Integrated Learning and Development Program DACUM Combined PM/SE Expert Group. The ILDP group of project/program and systems engineering experts was composed of individuals primarily from inside NASA in order to insure consensus on this innovative way for technical workforce career development.

Combined PM-SE DACUM Representatives	Affiliation
Mr. Moses Adoko	Consultant
Mr. Stephen Kapurch	NASA - Headquarters, Office of the Chief Engineer
Dr. Wiley Larson	Consultant
Mr. Ken Ledbetter	NASA - Headquarters, Space Science Mission Directorate
Mr. Anthony Maturo	NASA - Headquarters, ILDP
Mr. Robert Menrad	NASA - Headquarters, ILDP
Dr. Linda Morris	Consultant
Dr. James Ortiz	NASA - Johnson Space Center
Ms. Jonette Stecklein	NASA - Johnson Space Center
Dr. Kathleen VanScoyoc	Consultant
Mr. Carl Wales	NASA - Goddard Space Flight Center
Mr. R. Kern Witcher	NASA - Stennis Space Center

The categorization results for each occupation revealed that the distribution of tasks to be mastered as a function of time could be described as Gaussian in nature. Interestingly, the median for a systems engineer's development was observed to be in the mid-career period. By contrast the median for a project/program manager's development was observed to be in the late-career period. The ILDP team discussed these observations with the assembled experts to determine its importance and realized that the data had revealed the typical career path for individuals at NASA; generally speaking, individuals begin their career as discipline engineers then transition to systems engineers in the middle and then move onto project/program management positions later. Further data analysis determined that this workshop had also provided the needed information on how to approach the reality of individuals changing jobs as they spend time in the organization. This proved very useful in approaching the goal of identifying places in the ILDP development model analogous to a university student changing undergraduate majors; some courses will count towards the requirements for the new major but additional mid-level (i.e., level 200) courses may be required as a consequence of the change. By the end of the workshop the participants recognized the unique results that the team had generated. Table 8 presents the findings of this third DACUM. This data documents the significant overlap of the capabilities needed by project managers and systems engineers as documented in the center column.

TABLE 8. The Integrated Learning and Development Program (ILDP) DACUM—Integrating Systems Engineering and Project Management Development—Workshop Results. The focus here is the set of shared capabilities between systems engineers and project managers. Note that a significant number of capabilities are common. The systems engineers tend to focus on technical integrity, while the project manger must focus on the project's overall technical performance, cost, schedule and risk.

Primary Systems Engineering	Typically Shared PM and SE	Primary Project Management
Concepts and Architecture	**Leadership Development**	**Project Conceptualization**
Form Mission Need Statement	Coach and Mentor Proteges	Prepare Project Proposal
Describe System Environments	Communicate Effectively	Develop Project Requirements
Perform Trade Studies	Lead Teams and Organizations	Manage Acquisition
Create System Architectures	**Project Management/Control**	Plan the Project
System Design	Oversee Technical Acquisition	Estimate Lifecycle Cost
Define/Manage Technical Stakeholder Expectations	Manage Resources	Manage Project Risk
Define Technical Requirements	**Human Capital**	**Resource Management**
Logically Decompose System	Staff Technical Organization	Establish and Manage IT and IS
Design Systems	Oversee/Manage Performance	Manage Budget and Full-Cost Account
Technical Management	Manage Team Dynamics	Manage Capital Assets and Investment
Plan Technical Effort	**Organizational Environment**	**Project Implementation**
Manage Requirements	Understand Organizational Goals	Manage Systems Engineering Effort
Manage Interfaces	Apply PM/SE Guidelines	Oversee Design and Development Activity
Manage Technical Risk	Manage External Relationships	Manage Contracts
Manage Configuration	**Security, Safety and Mission Assurance**	**Delivery, Operation and Closeout**
Manage Technical Data	Organize Security, Safety and Mission Assurance	Manage Stakeholders
Manage Decision Process	**Knowledge Management**	Manage Logistics
Production, Transition, Operations	Capture Knowledge	Manage Technology Transfer and Comm
Implement the Product	Organize/Distribute Knowledge	Manage Transition, Delivery and Ops
Integrate Systems		**Project Control and Evaluation**
Verify the System		Track and Trend Project Performance
Validate the System		Perform Project Control
Transition the System		Organize/Manage Project Reviews and Evaluation
Conduct Operations		

With the DACUM workshops completed the ILDP team changed its focus from formulation to implementation; the creation of the integrated workforce development model (i.e., the ROCK) using the data collected. A 4-tier development framework for the model was chosen. This decision was made for several reasons:

- The APPL project/program competency set inherited by ILDP was a 4-tier framework and no requirements to modify it was identified during the workshops;
- 4-tier frameworks have been employed by other groups outside NASA thereby yielding an opportunity for consistency to be maintained;
- A framework with the minimum number of required tiers was considered optimized since tier-specific overhead activities would be reduced to the lowest level practical;
- Discussions with the stakeholders confirmed that the tiers categorized the spectrum of performance desired from the workforce in fewest terms.

The 4-tiers, referred to as performance levels, selected for the ROCK are:

- Know—the development objective for tier #1 is "awareness" and is calibrated to the "team member". To successfully complete the criteria an individual must be able to demonstrate an understanding of the organization at the agency, center, directorate and division levels.
- Apply—the development objective for tier #2 is "hands on" and is calibrated to the "leader of a small activity". To successfully complete the criteria an individual must be able to demonstrate their ability to develop small space mission systems or projects. Significant personal involvement with the work being done is assumed.
- Manage—the development objective for tier #3 is "to get work done through people" and is calibrated to the "leader of a large activity". To successfully complete the criteria an individual must be able to demonstrate their ability to lead a large-scale engineering team or project. At this point personal involvement with the work being done is minimal and the individual is managing the teams that are completing the work.
- Guide—the development objective for tier #4 is "to get work done through projects" and is calibrated to the "leader of a system of systems". To successfully complete the criteria an individual must be able to demonstrate their ability to lead a group of systems engineering teams or discrete projects. Here the individual is defining strategic vision for the organization and involved in knowledge sharing activities (e.g., Masters Forums).

The ILDP team translated performance goals into an overall curriculum for project/program managers and systems engineer development using the 4-tier framework described above and the products from the DACUM workshops. The curriculum was parsed into discrete courses with the target audience defined for each. The completion of this activity represents the agency's first integrated technical workforce development model addressing the career development requirements of project/program managers and systems engineers. Figure 2 presents the Requisite Occupation Competencies and Knowledge created by ILDP.

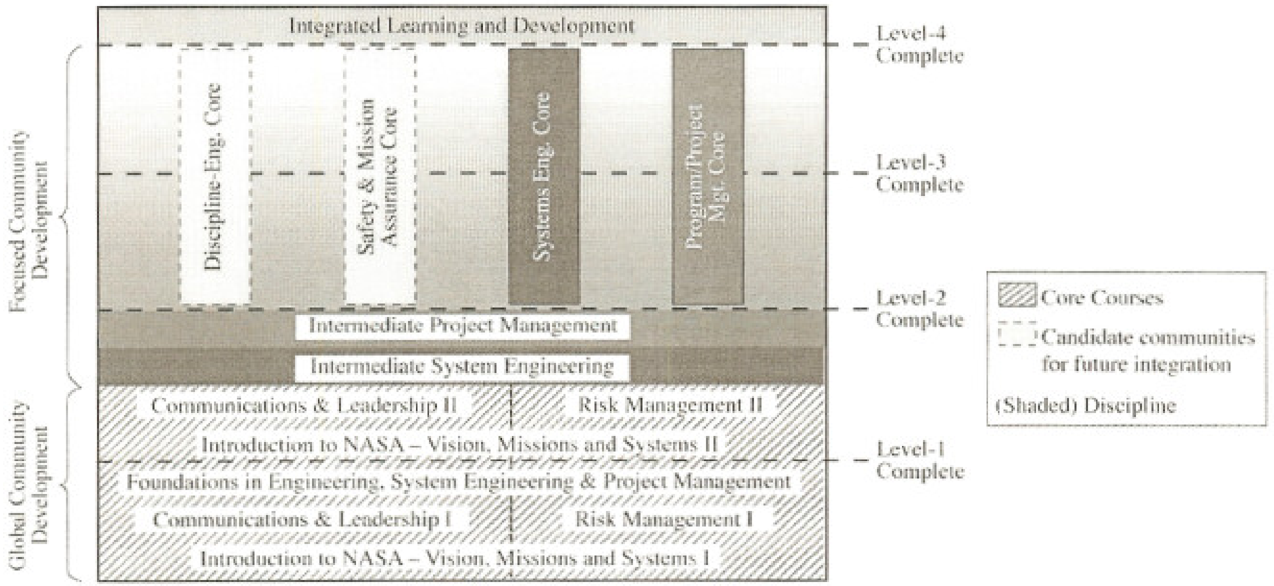

FIGURE 2. The Integrated Learning and Development Program (ILDP) Required Occupation Competencies and Knowledge Program (the ROCK). This version of the ROCK integrates the career development requirements of NASA project/program managers and systems engineers, as well as establishes the methodology for adding new communities such as discipline engineering or safety and mission assurance at a later date. Note: "Cross-Community Development" as defined herein only occurs when three or more communities are integrated into the model.

In detailed form, the ROCK identifies actual course modules for each performance level, sorted by targeted community, in order to permit detailed planning of the participant's development program.

EXTERNAL VALIDATION ACTIVITIES

External organizations have been involved in the validation of the systems engineer capabilities since the ILDP SE competency set was developed and validated within the NASA community. To date, 11 organizations have participated in a validation activity that focuses on performance level 2-application. In this validation activity, representatives from participating organizations have been presented with the ILDP SE capabilities and asked to categorize each capability as either CRITICAL to the development of their systems engineers, NECESSARY but not critical, or OPTIONAL. Organizations engaged in the validation activity include: NASA (Johnson Space Center, Ames Research Center, Glenn Research Center), US Air Force Space and Missile Center, Lockheed Martin (Denver), The Boeing Company (Space and Intelligence), Ball Aerospace, Deutsches Zentrum für Luft- und Raumfahrt (DLR), European Space Agency (ESA) European Space and Technology Center (ESTEC), Centre National d'Etudes Spatiales (CNES), and Agenzia Spaziale Italiana (ASI). The International Academy of Astronautics study team has vetted the capabilities with the SE community in the US and Europe.

To date, several organizations—within the United States and internationally—have elected to use the ROCK as the foundation to build their programs upon.

- The NASA – Headquarters "Academy of Program/Project & Engineering Leadership" (APPEL) is using the subject workforce development model to guide the development of its systems engineer leadership development program.
- The Stevens Institute of Technology has created a Masters-level and Graduate Certificate Program in Space Systems Engineering based on the capabilities defined in this workforce development program.
- Both NASA – Ames Research Center and NASA – Johnson Space Center have adopted the ROCK as the educational component of their system engineering leadership development programs.
- The Technical University of Delft's SpaceTech Masters Program in Space Systems Engineering adjusted its educational components to be in-line with the ROCK.

Table 9 presents the composite results of this validation activity as of August 1, 2008.

TABLE 9. Systems Engineer Capabilities. The left column lists systems engineer capabilities as documented by NASA/ILDP in the Requisite Occupation Competencies and Knowledge (the ROCK). The superscript "p" beside identifies those capabilities associated with NASA's procedural requirements in NPR 7123.1a "NASA Systems Engineering Processes and Requirements". Performance level-2 capabilities were assessed by 17 organizations as either Critical to SE development, Necessary (but not critical) or Optional. Only the results for systems engineer performance level-2 are shown here.

System Engineer Capabilities1	Performance Levels I - IV			
	I	II	III	IV
1.0 Concepts and Architecture	Aware	Apply	Manage	Strategy
1.1 Mission Needs Statement		C-N		
1.2 System Environments		C		
1.3 Trade Studies		C		
1.4 System Architecture		C		
2.0 System Design				
2.1 Stakeholder Expectation Definition & Management ^{p}		C		
2.2 Technical Requirements Definition ^{p}		C		
2.3 Logical Decomposition ^{p}		C		
2.4 Design Solution Definition ^{p}		C		
3.0 Production, Product Transition and Ops				
3.1 Product Implementation ^{p}		O		
3.2 Product Integration ^{p}		C		
3.3 Product Verification ^{p}		C		
3.4 Product Validation ^{p}		N		
3.5 Product Transition ^{p}		O		
3.6 Operations		N		

TABLE 9. Systems Engineer Capabilities. (Cont.) The left column lists systems engineer capabilities as documented by NASA/ILDP in the Requisite Occupation Competencies and Knowledge (the ROCK). The superscript "p" beside identifies those capabilities associated with NASA's procedural requirements in NPR 7123.1a "NASA Systems Engineering Processes and Requirements". Performance level-2 capabilities were assessed by 17 organizations as either Critical to SE development, Necessary (but not critical) or Optional. Only the results for systems engineer performance level-2 are shown here.

System Engineer Capabilities1	Performance Levels I - IV			
	I	II	III	IV
4.0 Technical Management				
4.1 Technical Planning [p]		C		
4.2 Requirements Management [p]		C		
4.3 Interface Management [p]		C		
4.4 Technical Risk Management [p]		C		
4.5 Configuration Management [p]		N		
4.6 Technical Data Management [p]		O		
4.7 Technical Assessment [p]		C		
4.8 Technical Decision Analysis [p]		C		
5.0 Project Management and Control				
5.1 Acquisition Strategies and Procurement		O		
5.2 Resource Management [p]		O		
5.3 Contract Management		O		
5.4 Systems Engineering Management [p]		N		
6.0 Internal and External Environments				
6.1 Organization Structure, Mission, Internal Goals		O		
6.2 PM/SE Procedures and Guidelines		O		
6.3 External Relationships		O		
7.0 Human Capital Management				
7.1 Technical Staffing and Performance		O		
7.2 Team Dynamics and Management		C		
8.0 Security, Safety and Mission Assurance				
8.1 Security		O		
8.2 Safety and Mission Assurance		N		
9.0 Professional and Leadership Development				
9.1 Mentoring and Coaching		O		
9.2 Communication		C		
9.3 Leadership		C		
10.0 Knowledge Management				
10.1 Knowledge Capture and Management		O		

SUMMARY

It is the human condition to respond to tragedy with a renewed commitment to excellence. It was in this spirit that ILDP was chartered by the NASA Office of the Chief Engineer. Here we have presented the ILDP activities that resulted in:

- A conceptual model for integrated workforce development spanning three categories of development;
- Re-validated competency set for project/program management and the introduction of a validated competency set for systems engineering;
- An integrated competency set for project/program managers and systems engineers;
- A 4-tier integrated development model entitled the ROCK.

Since the completion of this work resources continue to be expended on addressing the development needs of the systems engineering community based upon the ROCK. It is a critical position on any project team and the efficient development of this community represents a wide-spread need both inside and outside the aerospace sector [Larson and Hill, 2008][6]. The ROCK is an internationally recognized technical workforce development model. Several organizations are adopting the ROCK as the foundation for their systems engineering development program. At least one Masters level certificate program in Systems Engineering, based upon the ROCK, is now available in the United States of America.

The ROCK offers organizations considerable flexibility when addressing their technical workforce career development requirements. In instances where a single occupation will be focused upon (e.g., systems engineering), the ROCK provides a consistent and unified 4-tier development framework to guide a participant's development. When organizational needs require a framework for multiple technical occupations the ROCK continues to offer a stable framework to meet those needs. Hence, we believe the ROCK offers any organization a unique platform of stability for addressing technical workforce development requirements in a dynamic environment.

This paper would not be complete without calling attention to the contribution of the professionals who made up the ILDP Team and its support contractors. It was through their professional commitment and personal dedication that this work was accomplished. Special mention is made for Dr. Linda Morris, Dr. Kathleen VanScoyoc, and Dr. Gary Yale whose efforts resulted in the development of the Systems Engineering competency set presented herein.

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1 Mr. Menrad served as ILDP Program Manager during a one-year detail to NASA Headquarters, Washington, D.C.

2 Dr. Larson served as ILDP Deputy Program Manager - Curriculum while under contract to NASA Headquarters, Washington, D.C.

3 The CAIB Report: Volumes I – VI, Government Printing Office, Washington, D.C., 2003

4 Applied Project Management for Space Systems, edited by Chesley, Larson, McQuade, and Menrad, First Edition, McGraw Hill, 2008, (publication pending)

5 A Guide to the Project Management Body of Knowledge (PMBOK Guide), Third Edition, Project Management Institute, 2004

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