Systems Thinking Development and Capability Building in Established and Emerging Space Programs

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MIT Lean Advancement Initiative (LAI) Knowledge Exchange Event

Systems Thinking and Social Capabilities:

Toward a More Inclusive View of Engineering Competencies for High Performance in Sociotechnical Enterprises

Presentation Overview

- Highlight the impact of three factors that influence the development of systems thinking and early capability building in space organizations
  - Environment
  - Experiential Learning
  - Personal Characteristics

- Two Motivating Examples
  - Systems Thinking Development at NASA's Goddard Space Flight Center
  - Capability Building in Emerging Satellite Programs in Africa and Asia

Systems Thinking Development at NASA's Goddard Space Flight Center

Project Overview

- Building on doctoral study by Dr. Heidi Davidz (2006)
- Applying Davidz' definitions, data collection methods and analysis
  - *Definition of Systems Thinking*: Analysis, synthesis, and understanding of interconnections, interactions, and interdependencies that are technical, social, temporal, and multi-level
  - Sought to identify enablers to Systems Thinking Development
- Results aligned with Davidz' original findings that enablers of systems thinking development are in three categories
  - Experiential Learning, Enabling Environment, Personal Characteristics

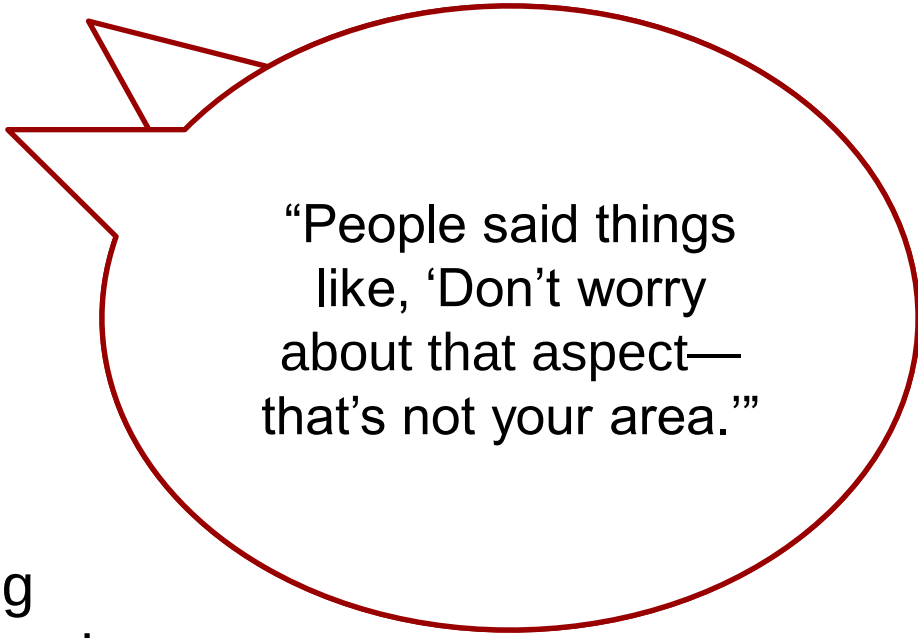
Davidz, Heidi. "Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers." PhD Dissertation. Massachusetts Institute of Technology. February, 2006.

Project Setting

- NASA's Goddard Space Flight Center (GSFC)
  - Large government laboratory with focus on earth science, astronomy and space science satellite missions
- GSFC Engineer Development Approach
  - Engineers start with narrow assignments within focused discipline of satellite engineering
  - As engineers develop, they can choose between various paths
    - Rotate among technical disciplines and prepare for systems level work
    - Develop deep technical knowledge in one discipline
    - Move into management
- Interview Subjects: 37 NASA engineers
  - 4 Expert Panelists;17 Senior Systems Engineers; 10 Junior Systems Engineers; 6 Senior Technical Specialists

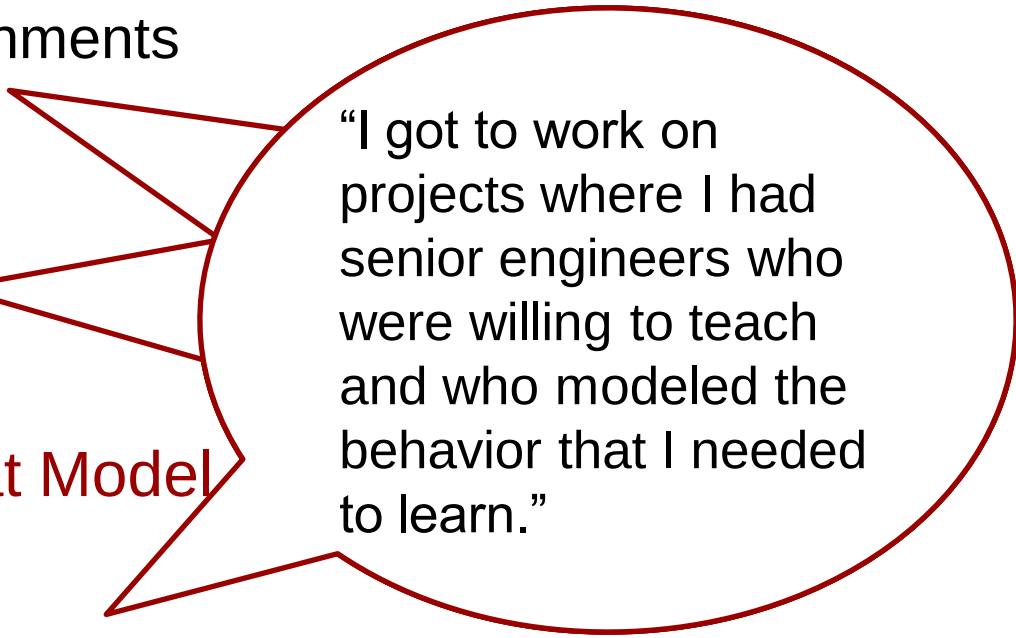
Environment as an Enabler of Systems Thinking Development

- Enabling Factors
  - Encouraging Relationships and Mentors
  - Organizational Definition of Engineer's Role
  - Community Level of Systems Understanding
- Organizational approaches to fostering systems thinking
  - Encouraging risk taking, giving awards for systems thinking, and providing funding for exploring new ideas



Experiential Learning as an Enabler of Systems Thinking Development

- Formal Training
  - Reflective Courses
  - On the Job training assignments under a mentor
- Diversity of Experience
- Working under leaders that Model Systems Thinking



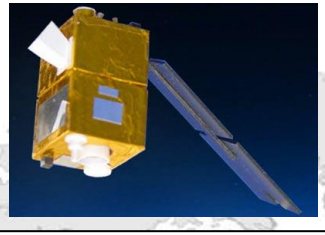
Personal Characteristics as an Enabler of Systems Thinking Development

- Natural Tendency Toward Thinking at Systems Level
  - A desire to understand how the parts of a system interact, a desire to experience new things periodically, a natural tendency toward big-picture thinking, sense of curiosity
- Strong Social Skills
  - Comfortable interacting with people, effective at communication, open to new ideas, humble, willing to ask questions

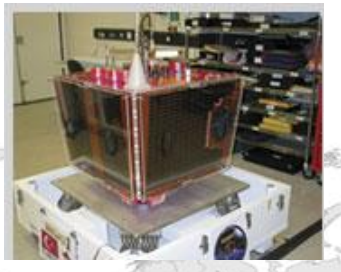
People can learn new personal skills. "I would ask him questions that would cause him to go back and revisit his assumptions "

Capability Building in Emerging Satellite Programs in Africa and Asia

Over 15 countries have implemented the Collaborative Satellite Development Project model



Algeria

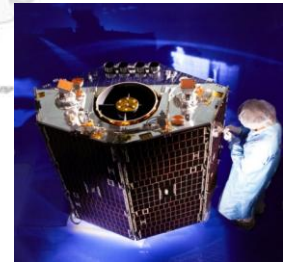


Turkey

Egypt

Chile

Nigeria



UAE

Malaysia

These countries seek to establish local capability to design and manufacture satellites.

Photo Credits: SSTL (http://www.sstl.co.uk/), EADS Astrium (http://www.astrium.eads.net/), SaTReC Initiative (Satrec Initiative (http://www.satreci.com/)), Yuzhnoye Design Office (http://www.yuzhnoye.com/?lang=en)

Potential Features of Collaborative Satellite Development Projects

- The benefits may include…
  - Opportunities to learn about satellite technology from experts
  - A combination of hands on and theoretical training
  - Exposure to the satellite lifecycle
- The challenges may include…
  - Misaligned incentives between partners (Sappington 1991)
  - Differences in culture and language (Kedia and Bhagat 1988, Hofstede 1983)
  - Tension between training and project execution (Hobday and Rush 1999)

The challenges of the projects require both technical and non-technical capabilities to overcome.

What is the impact of environment?

Explore the environment by defining the satellite project as a system with an architecture

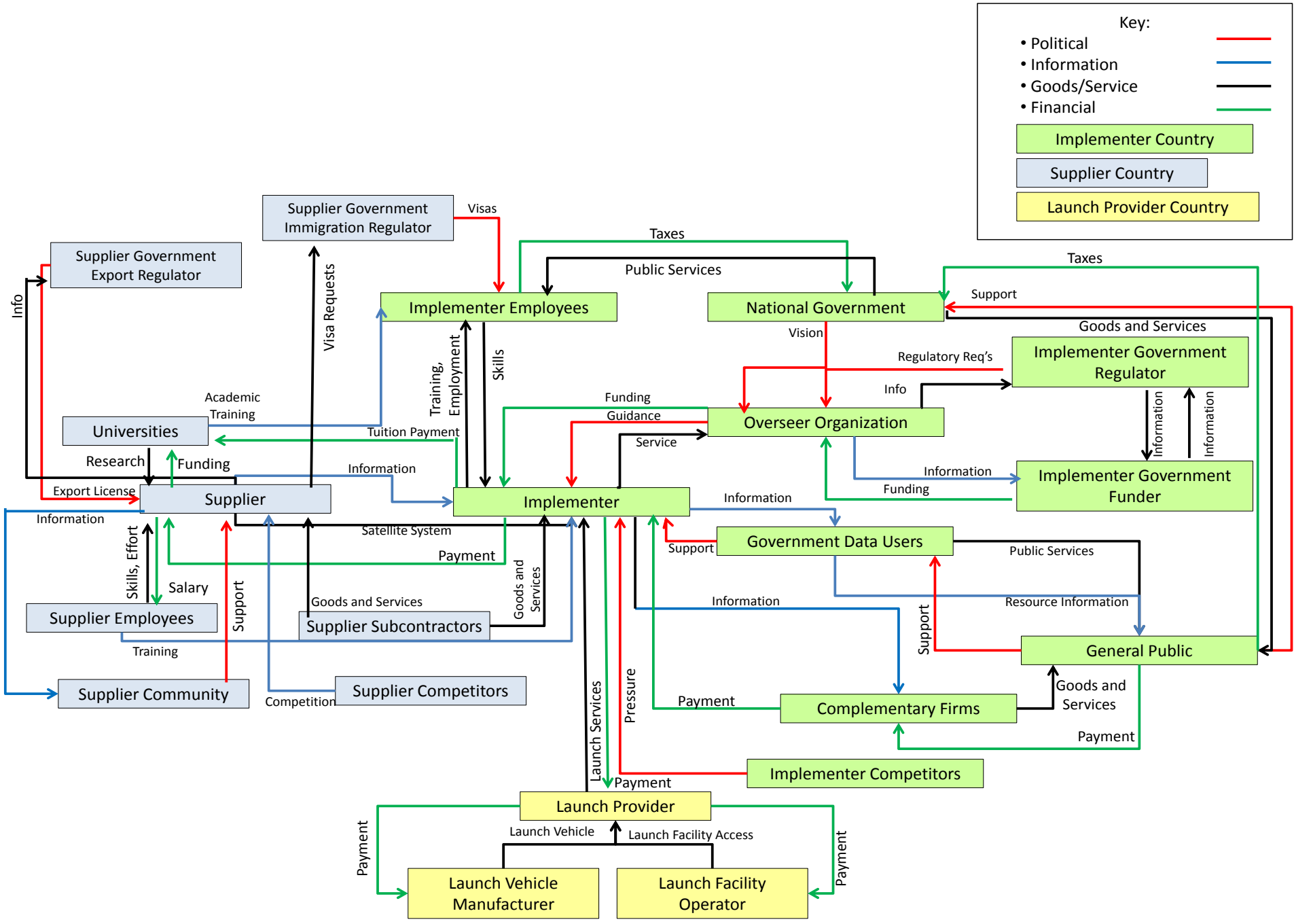
Analyzing the Environment using "Project Architecture"

1. Who are the primary **stakeholders?**

2. What is the **context**, including constraints, opportunities, requirements and objectives of the stakeholders?

3. What **functions** does the project achieve?

4. What **organizations, individuals, objects and personnel** execute those functions?


Key:
• Political
• Information
• Goods/Service
• Financial
Implementer Country
Supplier Country
Launch Provider Country
Supplier Government Immigration Regulator
Visas
Supplier Government Export Regulator
Info
Visa Requests
Taxes
Public Services
Implementer Employees
National Government
Taxes
Support
Goods and Services
Vision
Regulatory Req's
Implementer Government Regulator
Info
Information
Information
Training, Employment
Skills
Academic Training
Universities
Tuition Payment
Funding
Guidance
Service
Overseer Organization
Research
Funding
Information
Export License
Supplier
Implementer
Information
Information
Funding
Implementer Government Funder
Information
Satellite System
Payment
Skills, Effort
Salary
Support
Goods and Services
Goods and Services
Supplier Employees
Supplier Subcontractors
Training
Support
Government Data Users
Public Services
Information
Resource Information
Support
General Public
Supplier Community
Competition
Supplier Competitors
Launch Services
Pressure
Payment
Complementary Firms
Goods and Services
Payment
Payment
Implementer Competitors
Payment
Launch Provider
Launch Vehicle
Launch Facility Access
Payment
Payment
Launch Vehicle Manufacturer
Launch Facility Operator

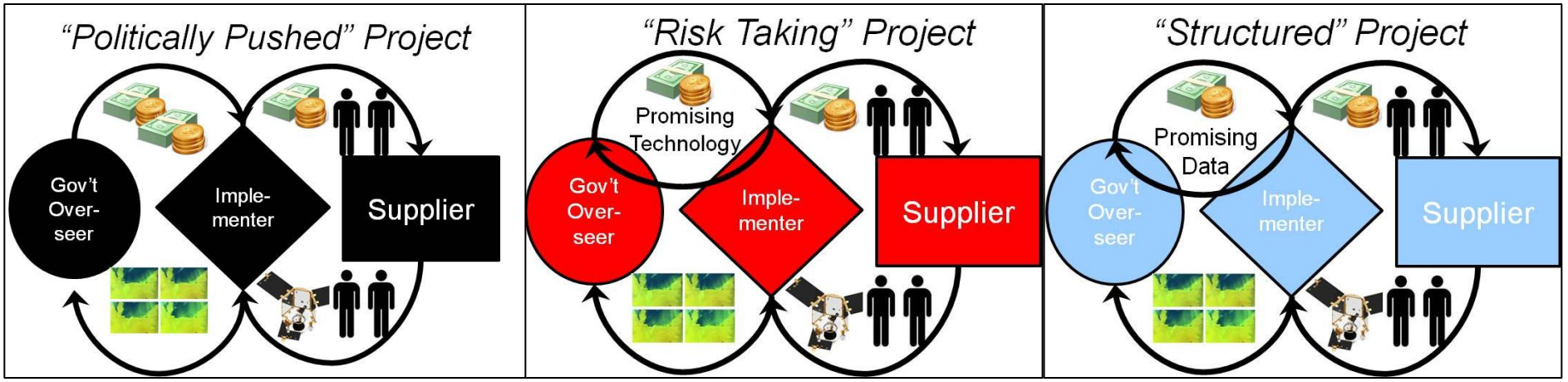
What are the Architectures of Collaborative Satellite Projects?

Generic Forms	Function	Alternative Forms				
Organizational View						
Project Initiation and Approval View						
Personnel Management View						
Supplier Selection View						
Facility View						
Supplier Facility Status	*Defining Supplier Facility State*	Temporary	Transitional	Purpose-Built		
Implementer Facility Status	*Defining Implementer Facility State*	Temporary	Transitional	Purpose-Built		
Implementer Facility Type	*Enabling Implementer Activity*	Data Reception	Satellite Operations	Satellite Integration and Test	Optical Laboratory	
Satellite Control System Operator	*Controlling Satellite*	Implementing Organization	Overseer Organization	Satellite Supplier		
Satellite Reception System Operator	*Receiving Satellite Data*	Implementing Organization	National Remote Sensing Center (non-implementer)	Satellite Supplier	Commercial Antenna Farm	
Satellite Environmental Test Facilities	*Hosting Satellite Environmental Tests*	Satellite Supplier	Government Research Organization	Commercial Firm		

How does architecture vary across satellite projects?

This set of Implementation Issues leads to definition of Archetypal Project Architectures	
Project Initiation and Approval	**High effort** vs **Low effort** fundraising process
Supplier Selection	**Formal** vs **Informal** Selection Process
Satellite Technology Product View	**More or Less Complex** Satellites
Training	Three categories of training based on **mentoring style**, types of **training activities** and project lifecycle **phases**

Archetypal Project Architectures



- The "Politically Pushed," "Structured," and "Risk Taking Project" are **archetypes** that capture key features of case studies.
- The case studies show that nations can blend archetypes and transition between them.
- The archetypes link context, implementation and capability building outcomes

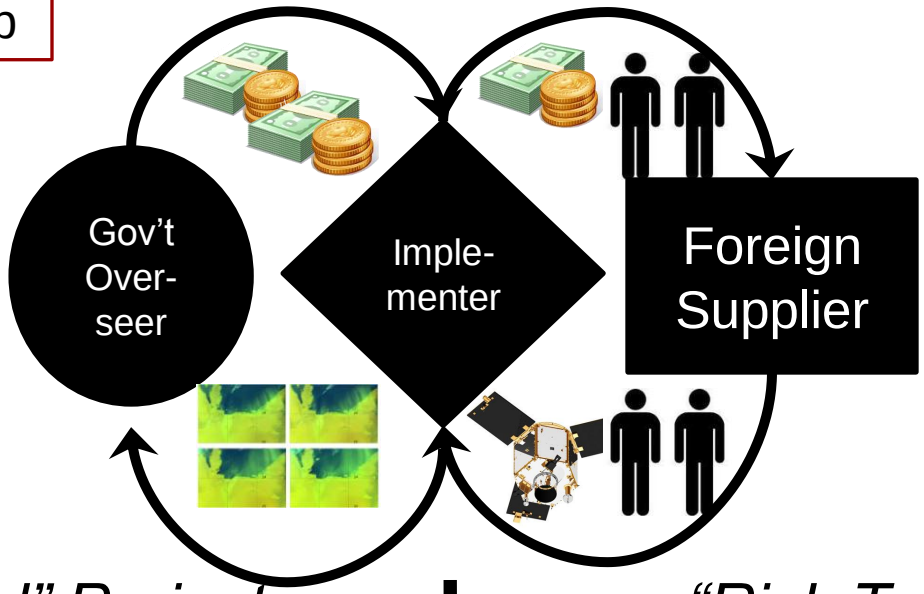
Archetypal Project Context

Strong, Supportive **National** Leadership

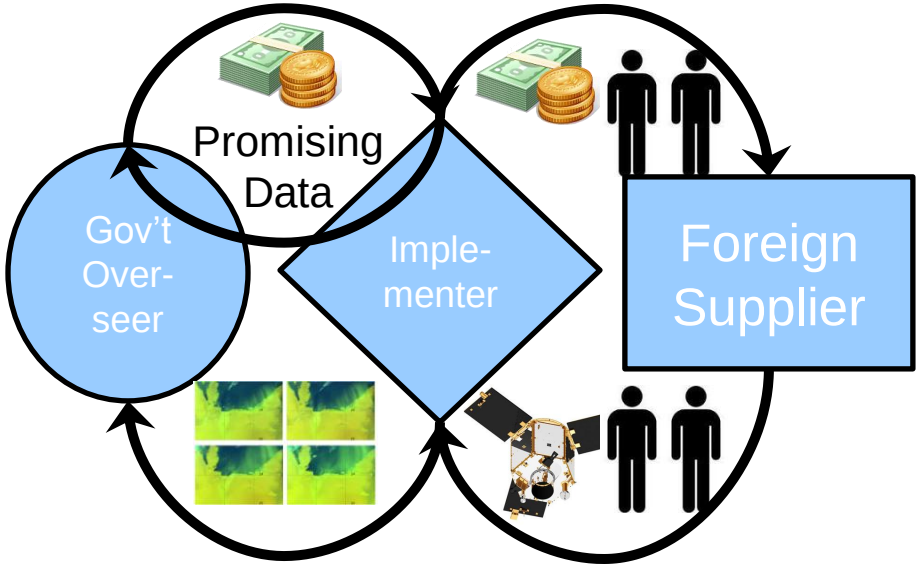
Bureaucratically Savvy **Implementer** Leadership

Technically Savvy **Implementer** Leadership

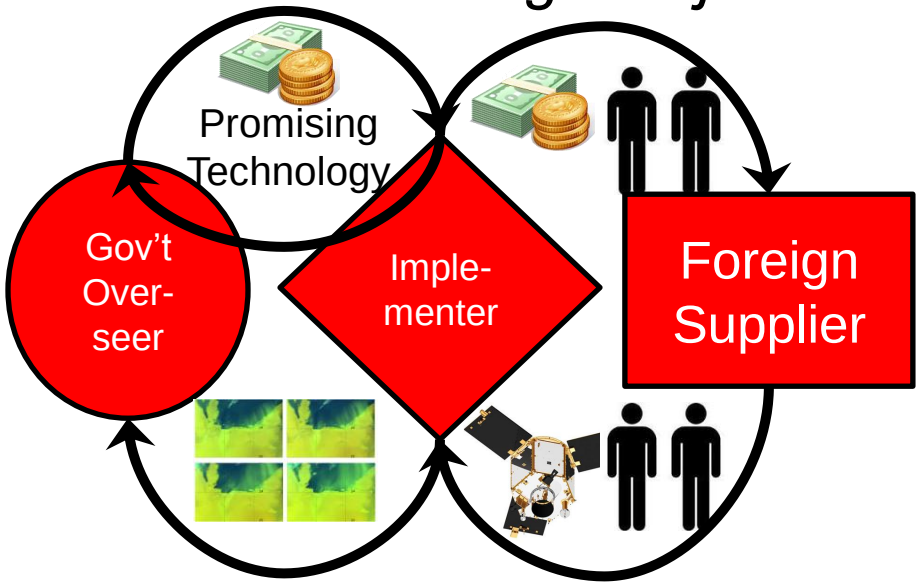
"Politically Pushed" Project



"Structured" Project



"Risk Taking" Project

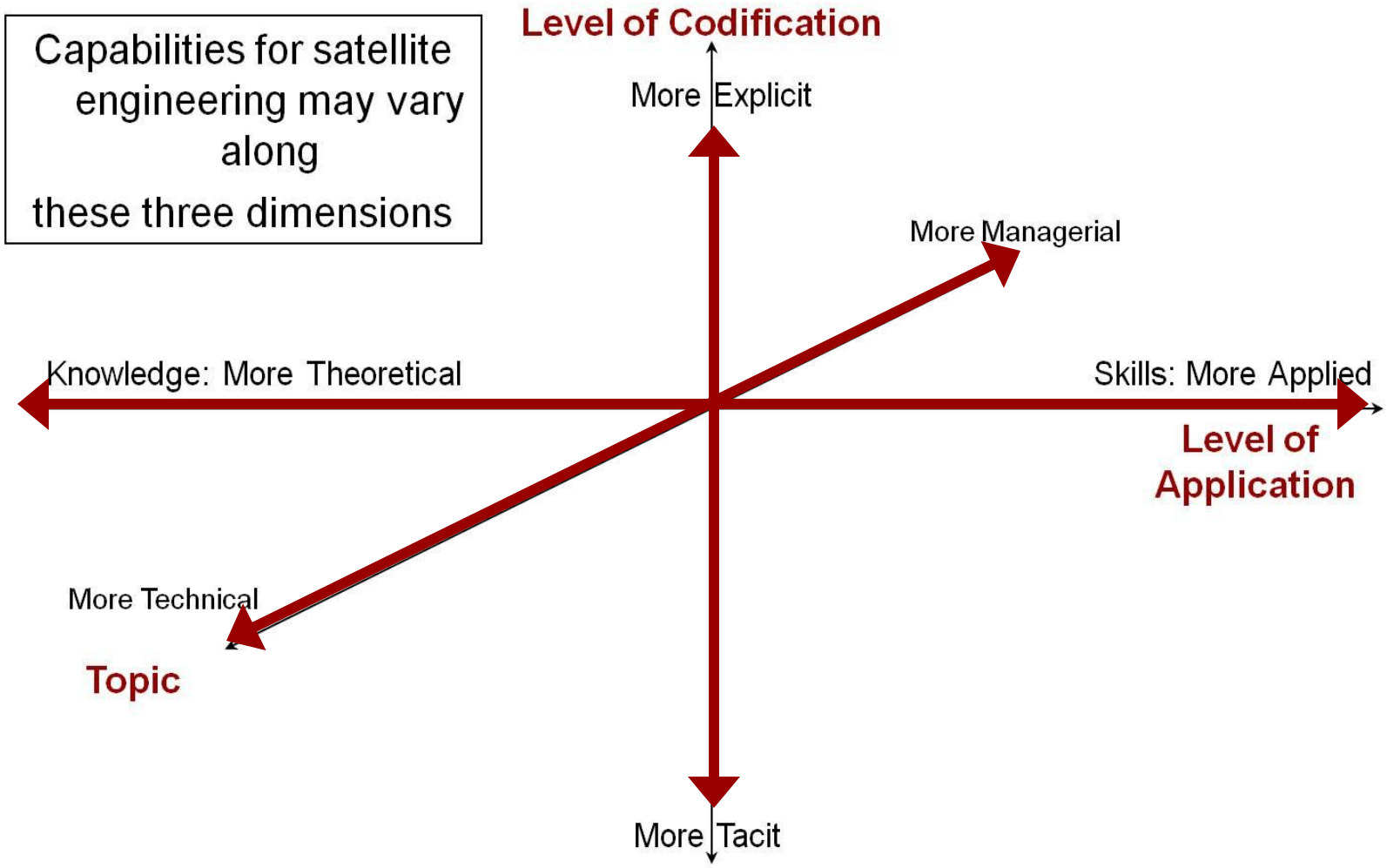


What is the nature of experiential learning?

Define capability building framework

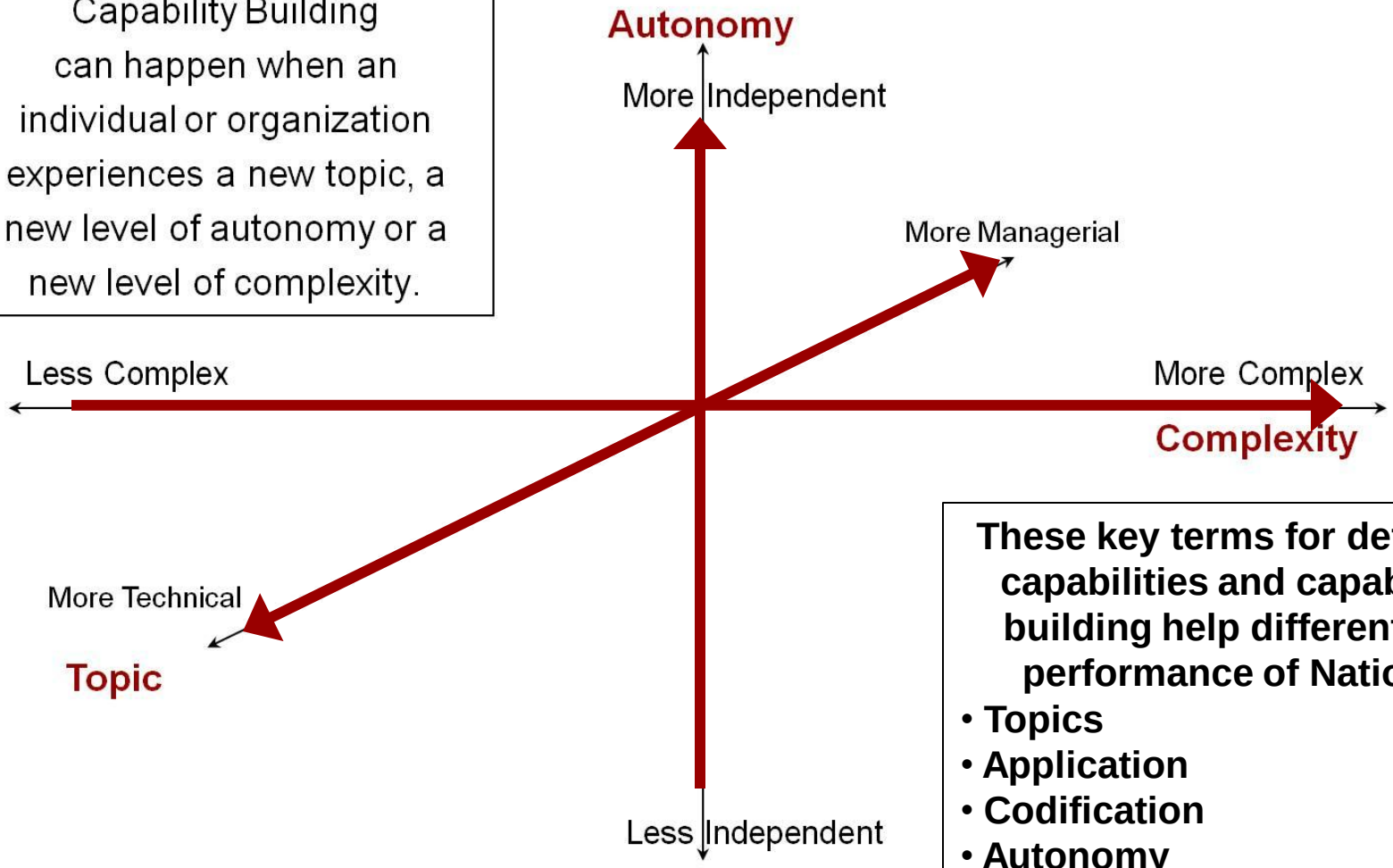
Individual capabilities for satellite engineering

Capabilities for satellite engineering may vary along these three dimensions



Capability building means…

Capability Building can happen when an individual or organization experiences a new topic, a new level of autonomy or a new level of complexity.



These key terms for defining capabilities and capability building help differentiate performance of Nations

- **Topics**
- **Application**
- **Codification**
- **Autonomy**
- **Complexity**

Scale of Opportunities for Individual Capability Building

Color Key
Red = Before Training
Yellow = During Training
Green = After Training

Long Term Individual Capability Building Profiles

Early Project Activities ⟷ Later Project Activities

Increasing Autonomy and Application ↑

	Project Definition	Req's	Soft-ware	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Manage-ment	Launch	Ops
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									

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Long Term Capability Building Profile For One Engineer

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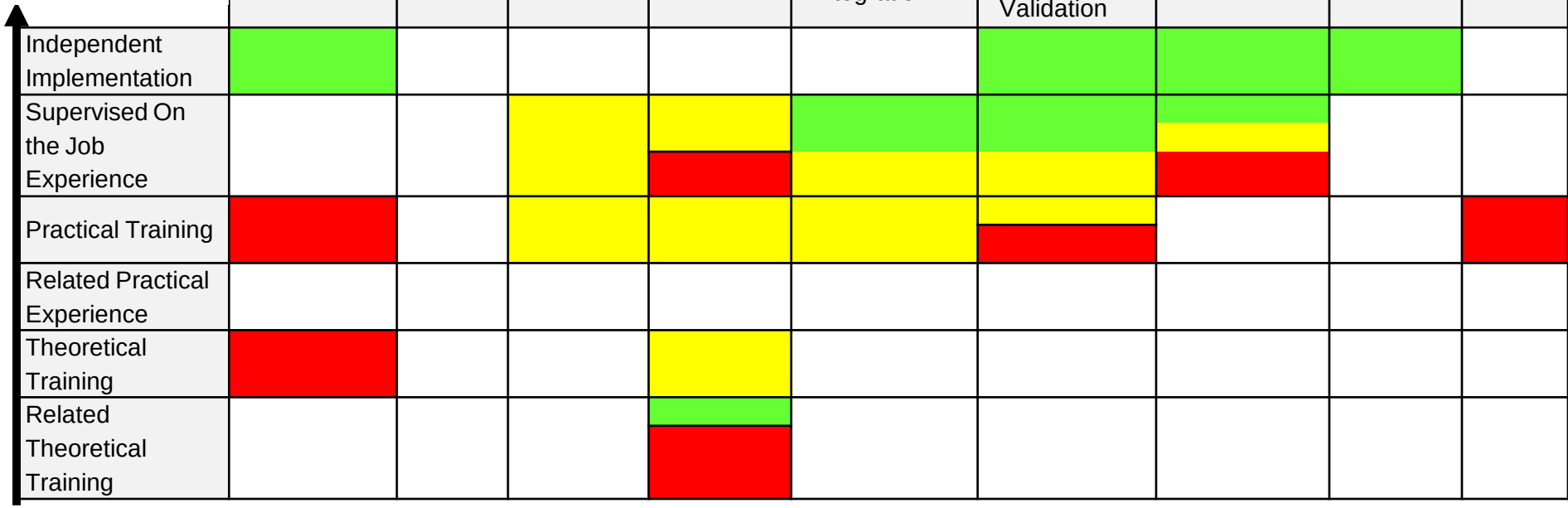

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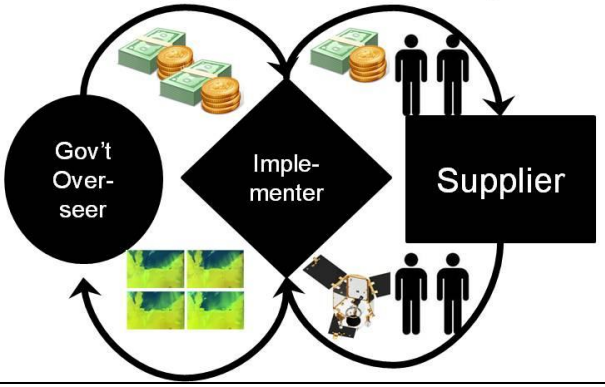
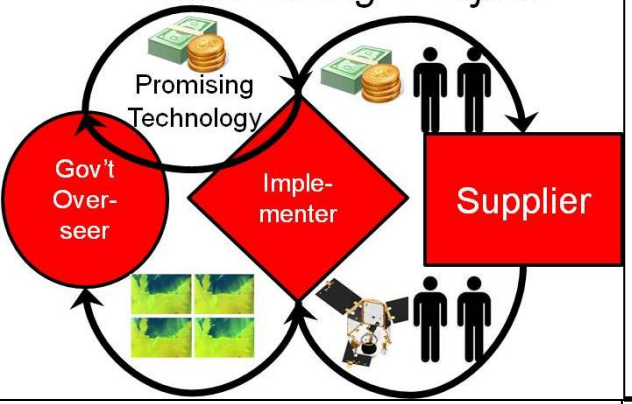
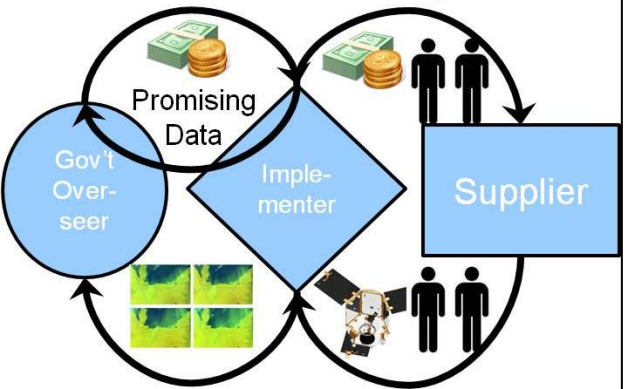
The patterns for all profiles shows how engineers moved toward **increasing application and autonomy** over time

How does the enabling environment relate to experiential learning?

During Project	Capability Building for Individuals	Capability Building for Organizations
"Politically Pushed" Project 	Groups access **practical** training	Achievement in new **topics**
"Risk Taking" Project 	Individuals access **on the job** training	Achievements in new levels of **autonomy**
"Structured" Project 	Individuals access **theoretical** training	Achievement in new levels of **complexity**

Long term Capability Building Achievements by Organizations

- Technical Learning literature defines long term progress as
  - Mastery, Adaptation, Diffusion, Innovation
- All four Nations focused on Mastery during satellite projects
- Two countries stand out for working toward adaptation and diffusion
  - Nation Alpha and Gamma brought models of their satellites to local facilities in order to test and operate them
  - Nation Alpha set up local assembly, integration and test facilities and manufactured some satellite components locally
- These countries had a stronger enabling environment for further capability building

How do personal characteristics impact experiential learning?

Individual Capability Building Profiles during Training

Early Project Activities ⟷ Later Project Activities

Increasing Application	Project Def.	Req.	Soft-ware	Design	Procure-ment, Assembly, Integra-tion	Testing, Verification and Validation	Manage-ment	Launch	Ops
Supervised On the Job Experience									
Practical Training									
Theoretical Training									

Individual Capability Building Profiles during Training

Subsystem Focused

Early Project Activities ⟷ Later Project Activities

Increasing Application ↑

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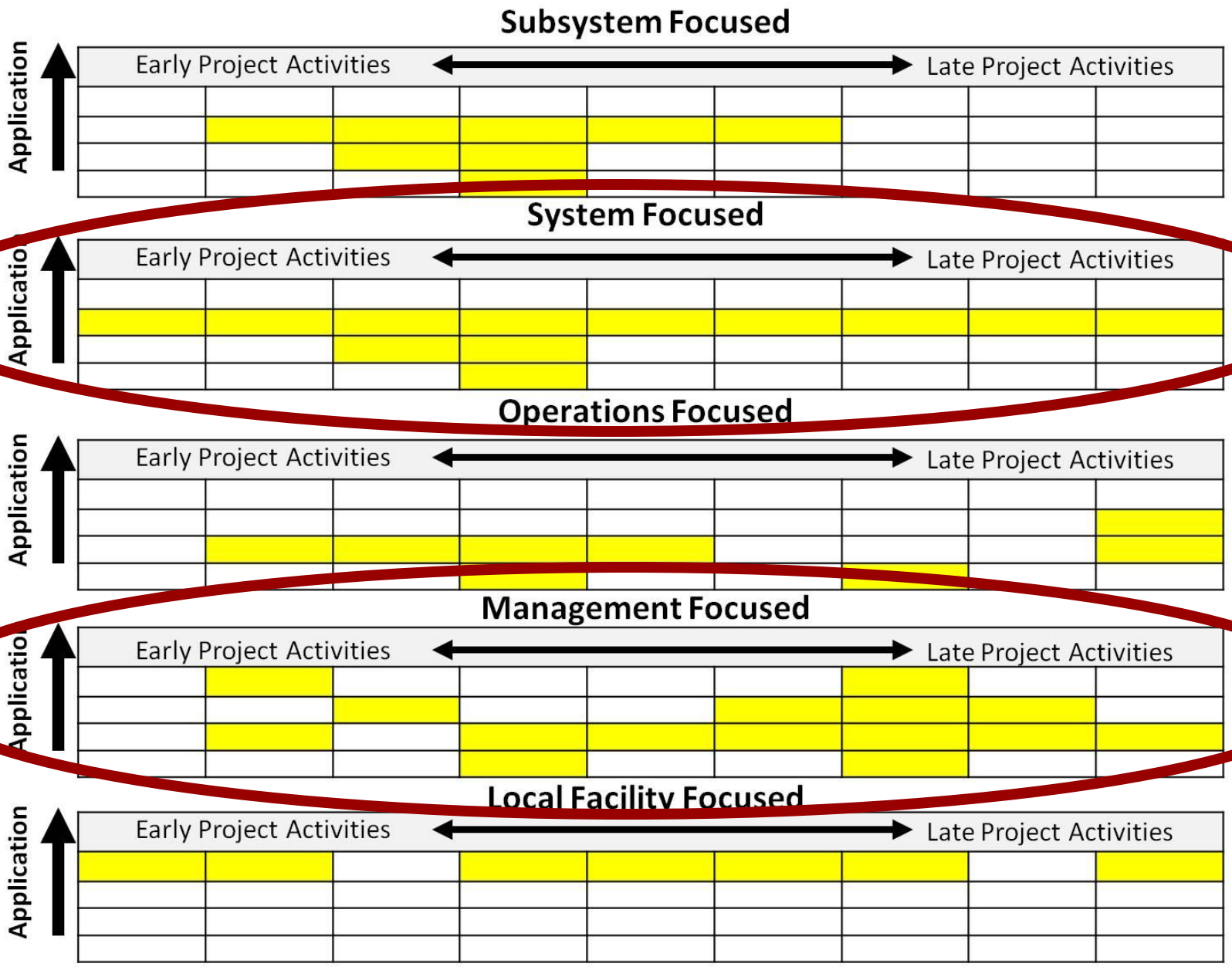
Supervised On the Job Experience									
Practical Training									
Theoretical Training						**Subsystem Focused**			

The Individual Capability Building Profiles during Training can be categorized according to the **range of topics** covered



Role of Personal Characteristics

Examples of Engineers Overcoming Obstacles during Capability Building Projects	
Obstacle	***Example of Resolution***
Schedule Delay	Some engineers used the unexpected delay to practice new skills, review previous work by their organization and learn from more experienced engineers.

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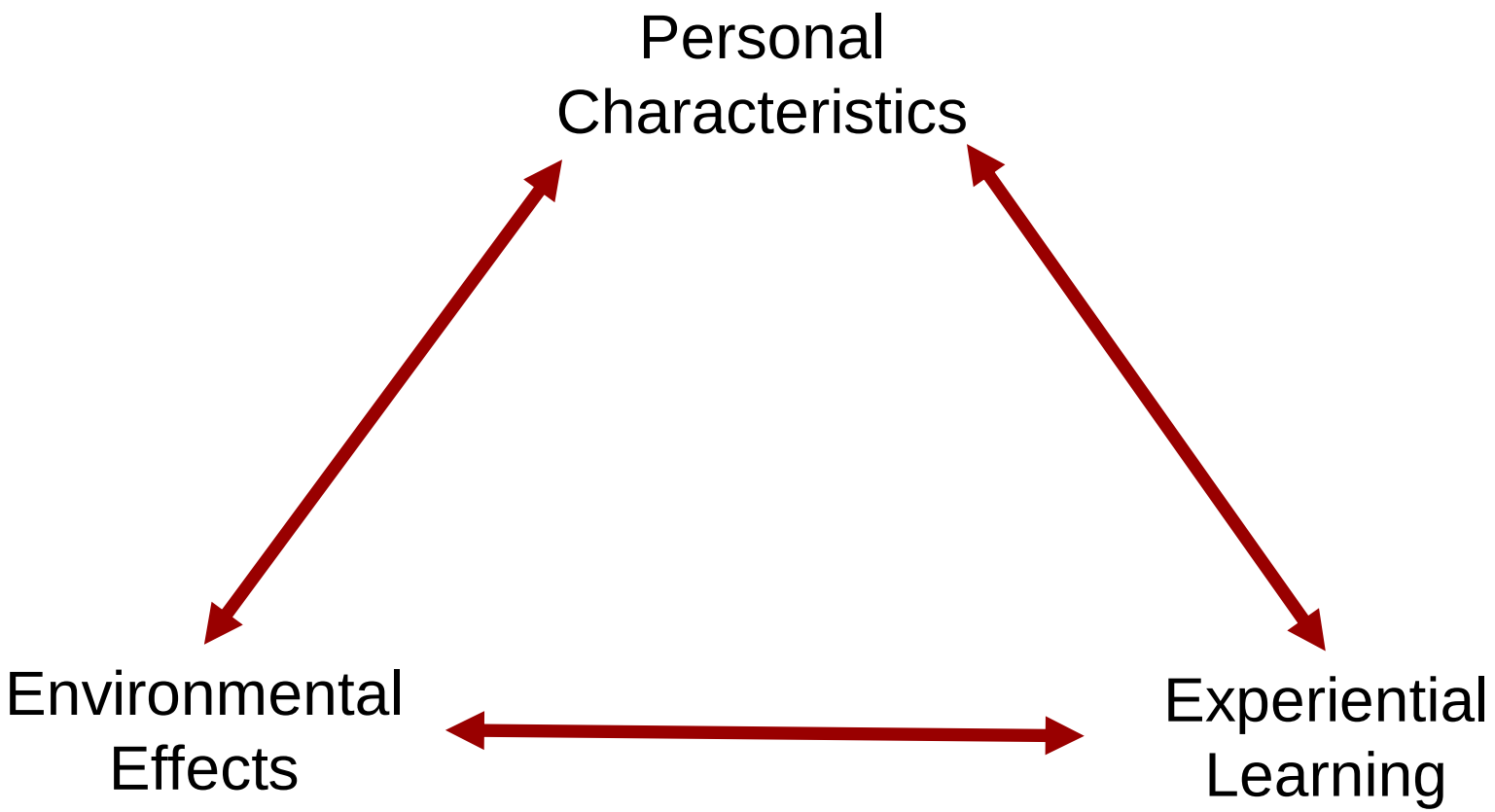
Overwhelming work load	One engineer made a difficult decision to forgo some theoretical training in order to focus on his responsibilities
Cultural Differences	One engineer worked closely with their mentor during the early part of their visit to get assistance with practical tasks in the community.
Inadequate Educational Background	One engineer found that he was able to be more successful at hands on work than theoretical work. He and his mentor re-defined his responsibilities to focus more on implementation rather than design.

Exploring Interconnections between Factors



Thank you!

Questions and Comments?