ESD.33 Systems Engineering

Lecture 5

Innovation in Systems Engineering

Qi Van Eikema Hommes

Customer-Centered Products

Creating Successful Products through Smart Requirements Management.

Ivy F. Hooks and Kristin A. Farry

Sample Chapter Titles:

- Chapter 2: Why Johnny Cannot Write Requirements?
- Chapter 5: One Day in the Life of a Product
- Chapter 7: Be Careful What You Ask For
- Chapter 10: But Will It Work?
- Chapter 15: Deaths, Taxes, and Requirements Changes

Course Layout

Lecture 4 ✔
Stakeholder Analysis and Requirements Definition

Lecture 2 ✔
Systems Engineering As Human Activity

Lecture 13
Design Verification and Validation, Lifecycle Management

Lecture 5 innovation in Systems Engineering
Lecture 6 Axiomatic Design and DM-DSM Method

Lecture 7 CPM and DFSS

Lecture 8
Trade Space Exploration Concept Selection

Lecture 10: Experiments
Lecture 11: Robust Design I
Lecture 12: Robust Design II

Lecture Outline

- Individuals' creativity in systems design
  - Know your users' needs
  - The characteristics of a creative person
  - Structured Innovation in Systems Design—TRIZ
- Innovation in large systems
  - Managing creativity
  - Innovation in the context of the technical systems
    - Architectural Innovation
    - The route of innovation management

Know Your User (Stakeholder) Needs

Class Discussion Questions

- Do we always know what customers really want?
- Do we always get to start with a complete set of requirements?
- Are systems always used as they are originally intended?

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Characteristics of A Creative Person

Teresa Amabile, HBR, 1998

- Ability to put existing ideas together in new combinations.
- Naturally tries out solution that departs from the status quo.
- Feels comfortable disagreeing with others.
- Habitually combines knowledge from seemingly disparate fields.
- Perseveres through long dry spells of tedious experimentation.
  - I have not failed. I've just found 10,000 ways that won't work. (Thomas Alva Edison)
- Have intrinsic motivation—passion and interest.

Characteristics of A Creative Person

Suh, Nam, *The Principles of Design, 1991*

- Risk Taker
- Good memory
- Good store of knowledge
- Interpolator / extrapolator
- Ability to reduce a complex array to a set (aggregation)
- Multi-disciplinary background

Is creativity something that one was born with?
Can One Learn to be Creative?

How did you learn to walk?
How did you learn to speak?
How did you learn to read?
How did you learn to do math?

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What did Altshuller Believe?

"You can wait a hundred years for enlightenment, or you can solve the problem in 15 minutes with these principles."

Genrikh Altschuller: Father of TRIZ

- 1926 – Born in Tashkent, USSR
- 1940 – Invented underwater breathing device at age 14.
- 1946 – As a Navy patent office, identified "patterns of invention", laying the foundation for TRIZ.
- 1948 – Wrote a letter to Stalin critical of innovation in the USSR.
- 1950 – Sentenced to 25 years of prison in Siberia
- 1954 – Released from the prison after Stalin's death. Produced his first publication on TRIZ.
- 1989 – first TRIZ Association in Russia
- 1999 – first TRIZ Institute in US. Altshuller passed away.

Atshuller, 40 Principles Extended Edition, 2005

TRIZ

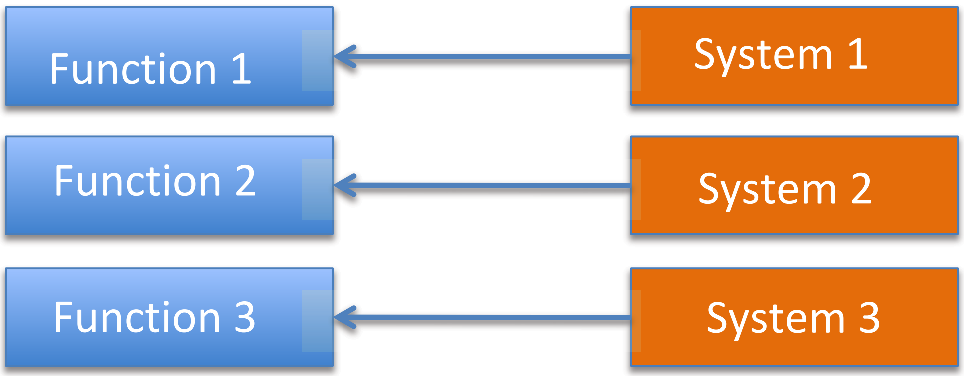
- TRIZ—Russian Acronym for Theory of Inventive Problem Solving.
- Altschuller reviewed 200,000 patents
- Algorithm steps for problem solving
- Database structured means for effective conflict resolution

Technical Systems

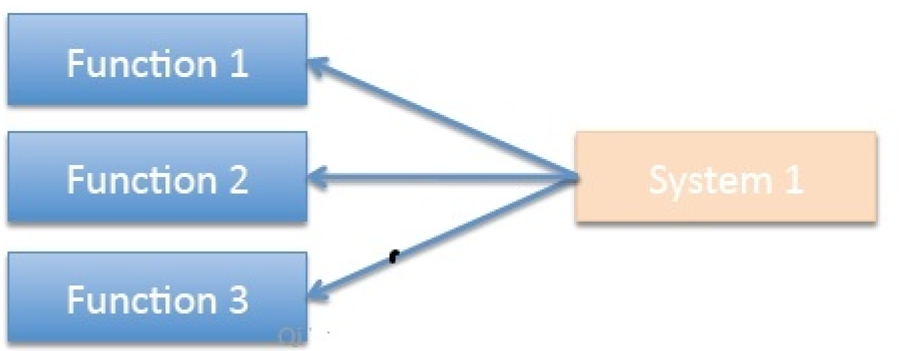
- Technical Systems—Everything that performs a function is a technical system.
- When solving a technical problem, always consider interaction of the existing technical system with those systems above and below it.
- TRIZ originated mostly from Mechanical Systems, but may be applied to other systems as well.

Law of Ideality

Conventional thinking: Additional function = additional system



TRIZ thinking: Adding function without increasing resources (or even use no resource).



The Law of Ideality

- Any technical system throughout its lifetime, tends to become more reliable, simple, and effective—more ideal.
- The further a system is away from its ideal state, the more complex the system will be. To return to ideal state, one may:
  - Increase amount of function of the system
  - Transfer as many function as possible to that working element which produces the systems' final action.
  - Transfer some functions of the system to a super system or to the outside environment
  - Utilize internal and external resources that already exist and are available.

Ideality Example

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The Russians launched an unmanned Lunar Probe to the moon's surface with the intention to transmit TV pictures to the Earth. A projector using a light bulb was designed to illuminate the lunar surface ahead of the vehicle. However, existing light bulbs would not survive the impact of landing on the Moon surface.

Even the most durable bulbs would crack at the joint between the glass and the screw base during tests.

Image by MIT OpenCourseWare.

Solution

ESD.33 2007 Dan Frey

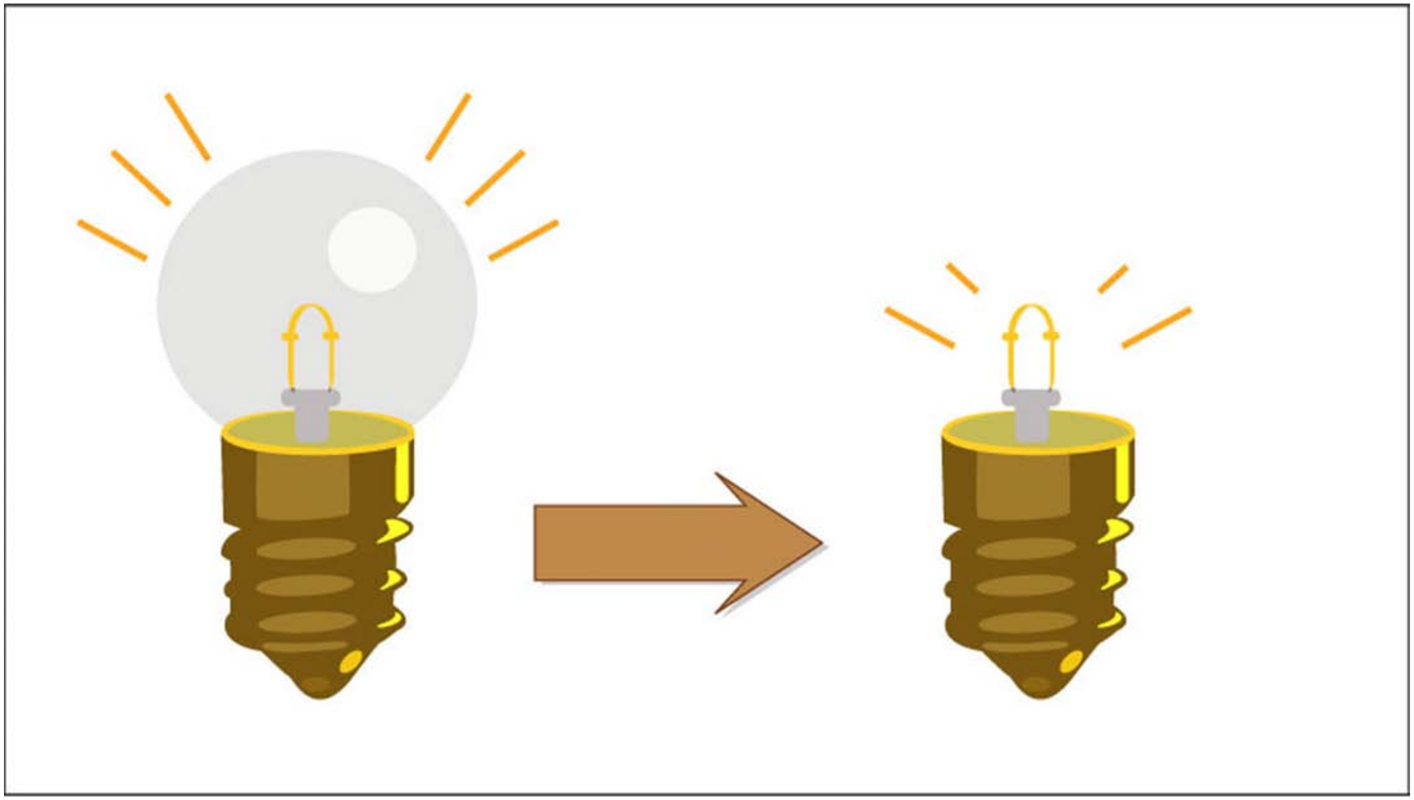


Image by MIT OpenCourseWare.

Ideality Example

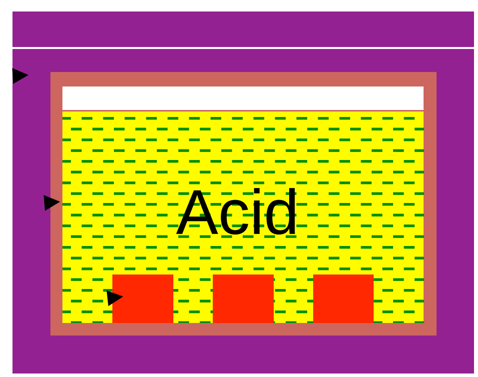
ESD.33 2007 Dan Frey

To study the effects of acids on metal alloys, specimens are placed into a hermetically sealed chamber filled with acid. The acid reacts not only with the specimen but also the walls, which necessitates a glass-coating to protect the walls. The glass coating cracks and has to be reapplied repeatedly for some tests.

Sealed chamber

Protective coating

Specimens



Solution

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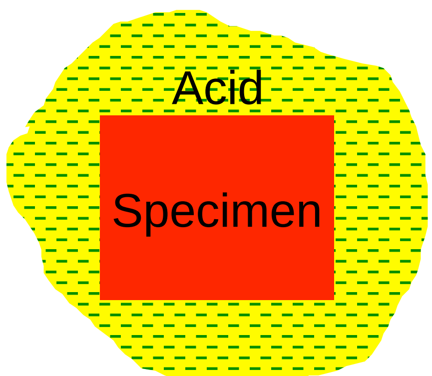
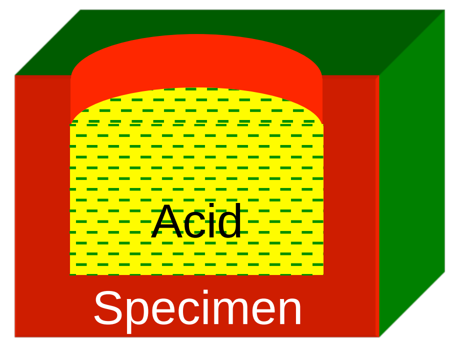


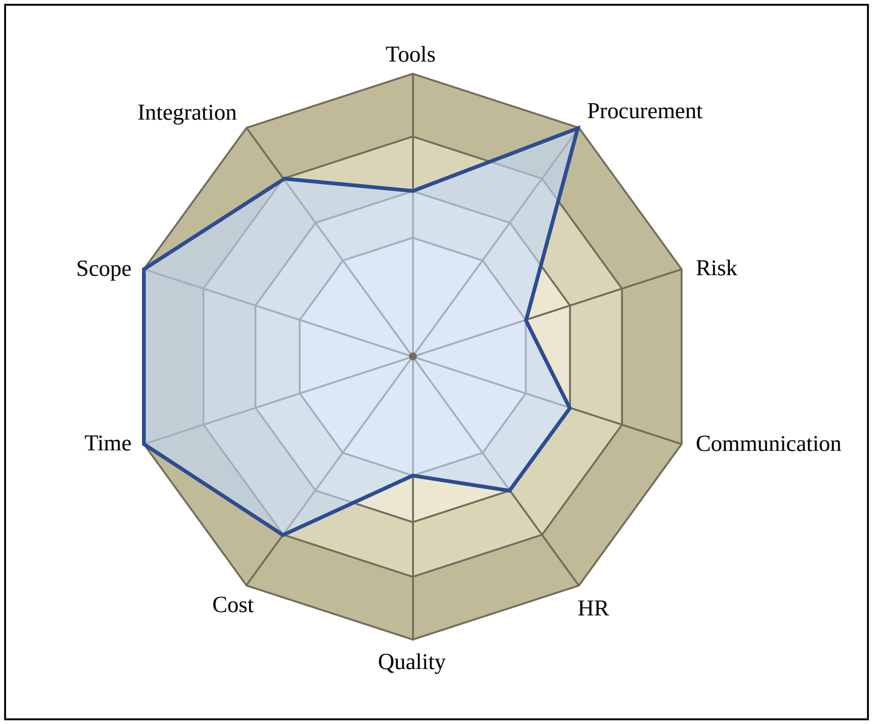
Transition to an Ideal Solution: Chamber is absent



Ideal Solution: Specimen-Chamber

Contradiction

- Contradiction often occurs when we try to improve one characteristic, or parameter, of a technical system, and cause another characteristic or parameter of the system to deteriorate.



http://www.niwotridge.com/images/BLOGImages/SpiderDiagram.jpg

TRIZ Thinking towards Contradictions

- Conventional thinking—find a compromising solution.
- TRIZ thinking—Overcoming technical contradictions without compromise.

The Three Steps

1. Analyze the technical system
   a. Determine the elements of the technical system
   b. Identify the origin of the problem
   c. Identify the characteristics that need to be improved.
2. State a technical contradiction
   a. Which characteristic needs to be improved?
   b. Which characteristic will deteriorate as a result?
3. Resolve the technical Contradiction using the TRIZ Principles

The 39 Technical Characteristics

1 Weight of a mobile object
2 Weight of a stationary object
3 Length of a mobile object
4 Length of a stationary object
5 Area of a mobile object
6 Area of a stationary object
7 Volume of a mobile object
8 Volume of a stationary object
9 Speed
10 Force
11 Tension/Pressure
12 Shape
13 Statility of composition
14 Strength
15 Time of action of a moving object
16 Time of action of a stationary object
17 Temperature
18 Brightness
19 Energy spent by a moving object
20 Energy spent by a stationary object
21 Power
22 Loss of energy
23 Loss of substance
24 Loss of an information
25 Loss of time
26 Amount of substance
27 Reliability
28 Accuracy of measurement
29 Accuracy of manufacturing
30 Harmful factors acting on an object from outside
31 Harmful factors developed by an object
32 Manufacturability
33 Convenience of use
34 Repairability
35 Adaptability
36 Complexity of a device
37 Complexity of control
38 Level of automoation
39 Capacity/Productivity

The 40 Principles

- TRIZ Principles—tools used to overcome technical contradictions.
- They are generic suggestions for performing an action to, or within, a technical system.
- They are Altshuller's view of the guiding principles of technical invention, after reviewing 200,000 patents.

The 40 Principles

1 Segmentation
2 Extraction
3 Local quality
4 Asymmetry
5 Consolidation
6 Universality
7 Nesting
8 Counterweight
9 Prior counteraction
10 Prior action
11 Cushion in advance
12 Equipotentiality
13 Do it in reverse
14 Spheriodality
15 Dynamicity
16 Partial or excessive action
17 Transtion into a new dimension
18 Mechanical vibration
19 Periodic action
20 Continuity of useful action
21 Rushing through
22 Covert harm into benefit
23 Feedback
24 Mediator
25 Self Service
26 Copying
27 Dispose
28 Replacement of mechanical system
29 Pneumatic or hydraulic construction
30 Flexible films or thin membranes
31 Porous materials
32 Changing the color
33 Homogeneity
34 Rejecting and Regernating parts
35 Transformation properties
36 Phase transition
37 Thermal Expansion
38 Accelerated oxidation
39 Inert environment
40 Composite materials

Example Problem

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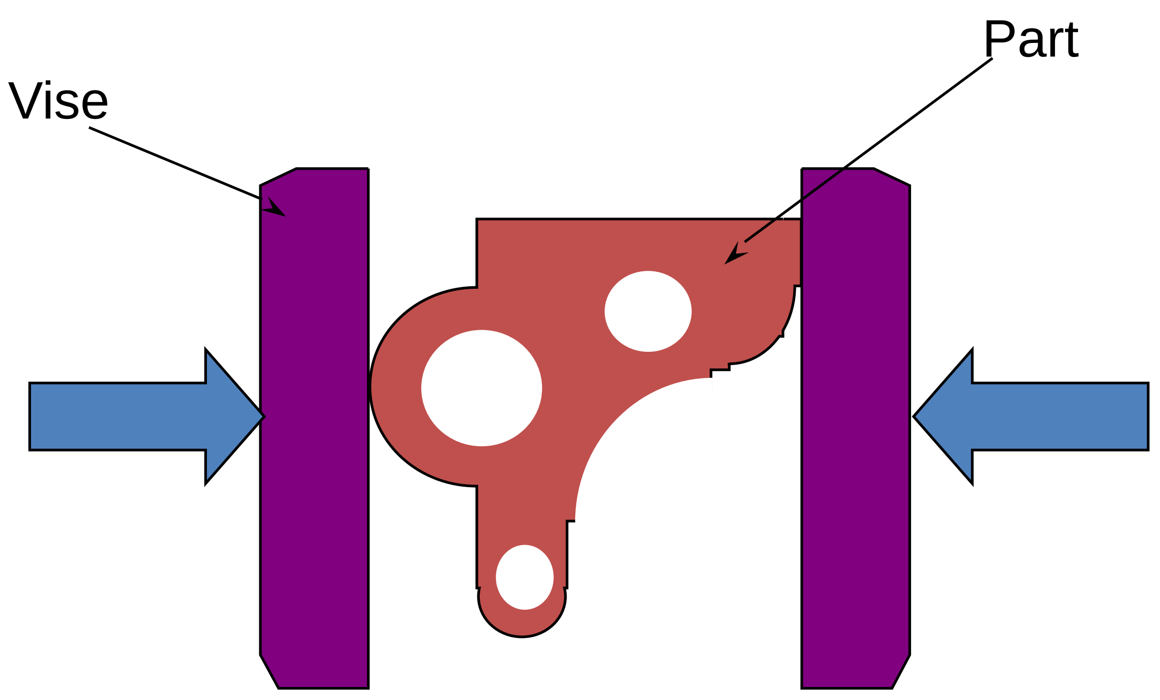

Class Exercise

- What are the system characteristics that need to be improved?
- Where is the technical contradiction?
- What is your solution?
- Form groups of 3 and discuss.
- Distance students may form groups on their own or think through this on their own.

Solution

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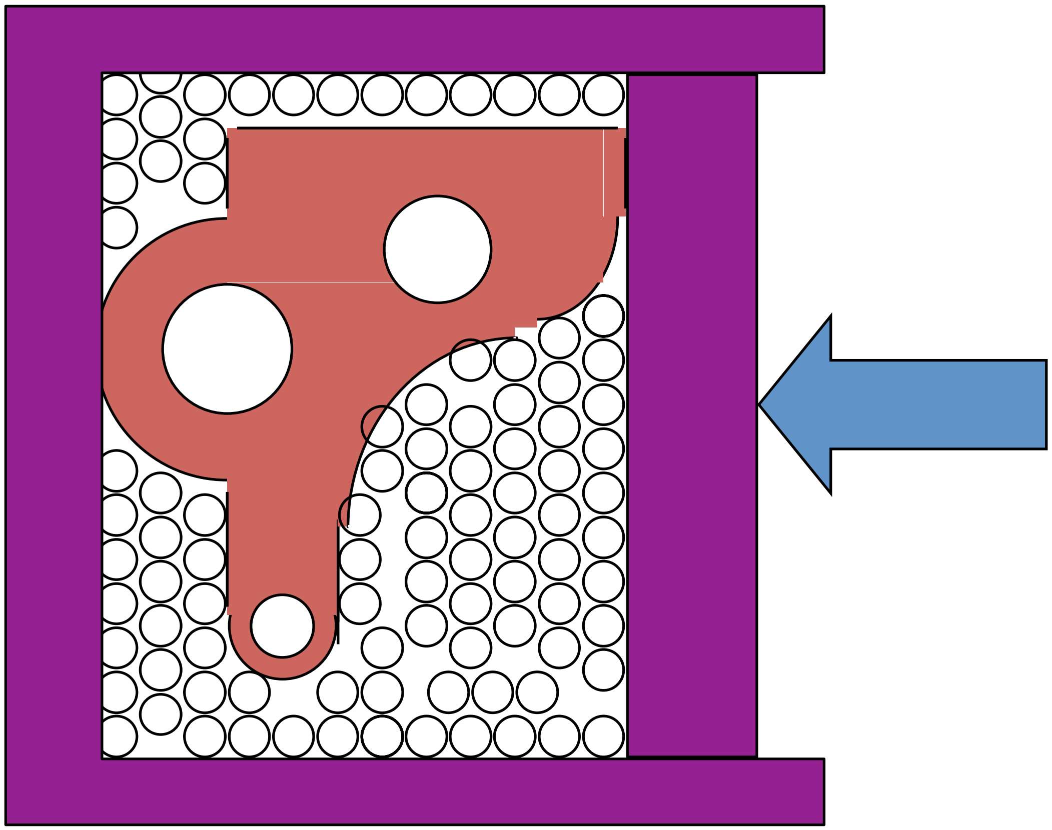
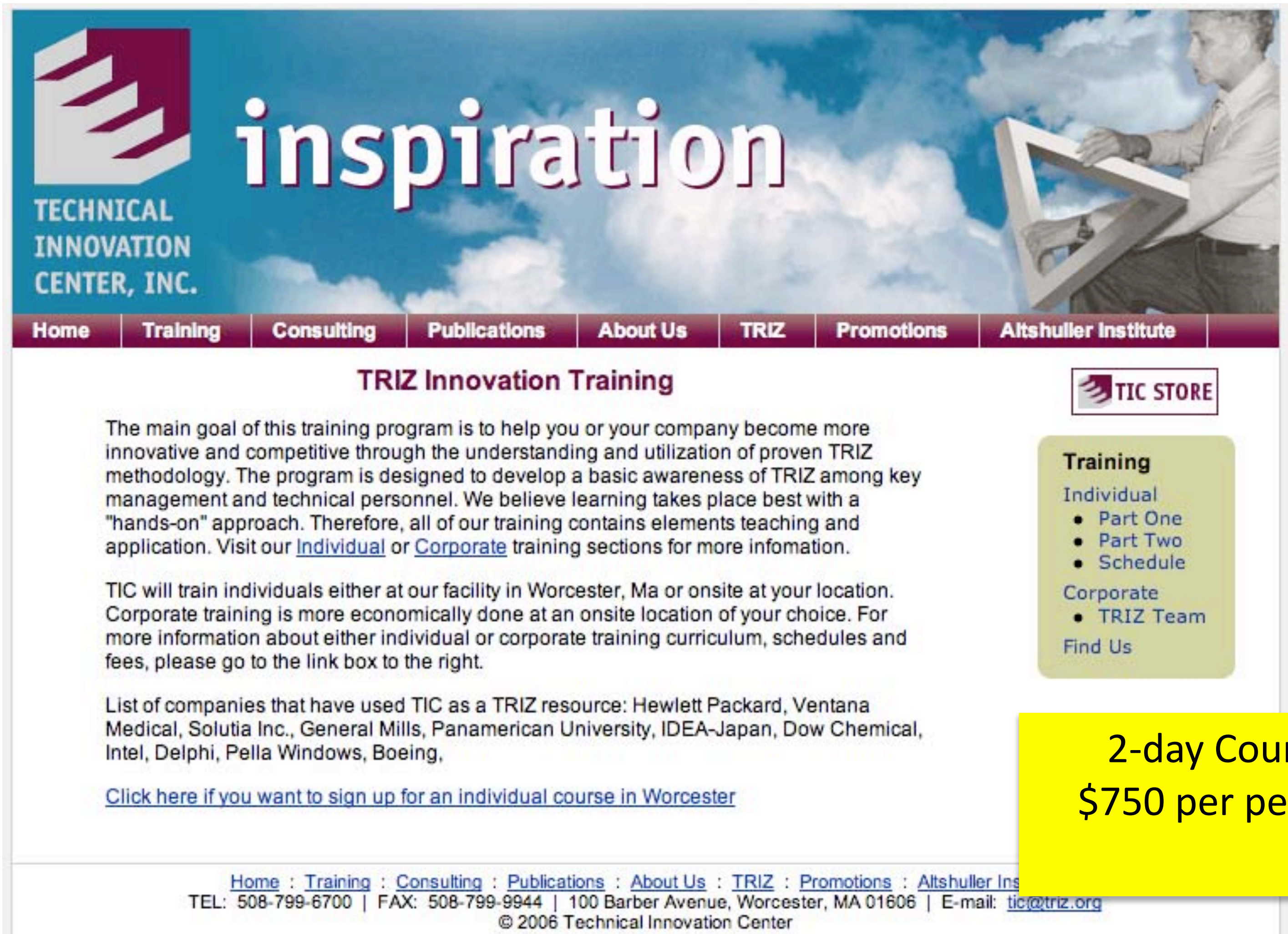


Class Discussion:
Your thoughts on TRIZ

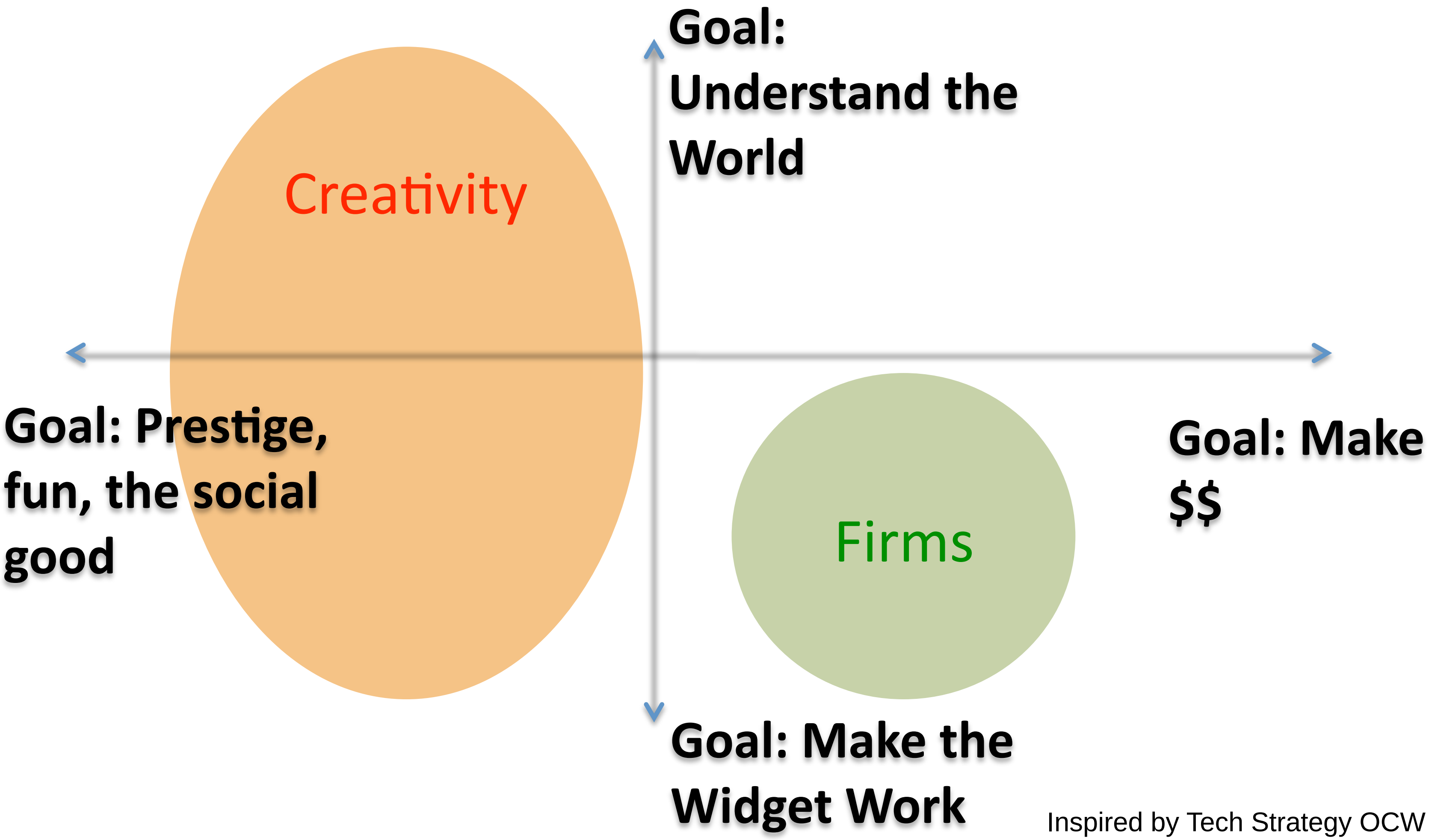
For More Information on TRIZ



2-day Course
$750 per person

The Productivity Dilemma

Graph is inspired by Tech Strategy OCW



Inspired by Tech Strategy OCW

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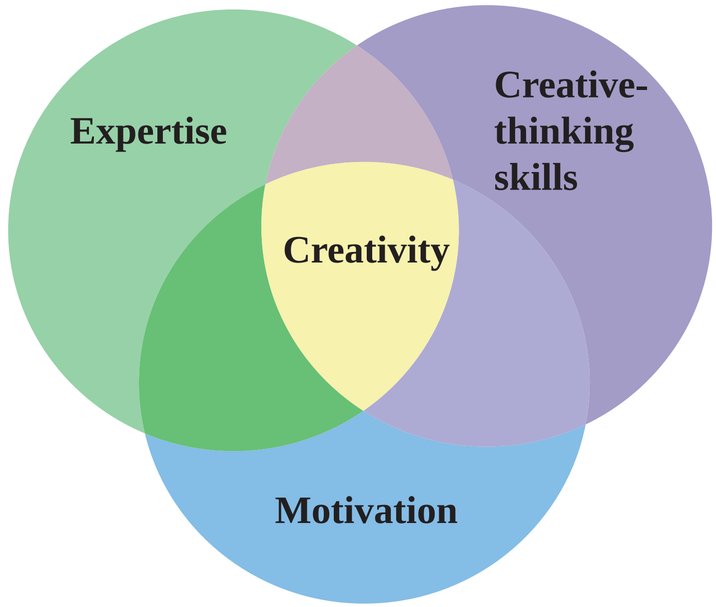
Three Components of Creativity for Every Individual

Amabile, HBR, 1998

Expertise is, in a word, knowledge - technical, procedural, and intellectual.



Creative-thinking skills determine how flexibly and imaginatively people approach problems. Do their solutions upend the status quo? Do they persevere through dry spells?

Not all **motivation** is created equal. An inner passion to solve the problem at hand leads to solutions far more creative than do external reward, such as money. This component-called *intrinsic motivation*-is the one that can be most immediately influenced by the work environment.

Image by MIT OpenCourseWare.

Six Managerial Practices that Affect Creativity

1. Challenge
2. Freedom
3. Resources
4. Work-group Features
5. Supervisory Encouragement
6. Organizational Support

Practice 1: Challenge

- Why is it important to give challenging assignments to the employees?
- Do you think there are right and wrong challenges?
- What does a manager need to do in order to provide the right challenge?

Practice 2: Freedom

- What does mean to give employees freedom in their assignments? What are the benefits?
- As a manager, what can you do to ensure the success of this approach?

Practice 3: Resources

- Does providing a lot of resources help improve creativity?
- What does too little resource do?
- Shall you still assign resources if the outcome of a project is uncertain?

Practice 4: Work Group Features

- Does it help put employees with similar backgrounds and similar interests in the same assignment?
- What are the responsibilities of managers in forming the right group?

Practice 5: Supervisory Encouragement

- Is a project successful only when the outcome is positive?
- As a manager:
  - How to sustain the creative passion?
  - How do you react to new ideas?
  - Are failed ideas bad ideas?

Practice 6: Organizational Support

- Put in place appropriate systems or procedures and emphasize values that make it clear that creative efforts are a top priority.
  - Properly reward creativity
  - Encourage exchange of ideas and collaboration
  - Intrinsic motivation increases when people are aware that those around them are excited by their jobs.

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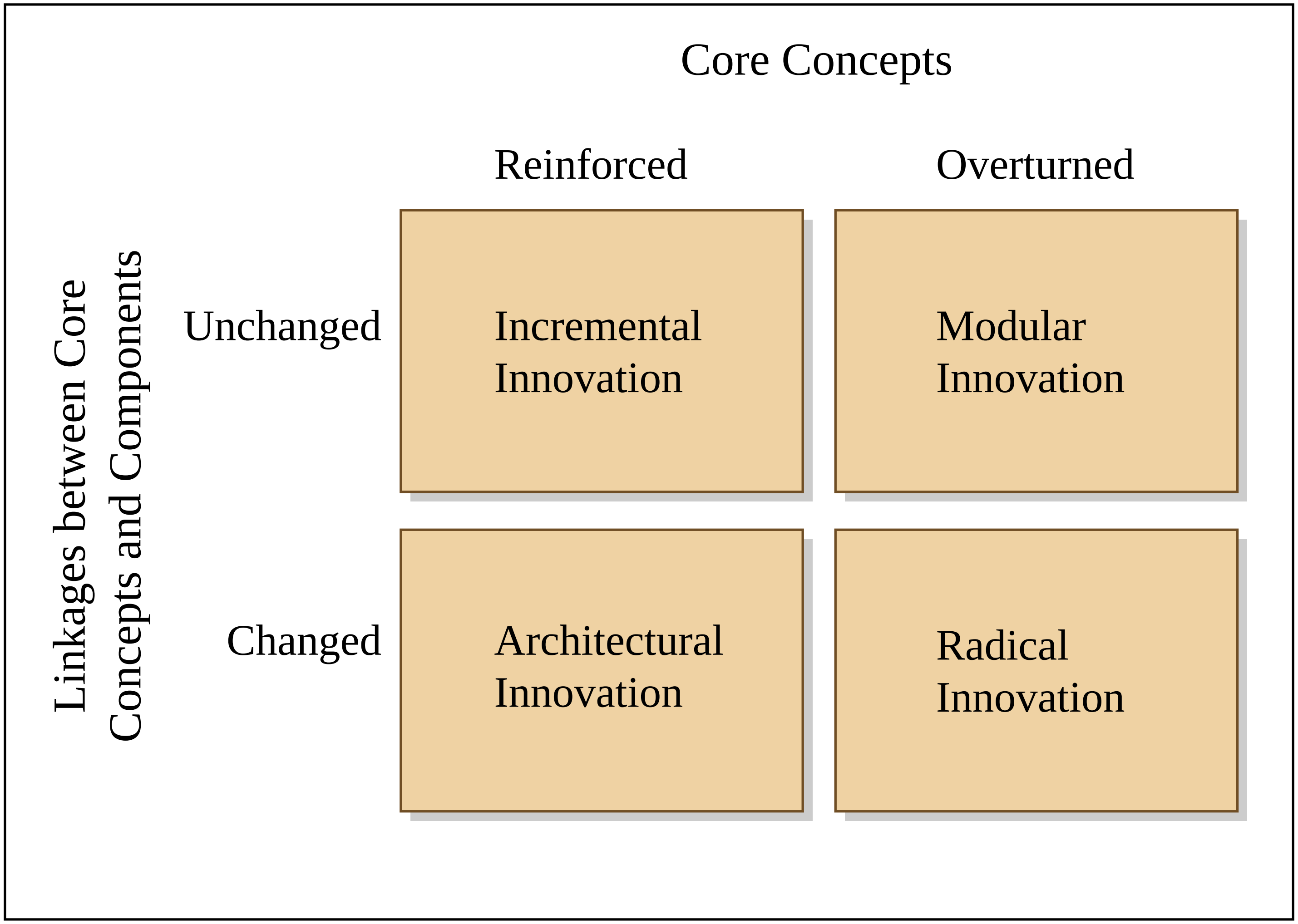
Thinking about Innovation in the Systems Context



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Henderson and Clark, HBR, 1998

Ceiling Fan Example

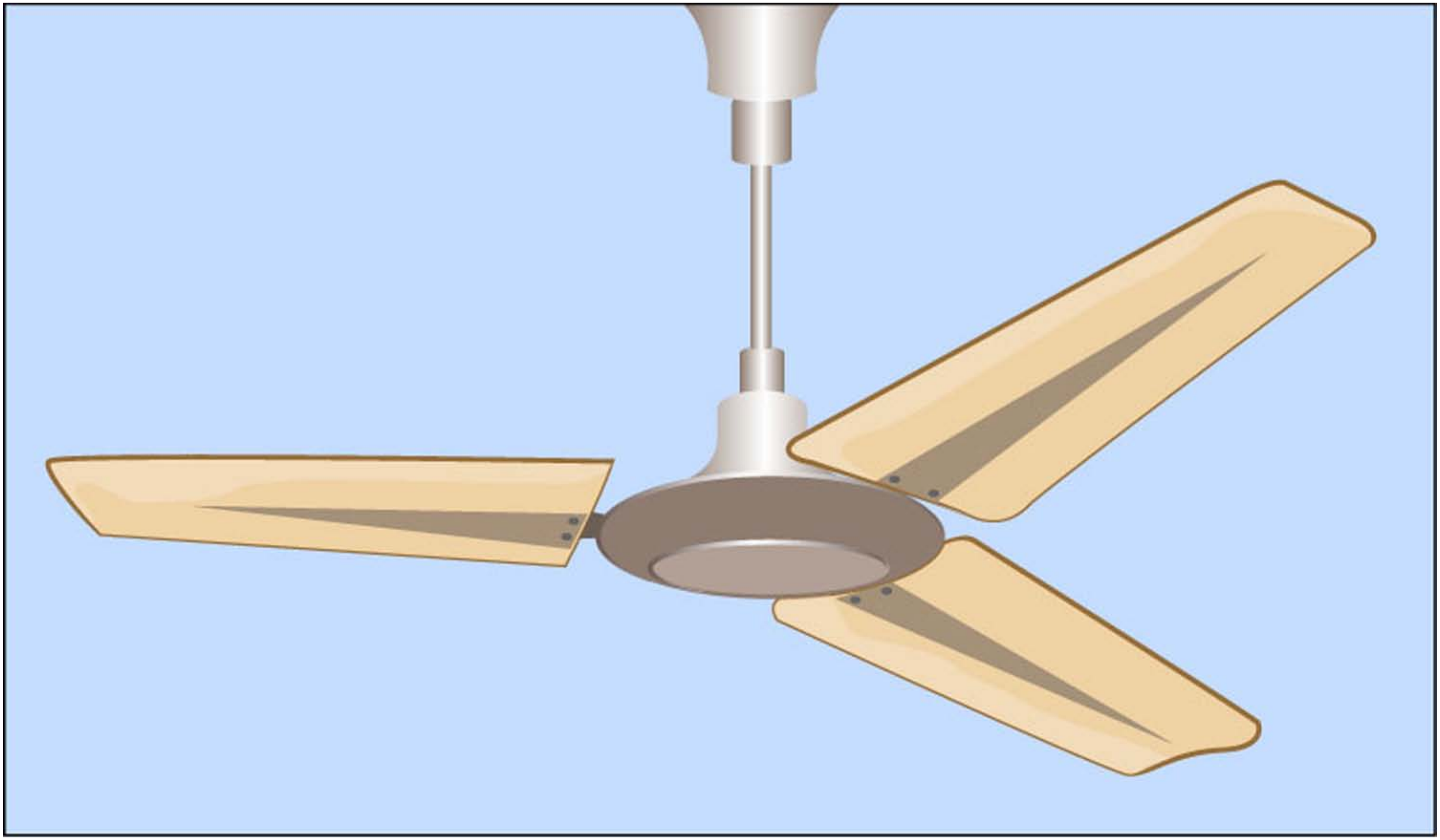


Image by MIT OpenCourseWare.

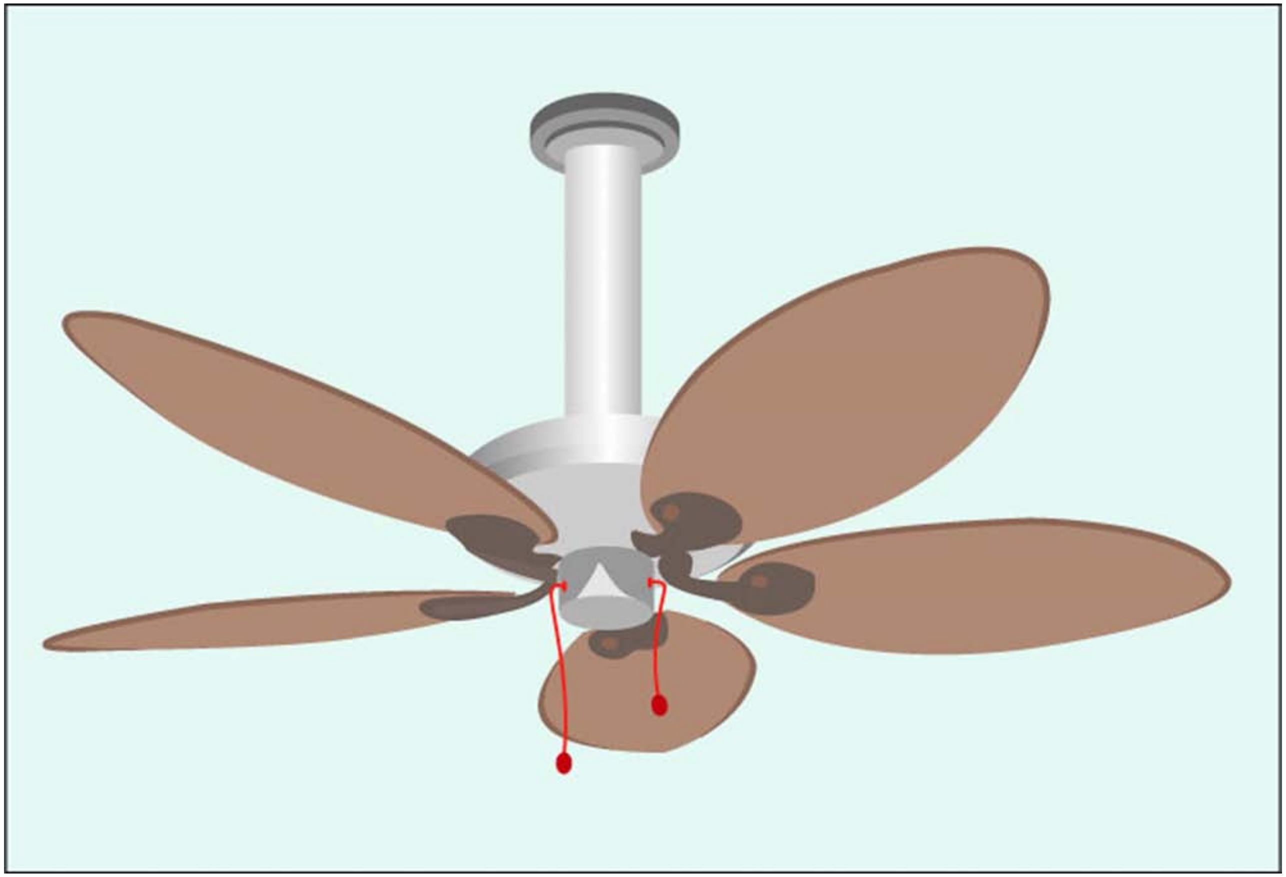
Radical Innovation

Core concept and architecture are both overturned.
Establishes a new dominant design.

Image by MIT OpenCourseWare.

Incremental Innovation

Core concept reinforced, and architecture unchanged. Improvements occurs in individual components.



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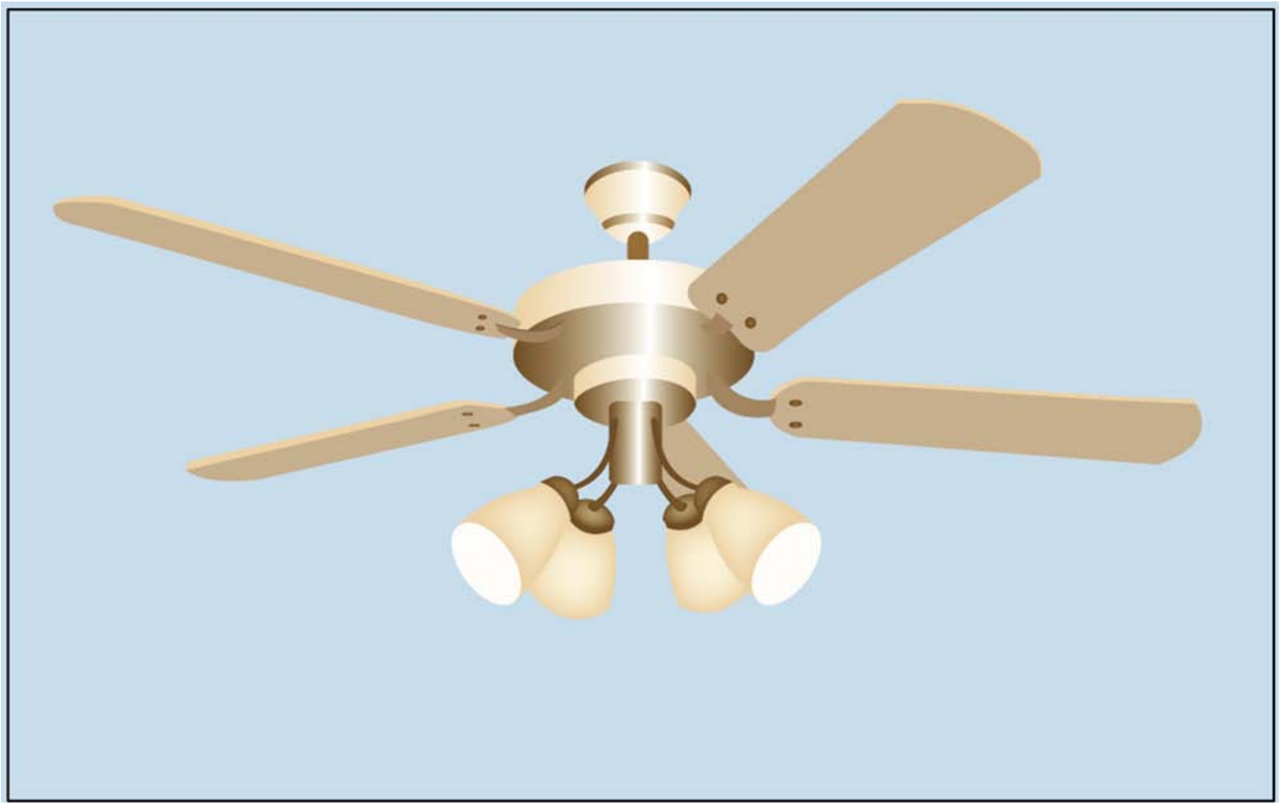
Modular Innovation

Core concept overturned, but architecture unchanged.



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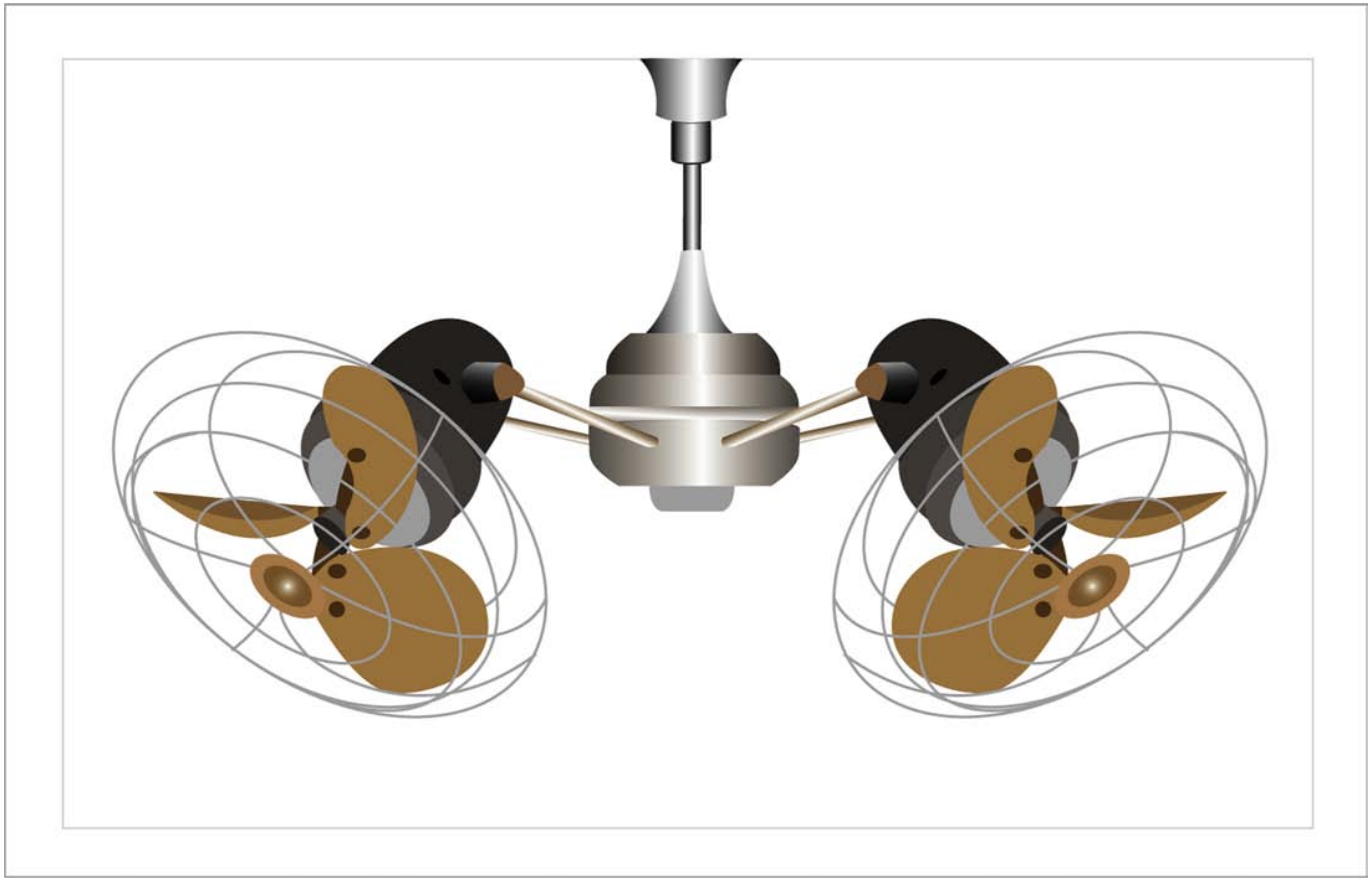
Architectural Innovation

Core concept reinforced, but architecture changed.



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Core Concepts

Linkages between Core Concepts and Components

	Reinforced	Overturned
Unchanged	 Incremental Innovation	 Modular Innovation
Changed	 Architectural Innovation	 Radical Innovation

Images by MIT OpenCourseWare.

Architectural Innovation

- Successful product development requires:
  - Component knowledge
  - Architectural knowledge
- We need to be aware of innovation that use many existing core design concepts in a new architecture and that therefore have a more significant impact on the relationships between components than on the technologies of the components themselves.

Dominant Design

- A set of core design concepts
- A single architecture of the product
- Examples—class discussion?
  - Automobiles

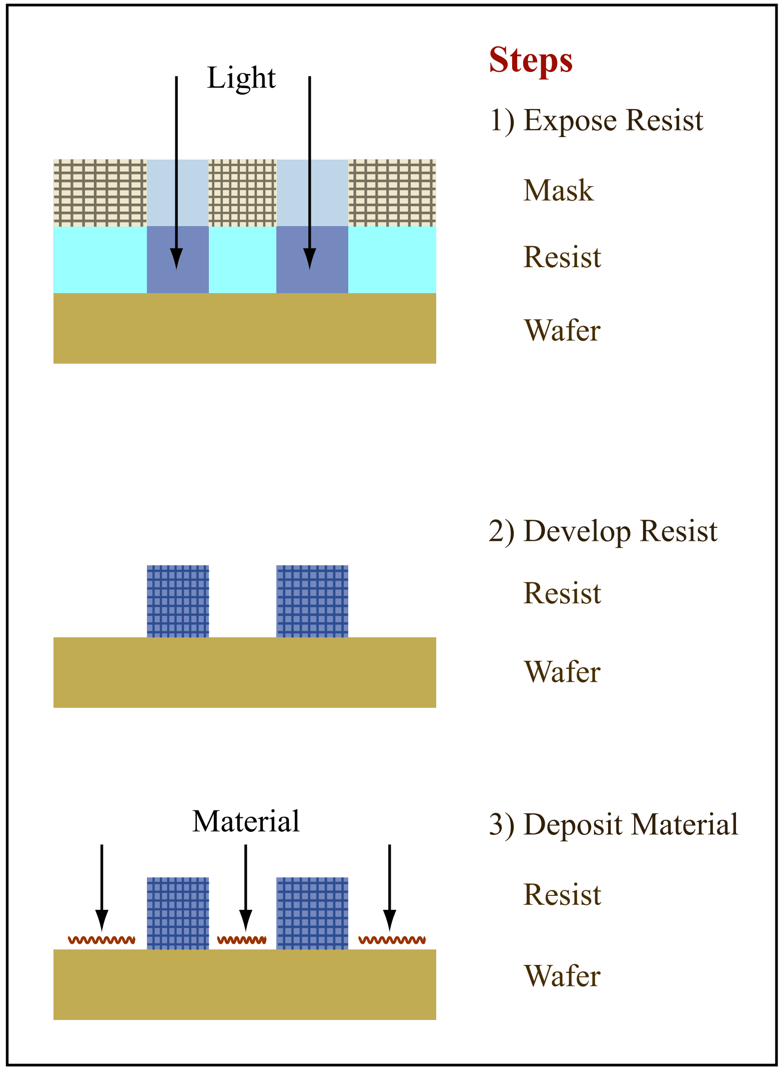
Implication of Dominant Design

- Progress is made on the improvements of components within the framework of a stable architecture.
- Single stable architecture shapes:
  – An organization's communication channel
  – Information filters
  – Problem solving strategies
- Established firms can work efficiently based on its knowledge of the dominant design and stable architecture.

Problems Created by Architecture Innovation

- Hard to identify the innovation has architectural implication, because the core concept seems to be the same.
- Established organizations have challenges to change its old way to communication and learning.
- New entrants with smaller organization find it easier to build the organization knowledge around the new architecture.

Steps of Lithographic Process



Henderson and Clark, 1998

Image by MIT OpenCourseWare.

Alignment Technology

A Summary of Architectural Innovation in Photolithographic Alignment Technology		
Major changes		
Equipment	*Technology*	*Critical relationships between components*
Proximity aligner	Mask and wafer separated during exposure.	Accuracy and stability of gap is a function of links between gap-setting mechanism and other components.
Scanning projection	Image of mask projected onto wafer by scanning reflective optics.	Interactions between lens and other components is critical to successful performance.
First-generation stepper	Image of mask projected through refractive lens. Image "stepped" across wafer.	Relationship between lens field size and source energy becomes significant determinant of throughput. Depth of focus characteristics—driven by relationship between source wavelength and lens numerical aperture—become critical. Interactions between stage and alignment system are critical.
Second-generation stepper	Introduction of "site-by-site" alignment, large 5x lenses.	Throughput now driven by calibration and stepper stability. Relationship between lens and mechanical system becomes crucial means of controlling distortion.

Image by MIT OpenCourseWare.

Henderson and Clark, 1998

Leading Manufacturers

Share of Deflated Cumulative Sales (%) 1962-1986, by Generation, for the Leading Optical Photolithographic Alignment Equipment Manufacturers*					
	Alignment Equipment				
Firm	Contact	Proximity	Scanners	Step and repeat (1)	Step and repeat (2)
Cobilt	44		<1		
Kasper	17	8		7	
Canon		67	21	9	
Perkin-Elmer			78	10	<1
GCA				55	12
Nikon					70
Total	61	75	99+	81	82+

* This measure is distorted by the fact that all of these products are still being sold. For second-generation step and repeat aligners this problem is particularly severe, since in 1986 this equipment was still in the early stages of its life cycle.

Image by MIT OpenCourseWare.

Henderson and Clark, 1998

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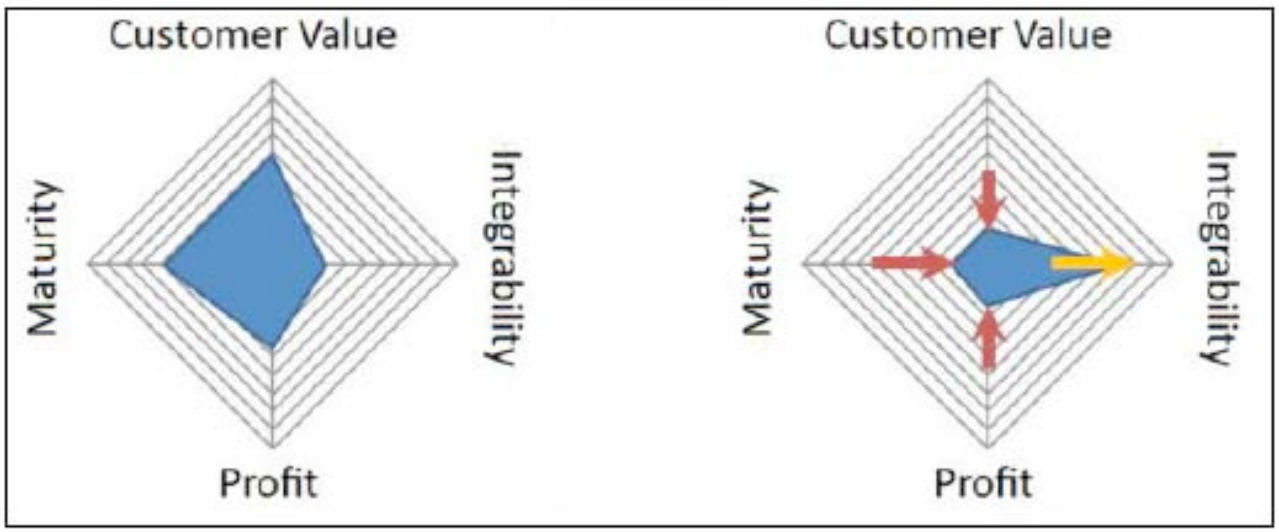
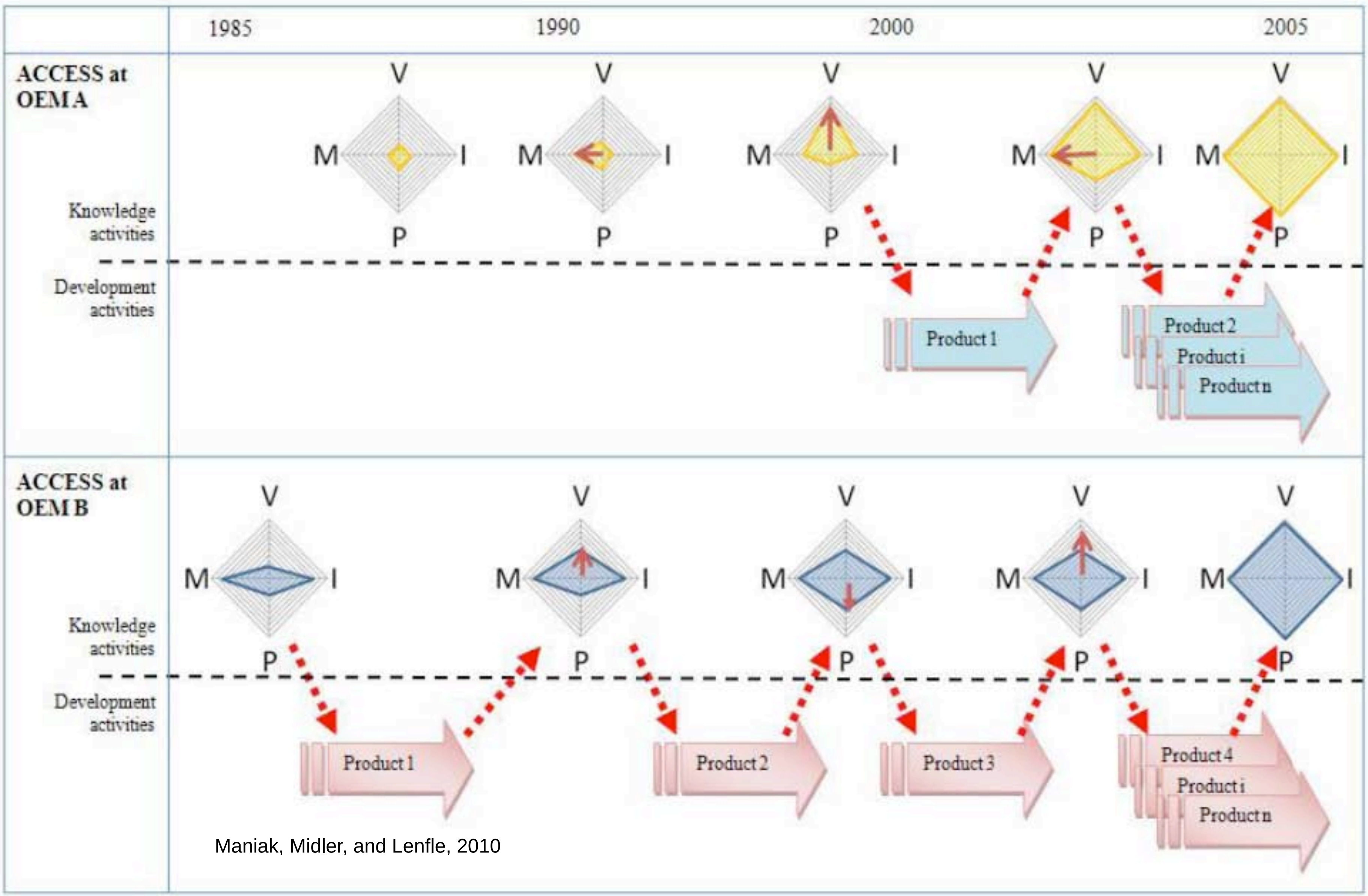
Four Criteria of the Value Proposition of an Innovation

- Customer Value
- Integrability
- Maturity
- Profit



Maniak, Midler, and Lenfle, 2010

Interplay between Innovation and Development



Maniak, Midler, and Lenfle, 2010

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