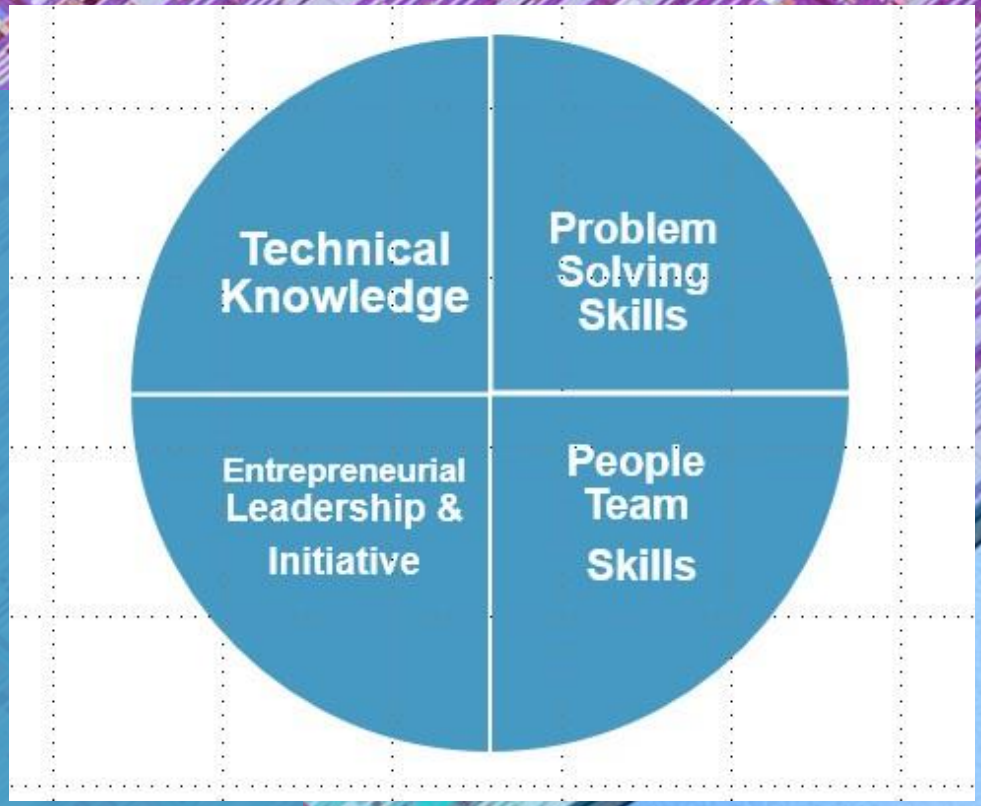
Electronics Impact of the World and Quality of Life

Current $1T each year

- **Historical impact:**
- Connectivity (Mobile + Internet), productivity / time saving
- Improvement in Medicine (Robotic surgery)
- Mobile Communication… especially in 3rd world (+ knowledge and news)
- Computation + Gig Economy => See **Four** by Scott Galloway
- Safety in Transportation

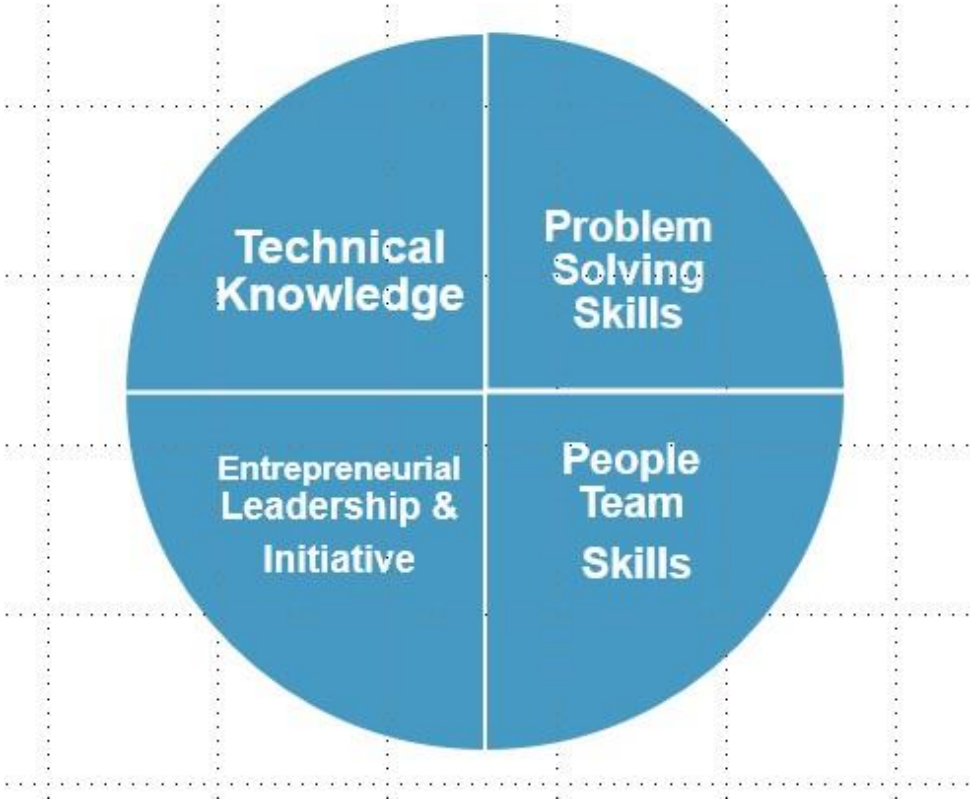
Accelerating R&D with insights from Industrial Problem Solving



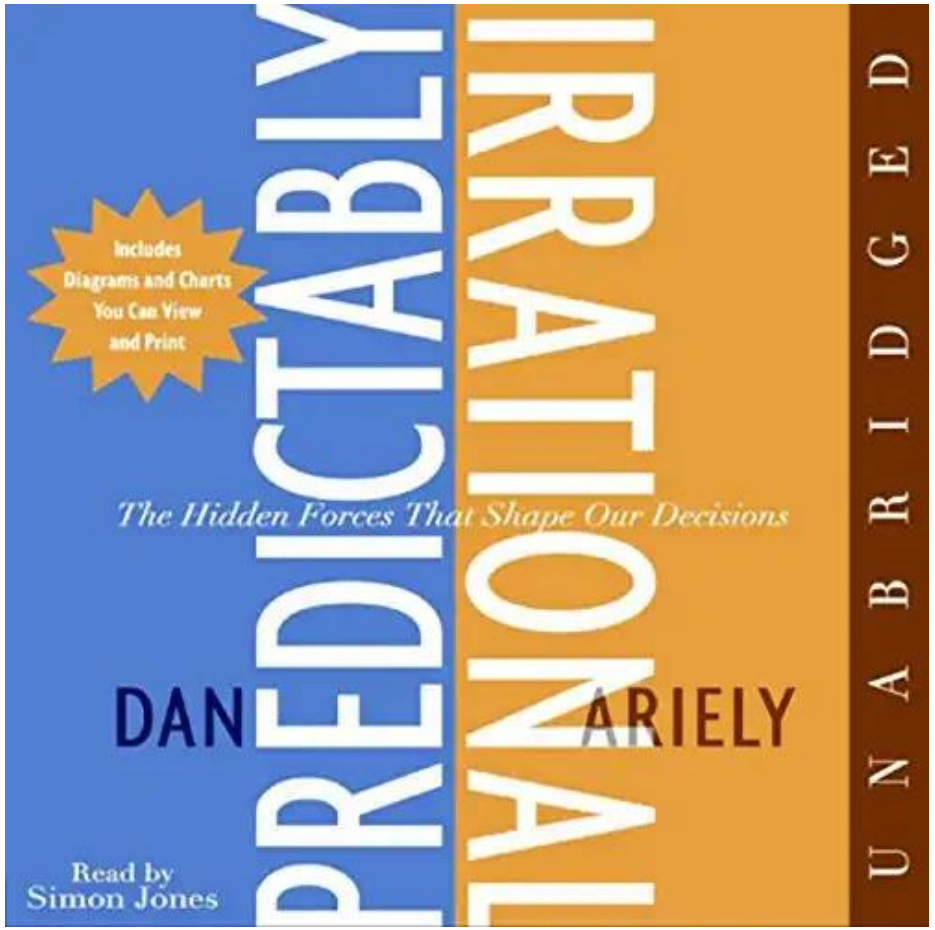
Chris Olsen, PhD
Sr. Director of Oxidation Products
Front End Products, Semiconductor Products Group (SPG)

Hiring Mangers looking for Career Skills

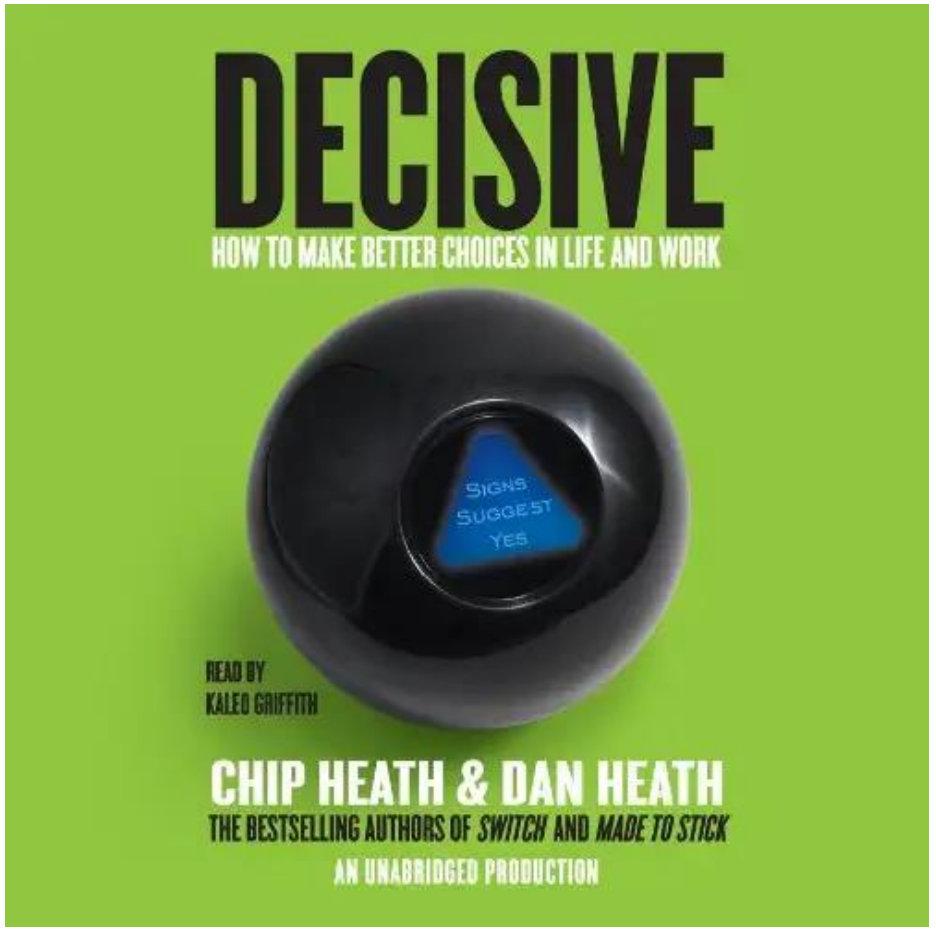
- Technical knowledge that lines up with the Job – Tough to match
  - Only 20% of STEM majors work in their same field as study
- Critical Thinking
- Problem Solving
- Data Analytic Skills
- People Skills
  - Concise Communication
  - Oral Presentation
  - Report Generation
- Takes Initiative



Decision Theory Books

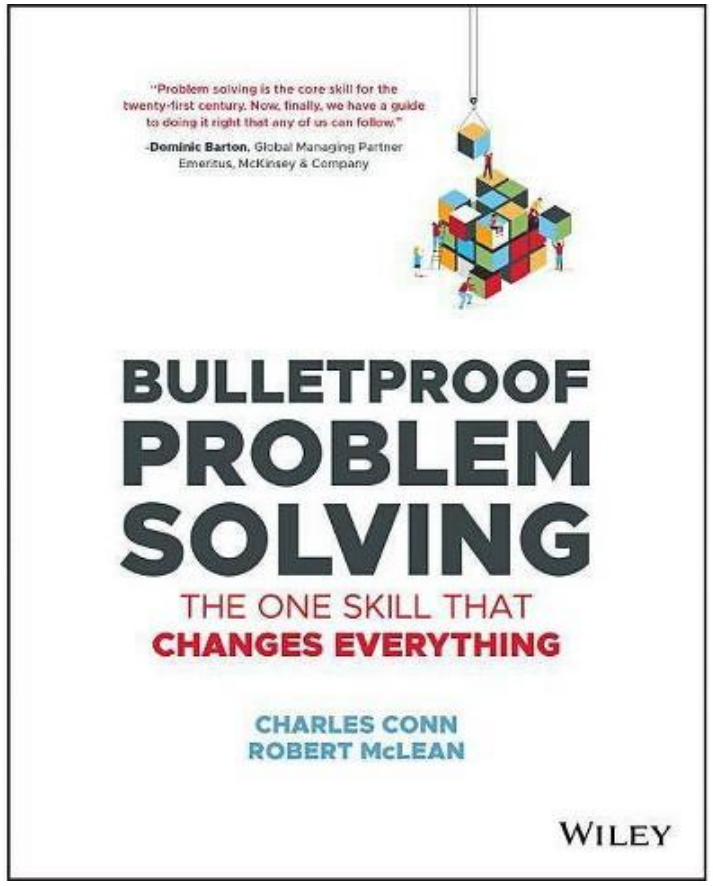


Cognitive Bias

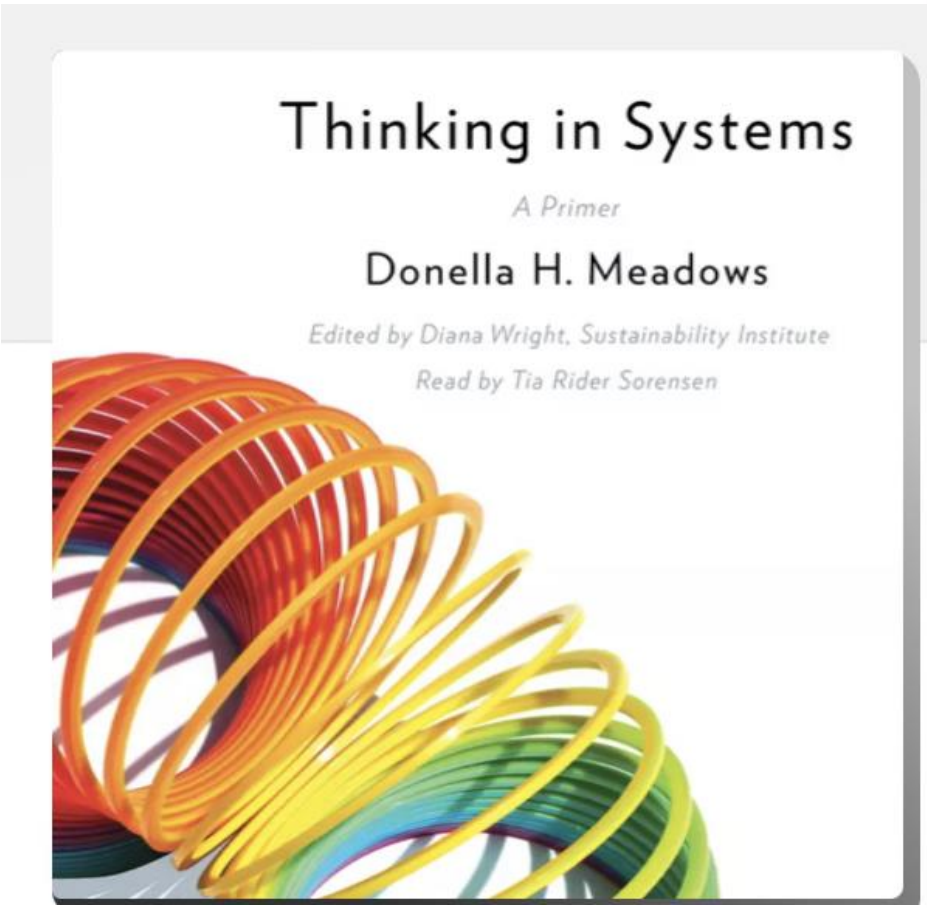


Best Practices in Decision Making

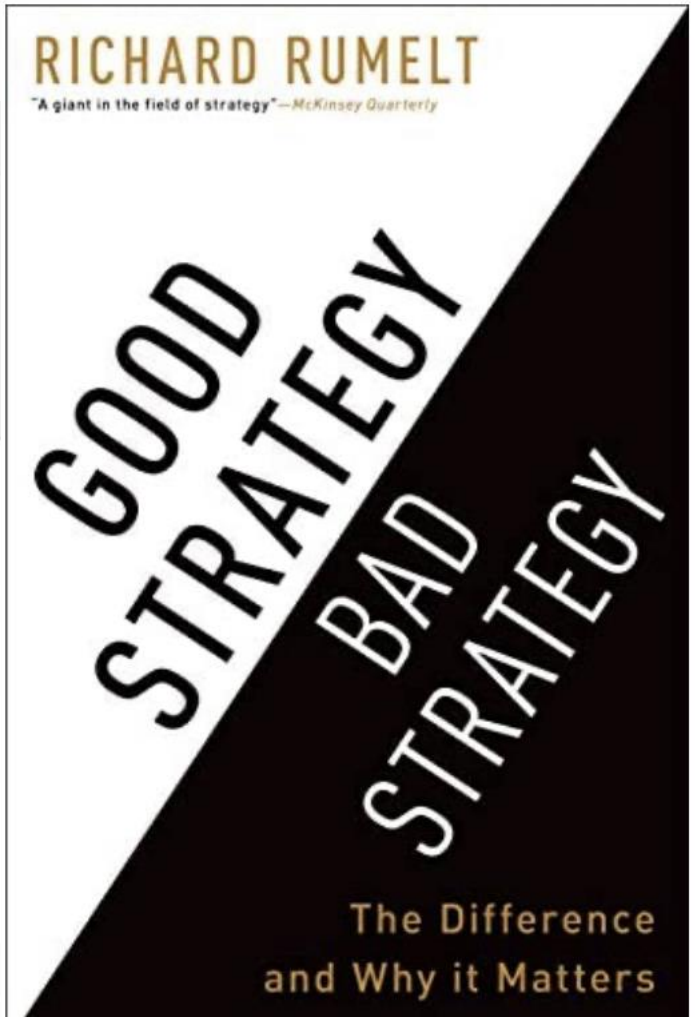
Growth Books



Systematic Problem Solving



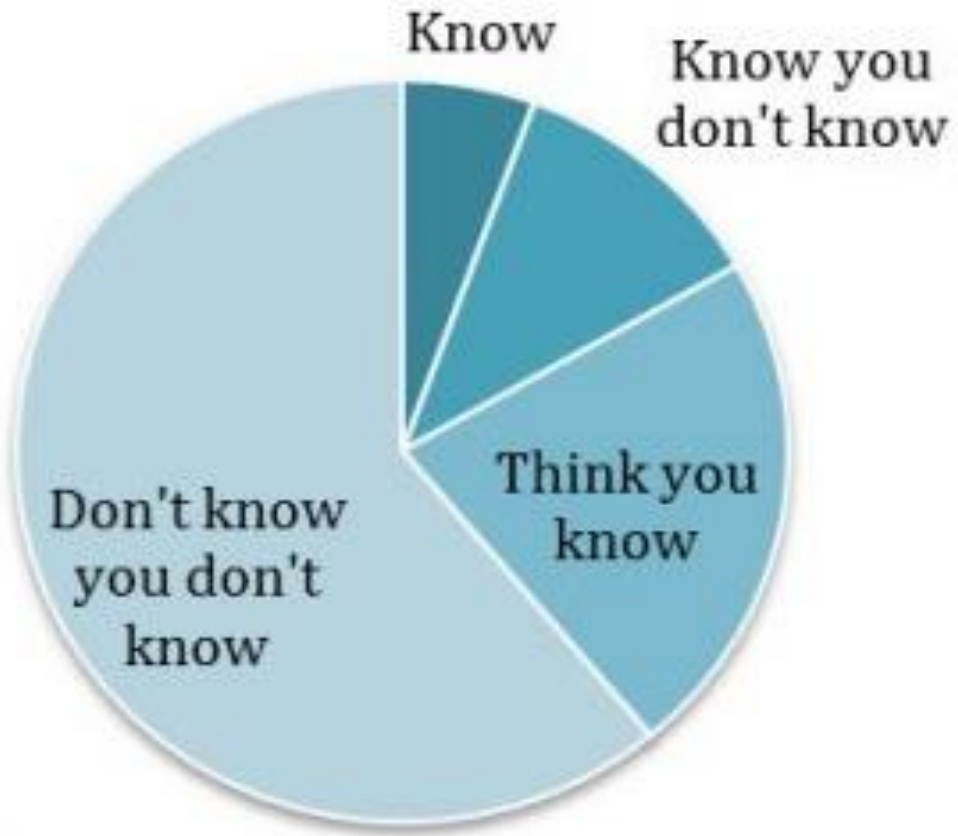
System Thinking



Proximate Coherent Strategy

Weak link analysis

Starting Premise:

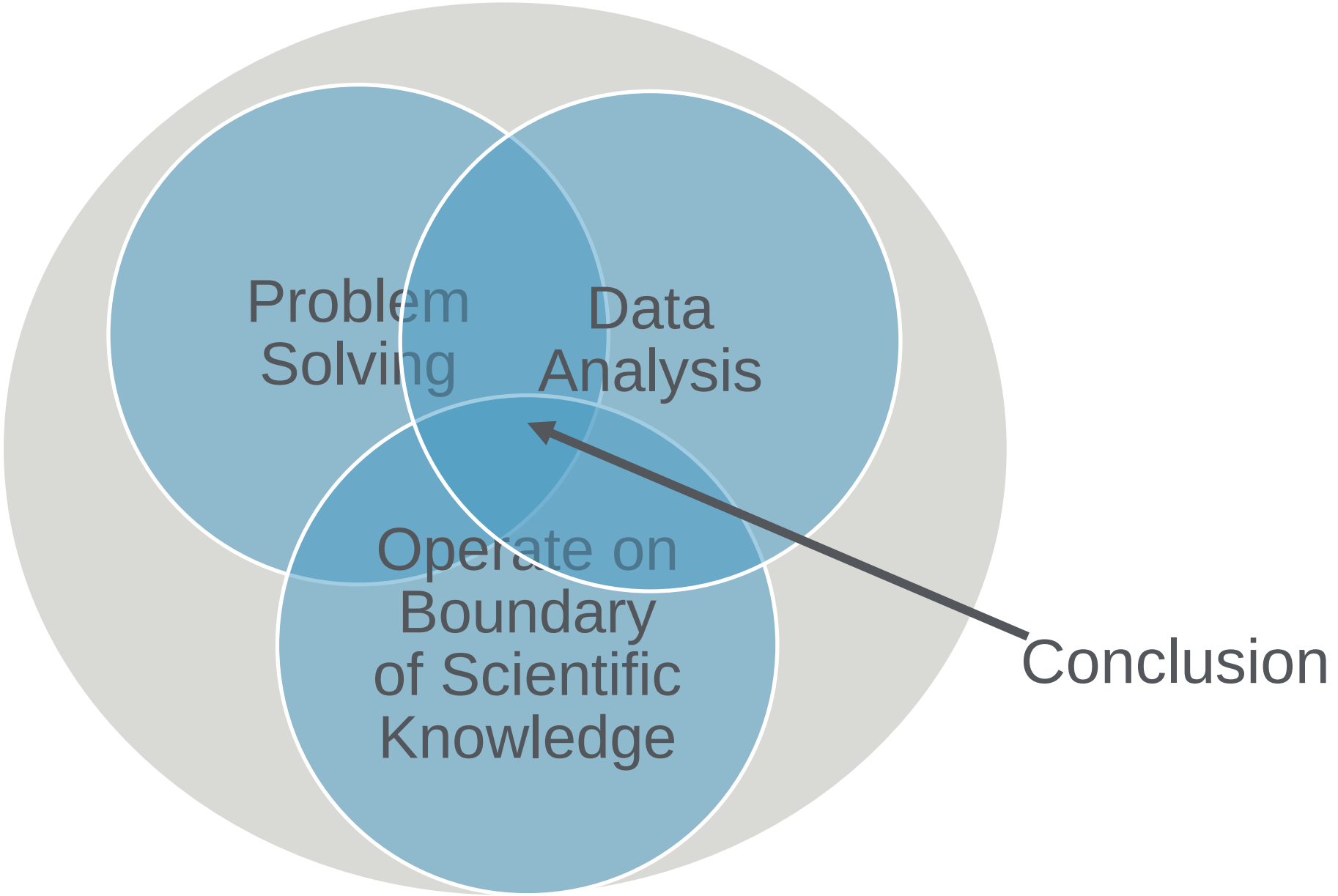


For the Professors / Professional Researchers in the seminar:
Would you accept 2x your Research Grants?

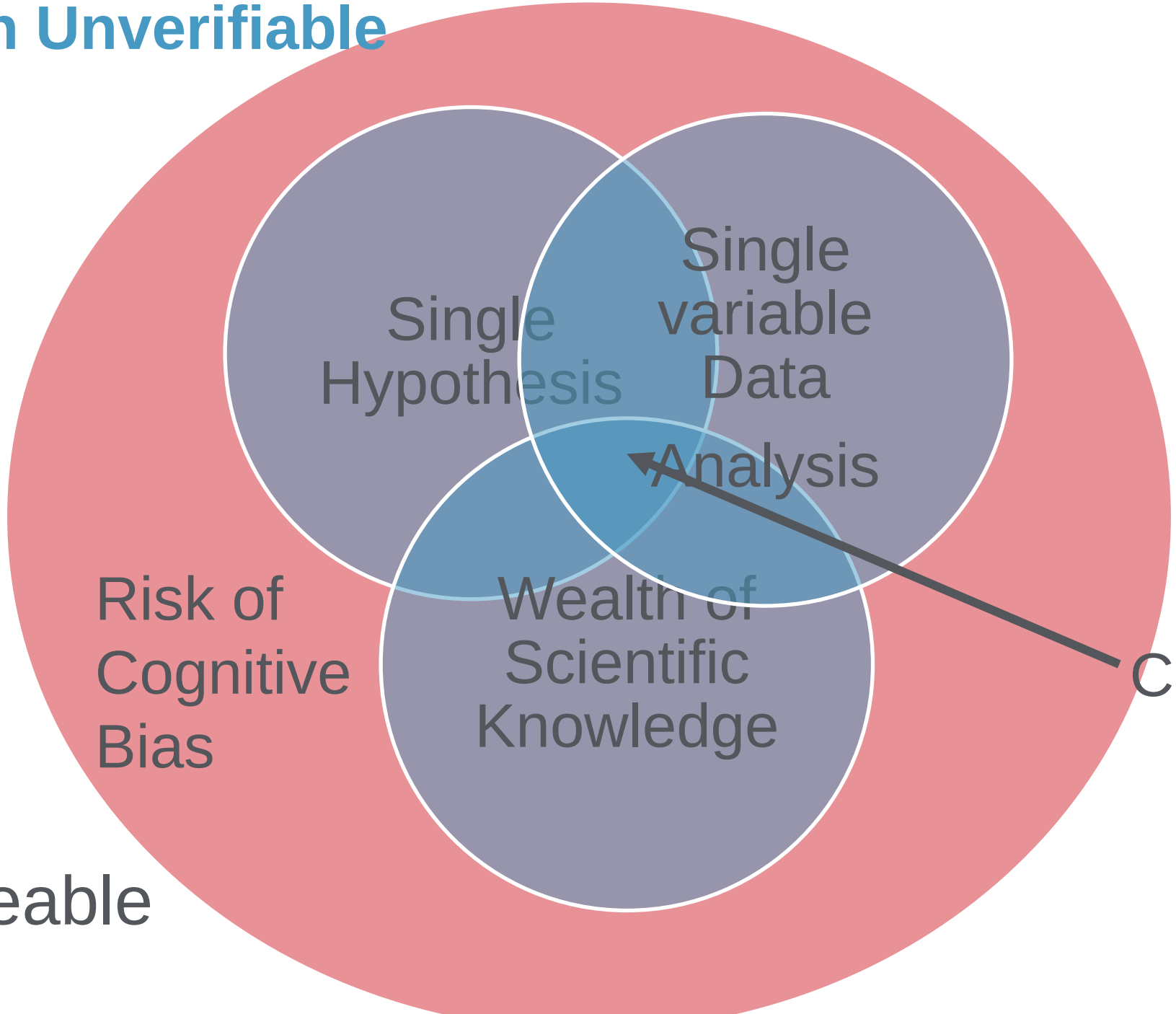
Graduate Student:
Would you like to finish your Doctorate in ½ the time?
Or Twice as many Publications?

This seminar focuses on Efficiency and Efficacy in R&D

Knowledge Discovery

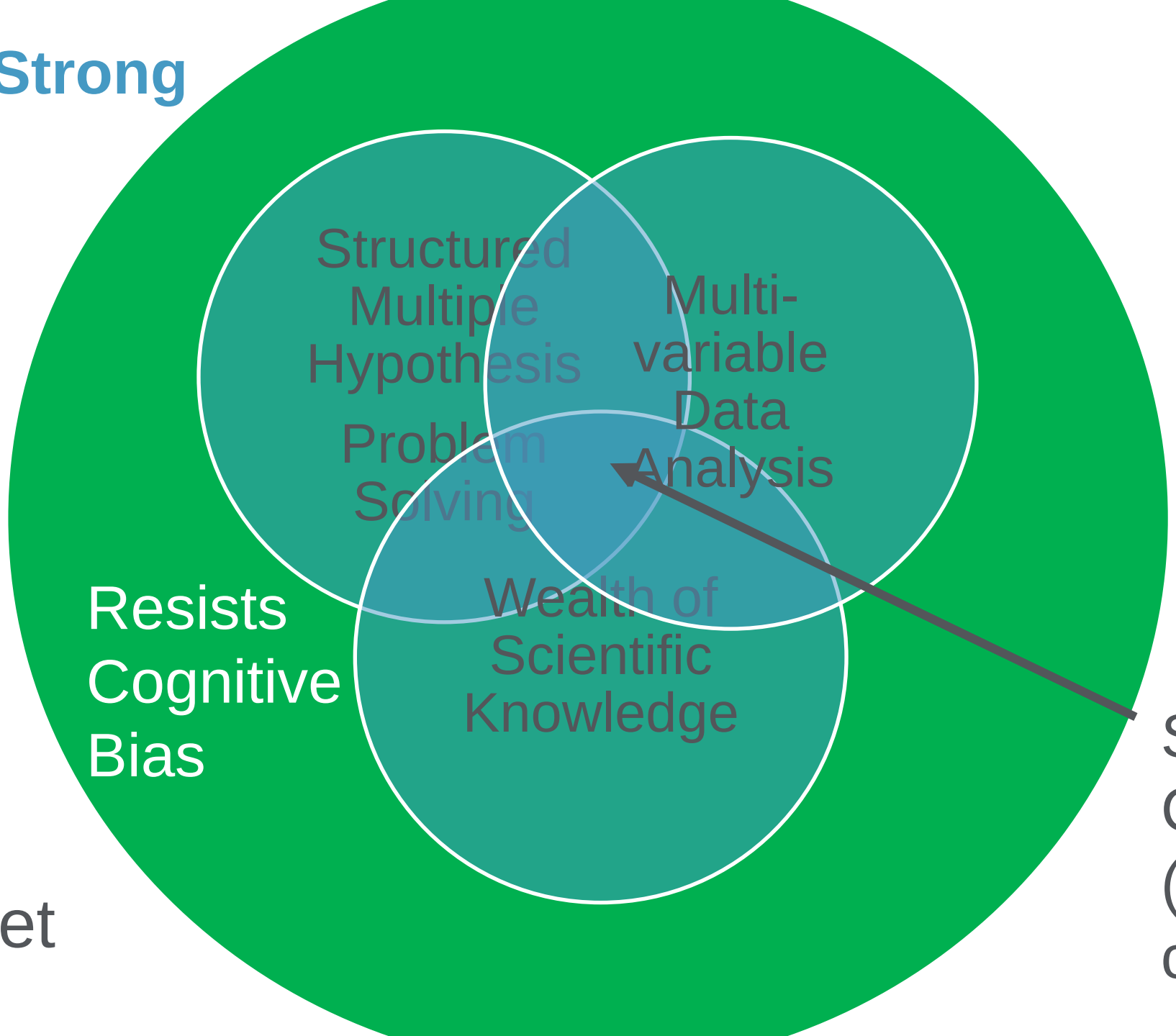


Problem on Unverifiable Research



39% of Literature is not reproduceable

Method for Strong Conclusion



Coherent Conclusion You can Make $M bet

Why Scientific Method is not Enough for Semi-IC

- University-Long Time Expert Fields
- Careers expand 20-40 years => Experts available to guide experimentation
- Expert help guide good hypothesis and scientific experimentation

- Semi-IC
- Re-inventing itself , new fields of research every 2-4 years
- Less Experts per topic
- Because hypothesis are weaker, requires more Empirical exploration

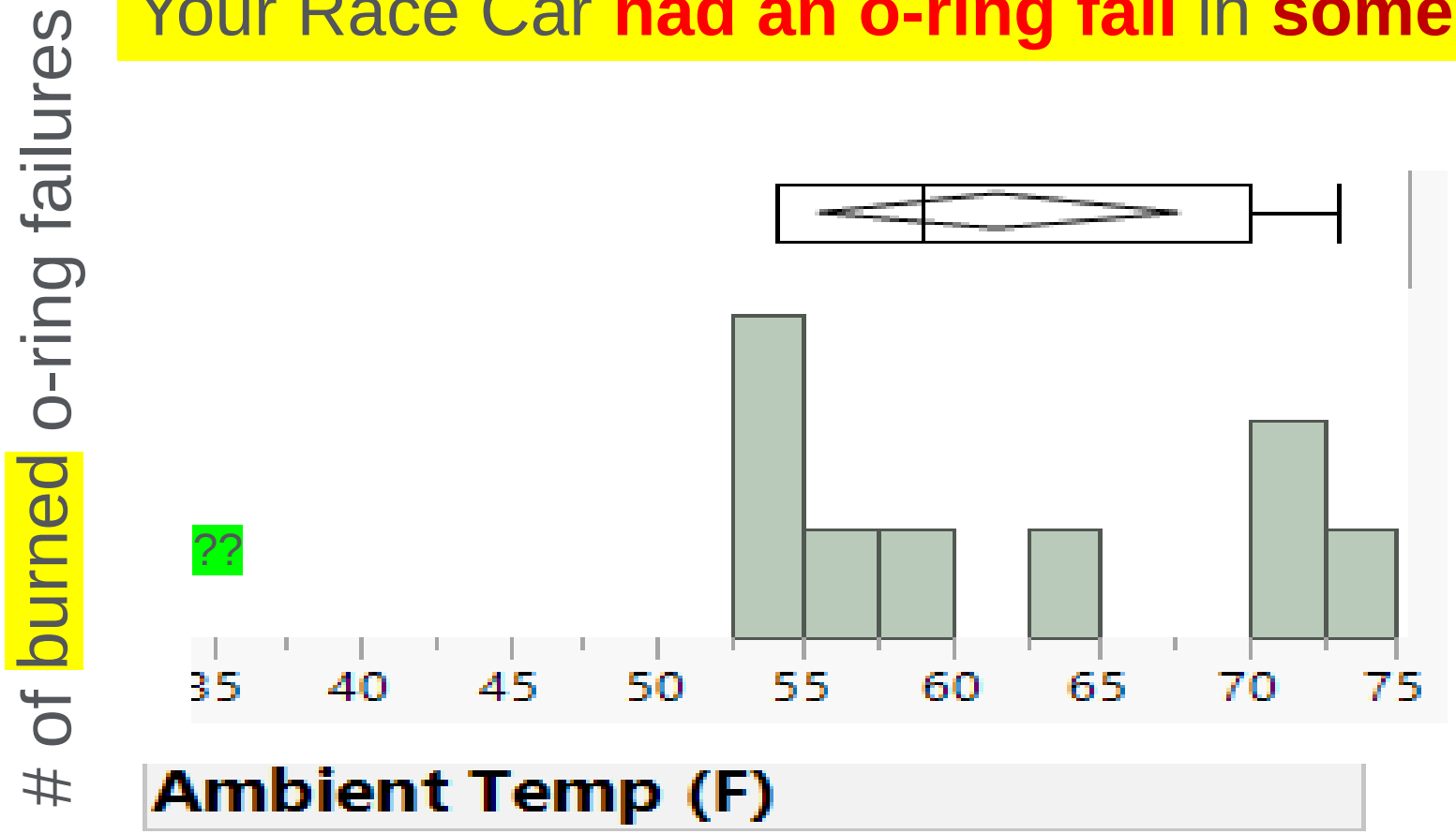
The world is getting more and more Complex!

parts of a system interact in ways that give rise to properties that can sometimes be quite surprising

https://phys.org/news/2022-08-world-exponentially-complex.htm

MBA Program example: Carter Racing

Your Race Car **had an o-ring fail** in **some** of your races

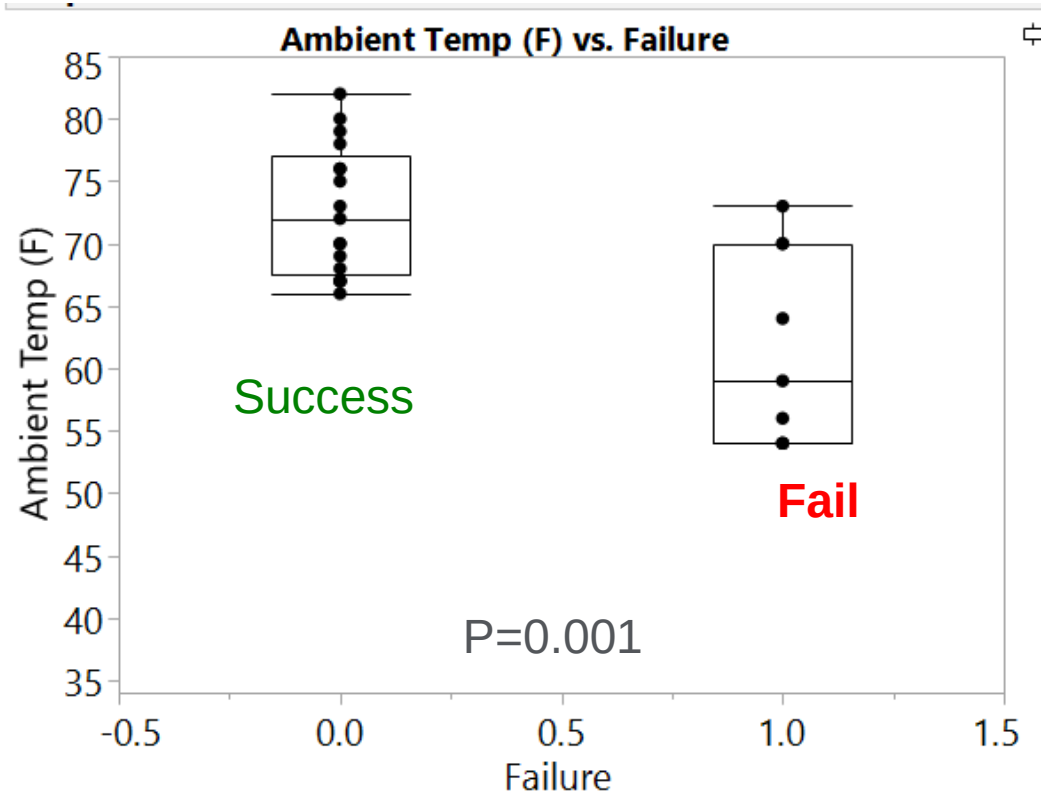


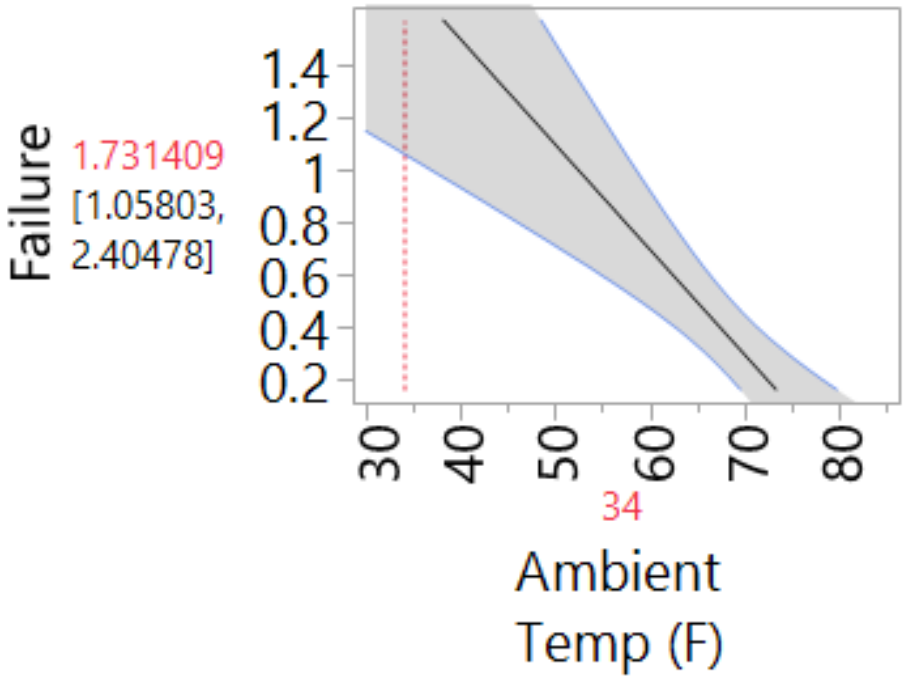
Should you Race at 34°F for $100k prize or risk losing your sponsor for the next Failure?

1986 Space Shuttle Challenger Disaster

- O-ring risk was known & discussed
- NASA had a failure of
  - Critical Thinking Culture
  - Cognitive Bias (people skills)
  - Data Graphical analysis

Statistics of the Same Data (99.9% statistical confidence)

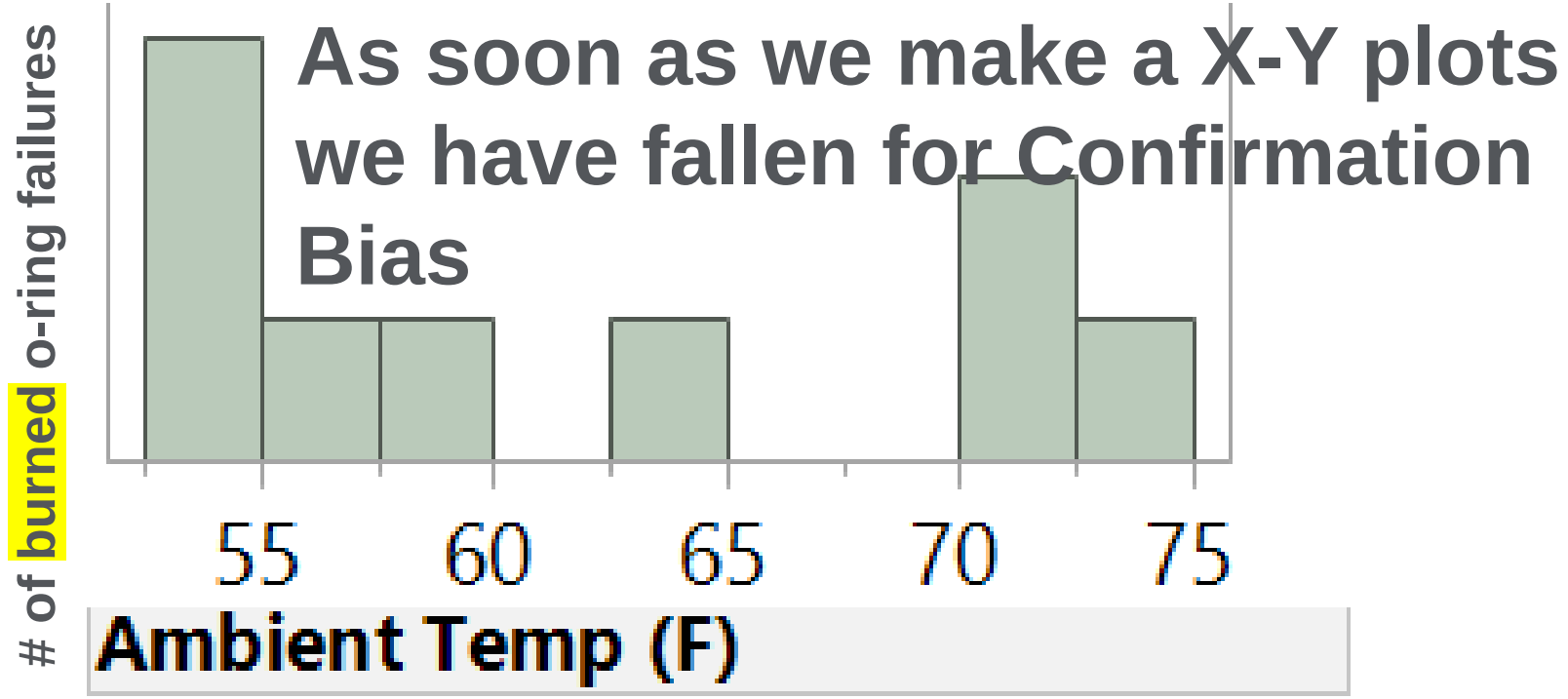




Human bias (Spot light effect) prevented Scientists from asking for more data or correct Graph

1) Statistical model applied after the fact predicted 99% failure
2) People Culture was broken to not ask for data proving that it was safe

Preliminary Conclusion



Single hypothesis and single variable data analysis are at Risk for Confirmation Bias

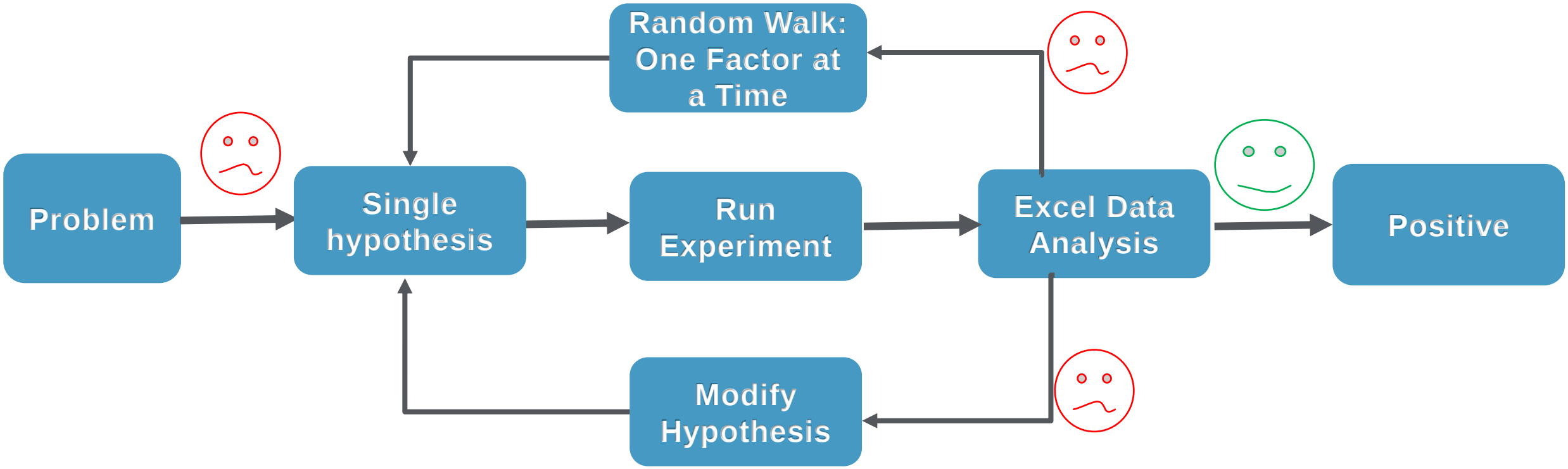
History of the Scientific Method

- **Aristotle** pioneered scientific method in **ancient Greece** alongside his empirical biology and his work on logic, rejecting a purely deductive framework in favor of generalizations made from observations of nature.
- **Galileo Galilei** pioneered the experimental scientific method and was the first to use a refracting telescope to make important astronomical discoveries. Albert Einstein called Galileo the “father of modern science.”
- The scientific method was used even in ancient times, but it was **first documented by Sir Francis Bacon** (1561–1626) who set up inductive methods for scientific inquiry. The scientific method can be applied to almost all fields of study as a logical, rational, problem-solving method.

Alternate Scientific Problem Solving Tools:

1. DMAIC (Define Measure Analyze Improve Control (1950s) -Deming
2. 8D (Ford) 1980s
3. Multiple hypothesis – Chamberlin, Geology (1897)

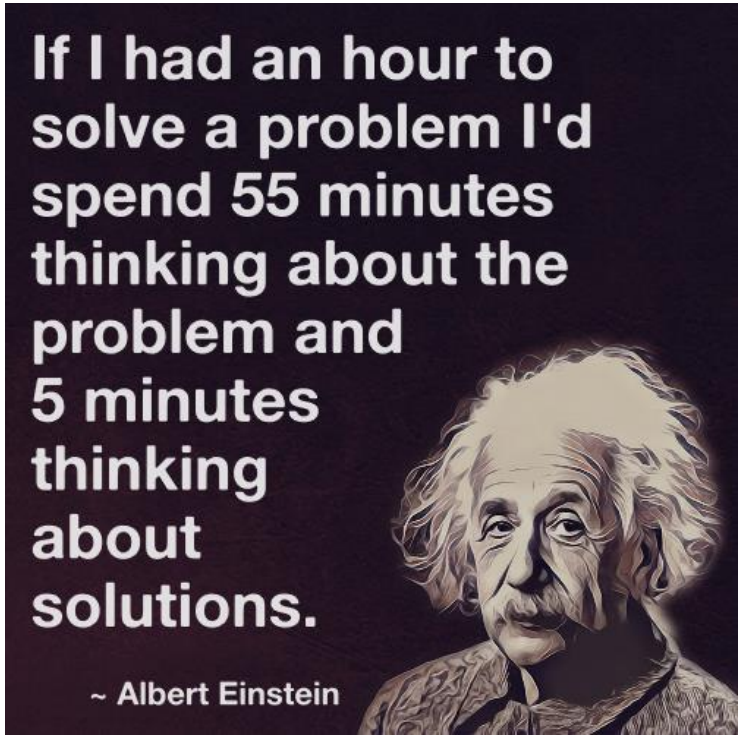
Scientific Method is the Universal Problem Solving Tool across University Departments



From High School and Through College We were all Taught the Single Hypothesis Scientific Method

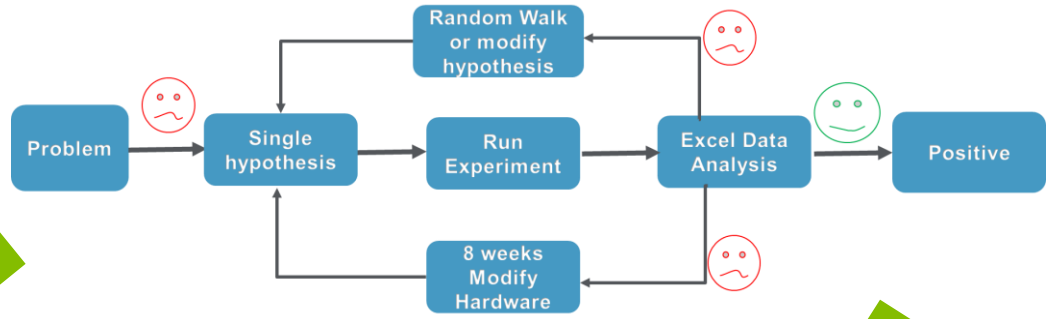
What goes wrong with Problem Solving?

- Time and Money are wasted solving the wrong problem
  1. Getting the problem statement incorrect or imprecise
  2. Using the wrong hypothesis (stuck on single hypothesis)
  3. Failure of weak Data Analysis tools, Confirmation Bias
  4. Failing to define success metric (at beginning)
  5. Test plans that don't discriminate between Hypothesis



Direction of Problem Solving for this Talk

Scientific Method



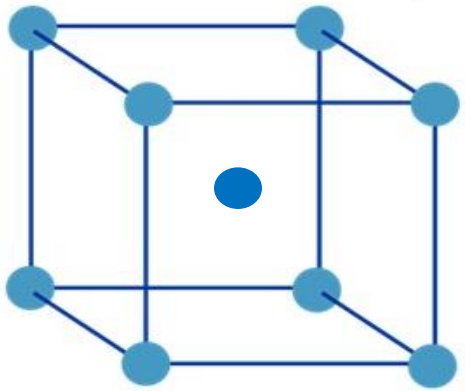
Scientific: Systematic & Parallel Multiple Hypothesis

Empirical: Learn through Data & Design of Experiments

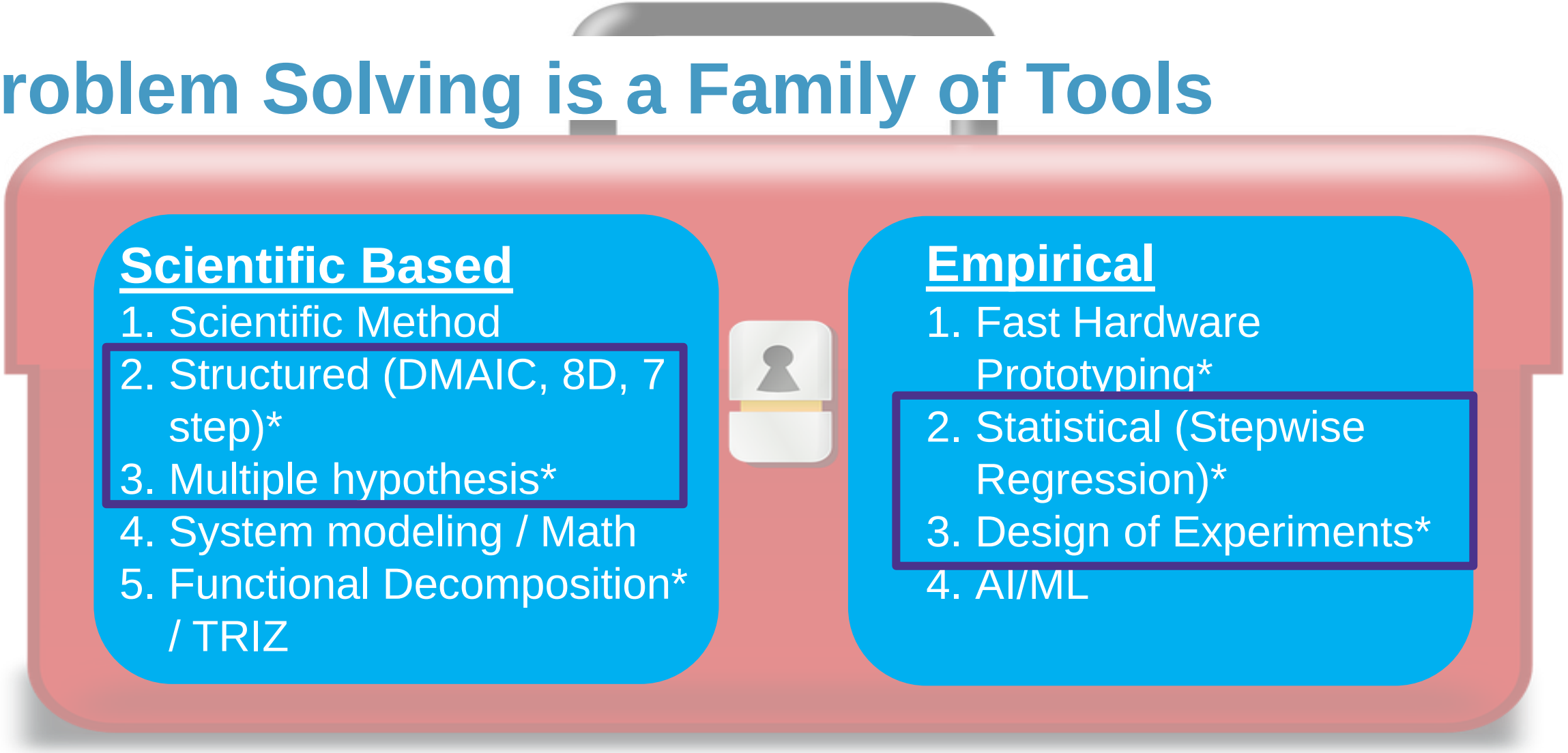
(Steps 1-5) Systematic Problem Solving Template

Problem Statement	
Success Criteria	
Observations	1. 2.

Potential Root Causes	Action/ Test to Prove / Disprove	Estimated Completion Date
C1:	T1:	
C2:	T2:	
C3:	T3:	
C4:	T4:	

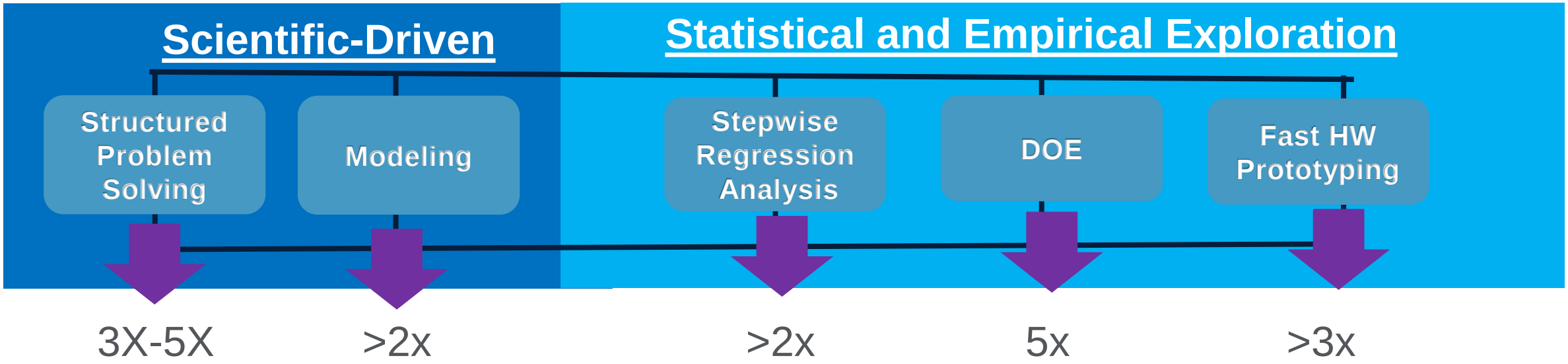


Problem Solving is a Family of Tools



*Tools are designed to resist Human Cognitive Bias

Problem Solving Tools Efficiency



Compared to Single Hypothesis Scientific Method

R&D Problem Solving can be 2-5x faster / efficient than Single Hypothesis and One Factor at a Time (Random Walk)

What University Departments offers these Methods

Scientific Based

1. Scientific Method - all STEM
2. Systematic (DMAIC, 8D, 7 step)
3. Multiple hypothesis – Geology
4. System modeling –EE / MSE / …
5. Functional Decomposition - many Eng in design phase

Empirical

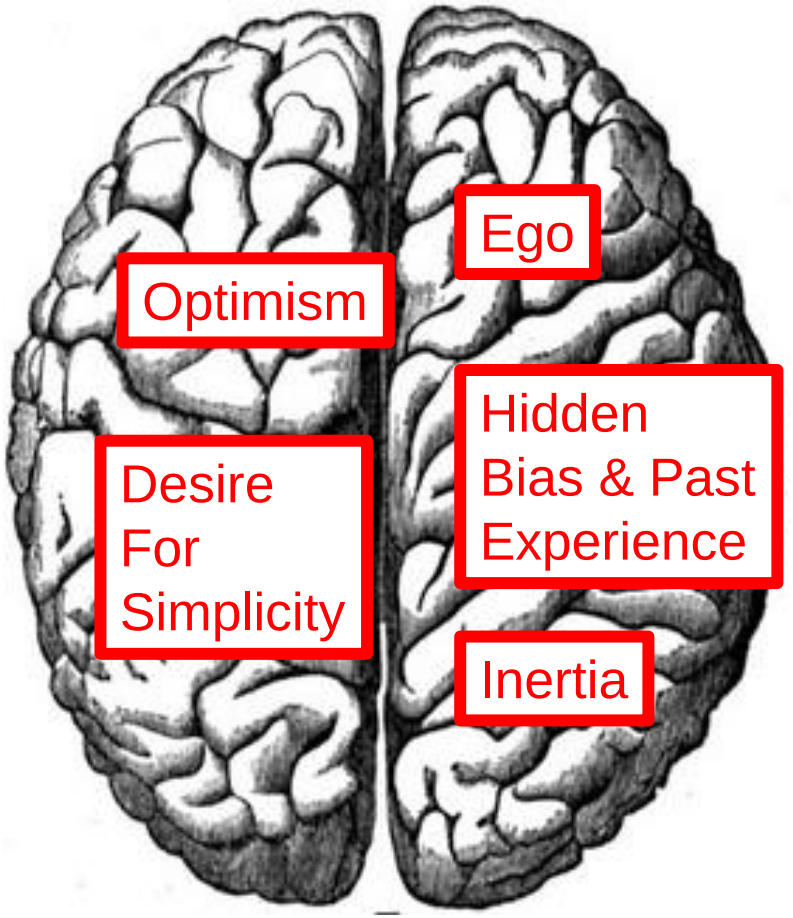
1. Fast Hardware Prototyping – Mech Eng
2. Statistical (Stepwise Regression) - Biology
3. Design of Experiments – Chem Eng
4. Machine Learning - CS

The Default Path: You will not acquire these skills by accident
Need to take some Initiative to Teach yourself

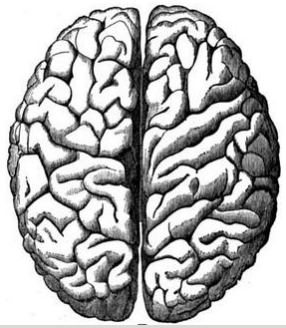
My Personal Story (from 2012)

- My product Part-to-Part Repeatability (known issue from 2009) with the linear showerhead
- New Customer exhibited similar signatures of the Problem
- 2 hypothesis identified
- Incorrectly worked on the wrong hypothesis for 6 months rather than solving the customer's root cause

Brain Limitations



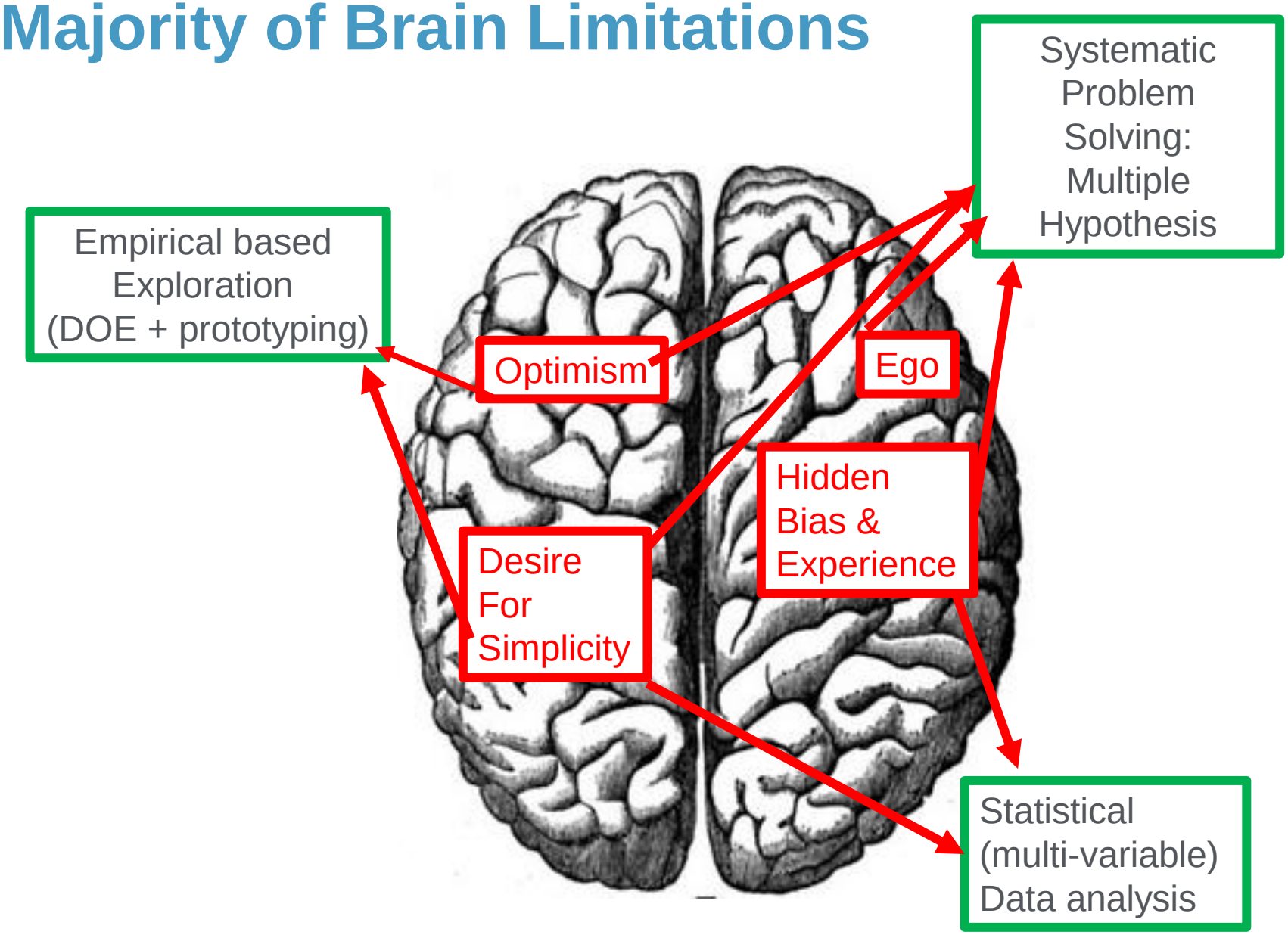
Human cognitive biases (simplifiers) that disrupts Problem Solving



Optimism Bias Overconfidence	Groupthink	Confirmation Bias	Not Invented Here	Authority Bias
Believing that you are less at risk of experiencing a negative event compared to others	Believing because many other people (senior engineers or managers) believe the same	Interpreting information in a way that confirms your preconceptions (believing your own marketing)	Engineers have blinders on product because their **ego** is attached; Don't leverage prior team's learnings	We default to believing the leader / manager knows the answer

The Problem Solving Techniques in this Seminar Resist and Counteract Cognitive Bias

Problem Solving Systematic Templates Counteract the Majority of Brain Limitations

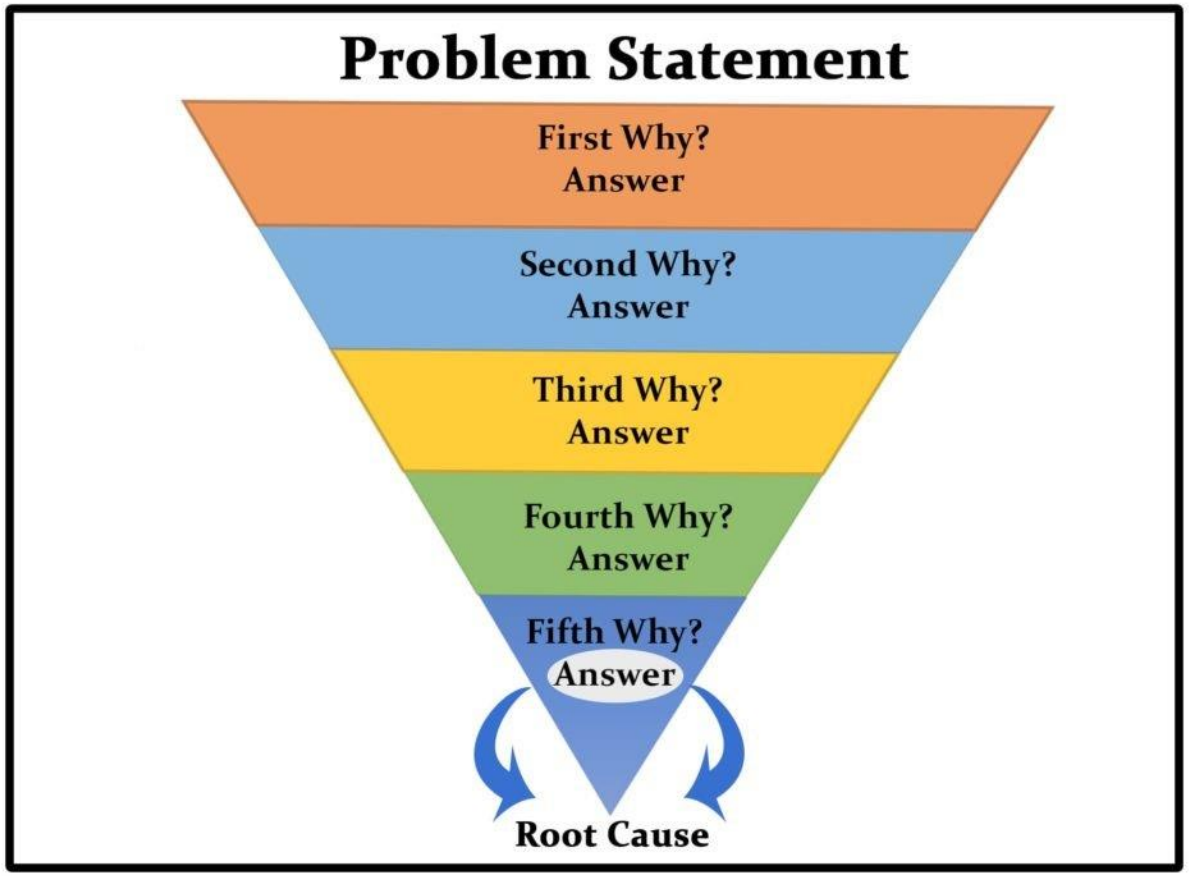


#1 Recommendation: Structured Problem Solving

Problem Statement	
Success Criteria	
Observations	1. 2.

Potential Root Causes	Action/ Test to Prove / Disprove	Estimated Completion Date
C1:	T1:	
C2:	T2:	
C3:	T3:	
C4:	T4:	

Step1 Getting the Problem Statement correct



1. 5 Why's: Refining the Problem Statement with the Team gets us to the root Problem
2. Alignment with the Team that this is the Problem

Step2: Collect Data associated with the Problem

- Decide whether we need a containment action (if yes, which one?)
- Collect as much Data about the Problem
  - Collect evidence (What, When, Where, How Big)
  - Collect details about Failures versus Good Reference
  - Use Pareto
  - SPC – time based
  - IS/IS Not

Iterate Step1 and Step2: Use Data Analysis to Modify the Problem Statement

Step3: Define Success Criteria

- Develop a Success Metric of “When the Problem is Solved”
- Helps to prevent Scope Creep
- Identify Collection plan based on Signal to Noise ratio
- Should be Measurable, Quantitative, a number or percentage.
- Zero is not statically achievable; prefer < 0.01% small rate

Alignment with the Team on when to Claim success / Stop spending Resources

D4: Identify Potential Root Cause(s) Hypothesis

- Identify the potential root cause(s) focus on Mechanism
- Go to existing Fishbone (Man, Machine, Method, Measurement,…) and pick 3 to 5
- Functional Block Diagram of Process or Hardware
- Literature Search
- Pick the brain of Teammates, or other Experts
- Search Databases
- **Combine** the Hypothesis for new Alternate Hypothesis

Most critical step to involve the Team

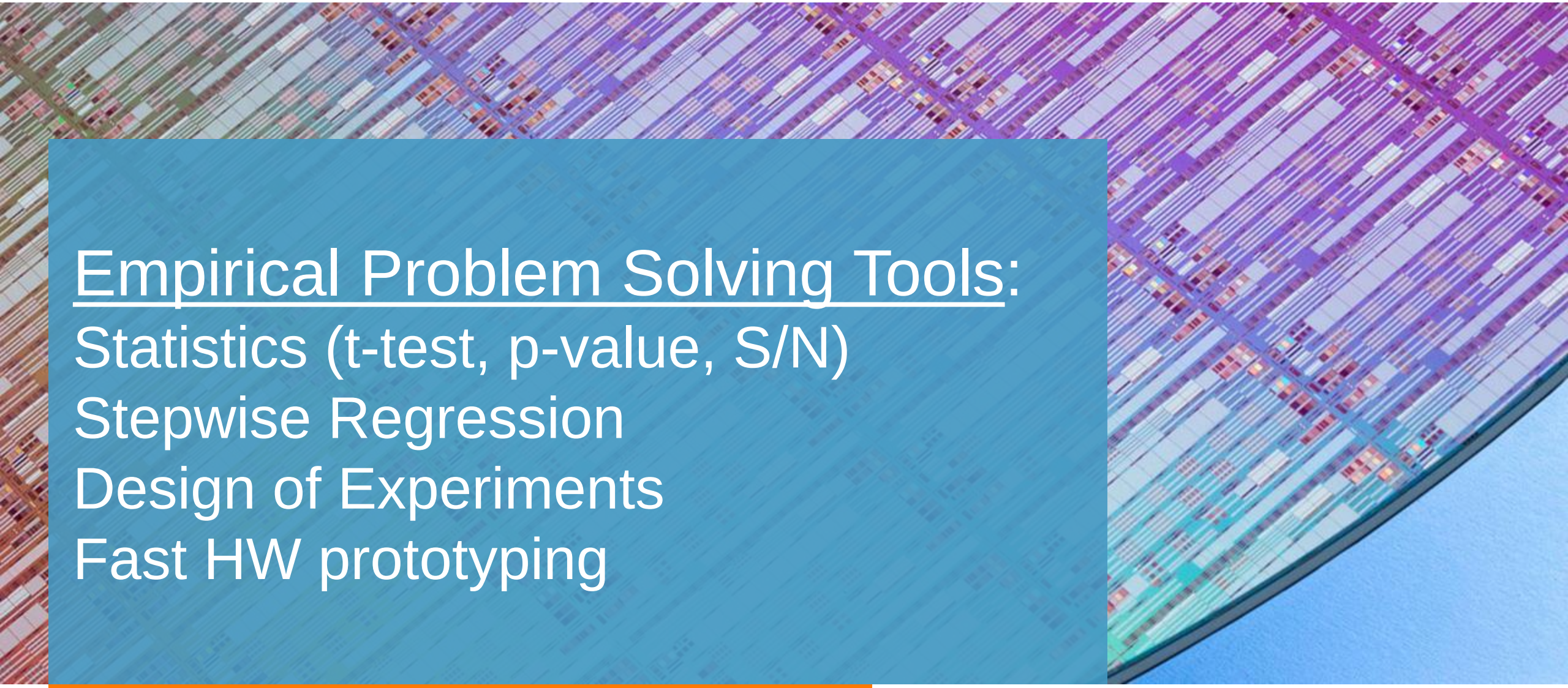
Step 5: Test per Root Cause Hypothesis

Problem Statement	
Success Criteria	
Observations	1. 2.

Potential Root Causes	Action/ Test to Prove / Disprove	Estimated Completion Date
C1:	T1:	
C2:	T2:	
C3:	T3:	
C4:	T4:	

Preliminary Conclusions

- Structured Problem Solving:
  - Works to get the Problem Statement correct
  - Success Metric Defines when we are done or sets Goal
  - Multiple hypothesis
    - increase Speed and accuracy in Complex environment
    - Fights Cognitive Bias



Empirical Problem Solving Tools:

Statistics (t-test, p-value, S/N)

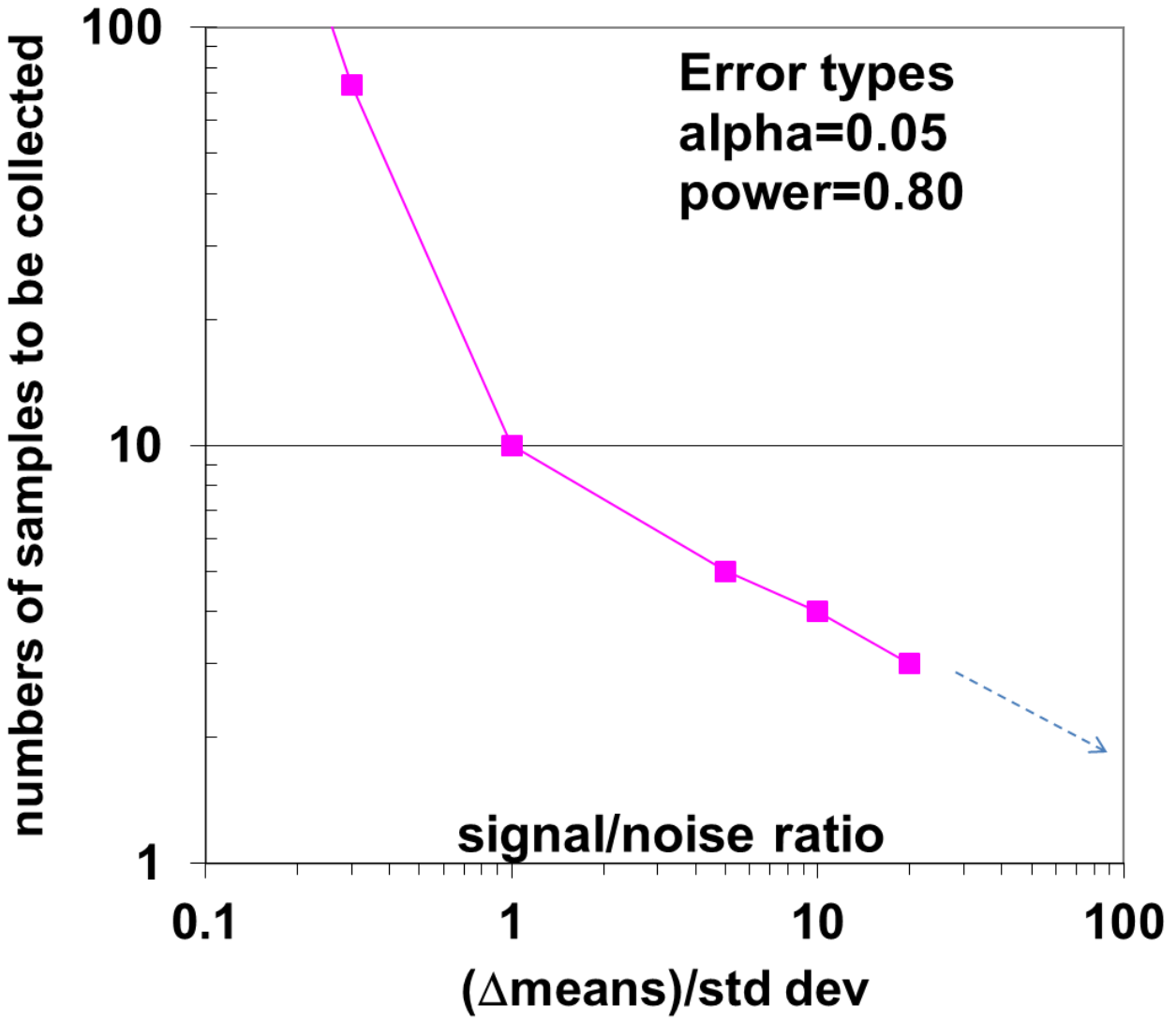
Stepwise Regression

Design of Experiments

Fast HW prototyping

Most valuable for planning an experiment: Reference for making a strong conclusion

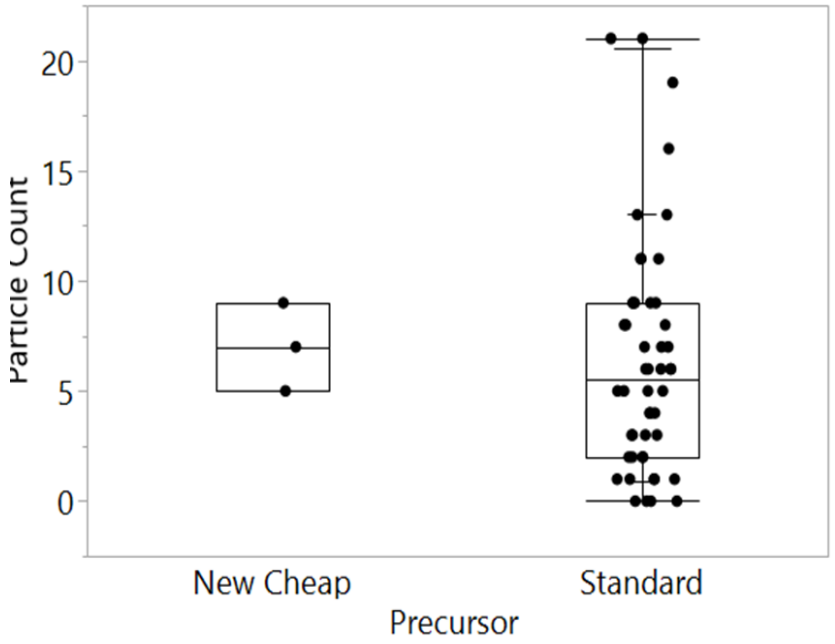
- The Real World has Noise in Measurement and in Process Reactors
- Signal/Noise is Low for many experiments
  - particles (typical ~1-2)
  - metal contamination
- If you have to “repeat” an experiment, what does that mean?



P-value provides quantitative percentage confidence in your conclusion

- The p-value is the probability that these two samples came from the same population.
- P < 0.05 as indicative that the difference is significant; Confidence Level (1-p) of 95%

T-test



Same or Different?

Stepwise Regression (Learning Through Data)

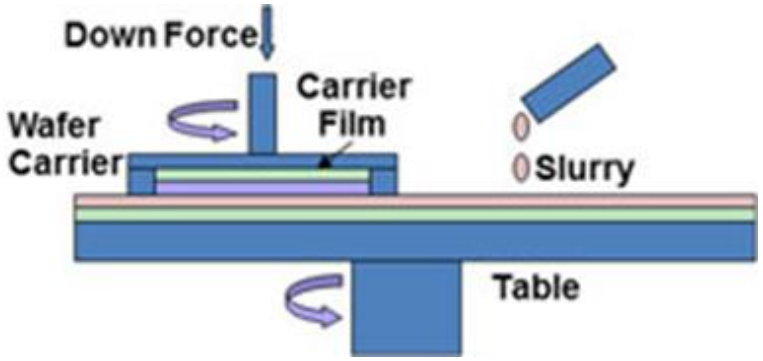
- Stepwise Regression is an automatic algorithm in JMP / Minitab that determines the significant variables in a model from data
- It can be a powerful tool that can build models of
  - Multiple X_1, X_2, X_3 variables
  - Multiple variables interacting (which we call cross-term interaction X_2*X_3)
- How do we go about diagnosing or proving a root cause?

6 x-factors

	Down Force	Back Force	Oscillations	Pad	Carrier Velocity	Table Velocity	Y-Polish Rate A/min	Y-Standard deviation A/min
1	180	50	0	0	10	10	869	142
2	250	50	0	0	100	10	1493	490
3	180	100	0	0	100	100	1042	414
4	250	100	0	0	10	100	1327	213
5	180	50	1	0	100	100	1099	753
6	250	50	1	0	10	100	1382	299
7	180	100	1	0	10	10	853	175
8	250	100	1	0	100	10	1489	429
9	180	50	0	1	10	100	1090	535
10	250	50	0	1	100	100	1558	552
11	180	100	0	1	100	10	1075	381
12	250	100	0	1	10	10	1126	249
13	180	50	1	1	100	10	1085	552
14	250	50	1	1	10	10	1151	262
15	180	100	1	1	10	100	1103	527
16	250	100	1	1	100	100	1680	622

Stepwise Regression:

Determine 6 key parameters if they have significance and Do they interact with each other?



Fit Model - JMP

Model Specification

Select Columns

8 Columns

- Down Force
- Back Force
- Oscillations
- Pad
- Carrier Velocity
- Table Veloxity
- Polish Rate A/min
- Stdev A/min

Pick Role Variables

Y: Polish Rate A/min, Stdev A/min, *optional*

Weight: *optional numeric*

Freq: *optional numeric*

By: *optional*

Personality: Stepwise

Help | Run | Recall | Keep dialog open | Remove

Construct Model Effects

Add | Cross | Nest | Macros

Degree 2

Attributes | Transform | No Intercept

- Down Force& RS
- Back Force& RS
- Oscillations
- Pad
- Carrier Velocity& RS
- Table Veloxity& RS
- Down Force*Down Force
- Down Force*Back Force
- Back Force*Back Force
- Down Force*Oscillations
- Back Force*Oscillations
- Down Force*Pad
- Back Force*Pad
- Oscillations*Pad
- Down Force*Carrier Velocity
- Back Force*Carrier Velocity
- Oscillations*Carrier Velocity

A A^2
B B^2 A*B
C C^2 B*C. A*C
D D^2 A*D, B*D, C*D
E E^2 A*E B*E, C*E, D*E
F F^2 A*F B*F, C*F D*F E*F

Determine 26 possible coefficients, resists cognitive bias

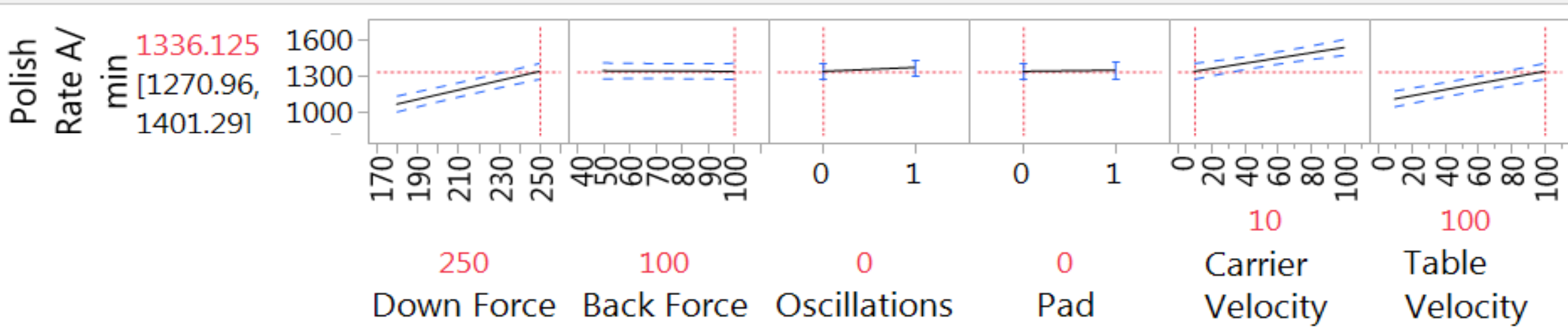
http://blog.minitab.com/blog/applying-statistics-in-quality-projects/a-doe-in-a-manufacturing-environment-part-1

CMP Empirical Model

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	P-value
Down Force	5.3392857	0.240601	22.19	<.0001*
Table Velocity	1.5833333	0.187134	8.46	0.0001*
Carrier Velocity	1.9222222	0.264648	7.26	0.0003*
(Down Force-215)*(Carrier Velocity-55)	0.0336508	0.005347	6.29	0.0007*
(Carrier Velocity-55)*(Table Velocity-55)	-0.020556	0.004159	-4.94	0.0026*
Pad[1-0]	39.25	16.8421	2.33	0.0586
Oscillations[1-0]	32.75	16.8421	1.94	0.0998
Pad[1-0]*(Carrier Velocity-55)	0.6555556	0.374269	1.75	0.1304
Back Force	-0.08	0.336842	-0.24	0.8202

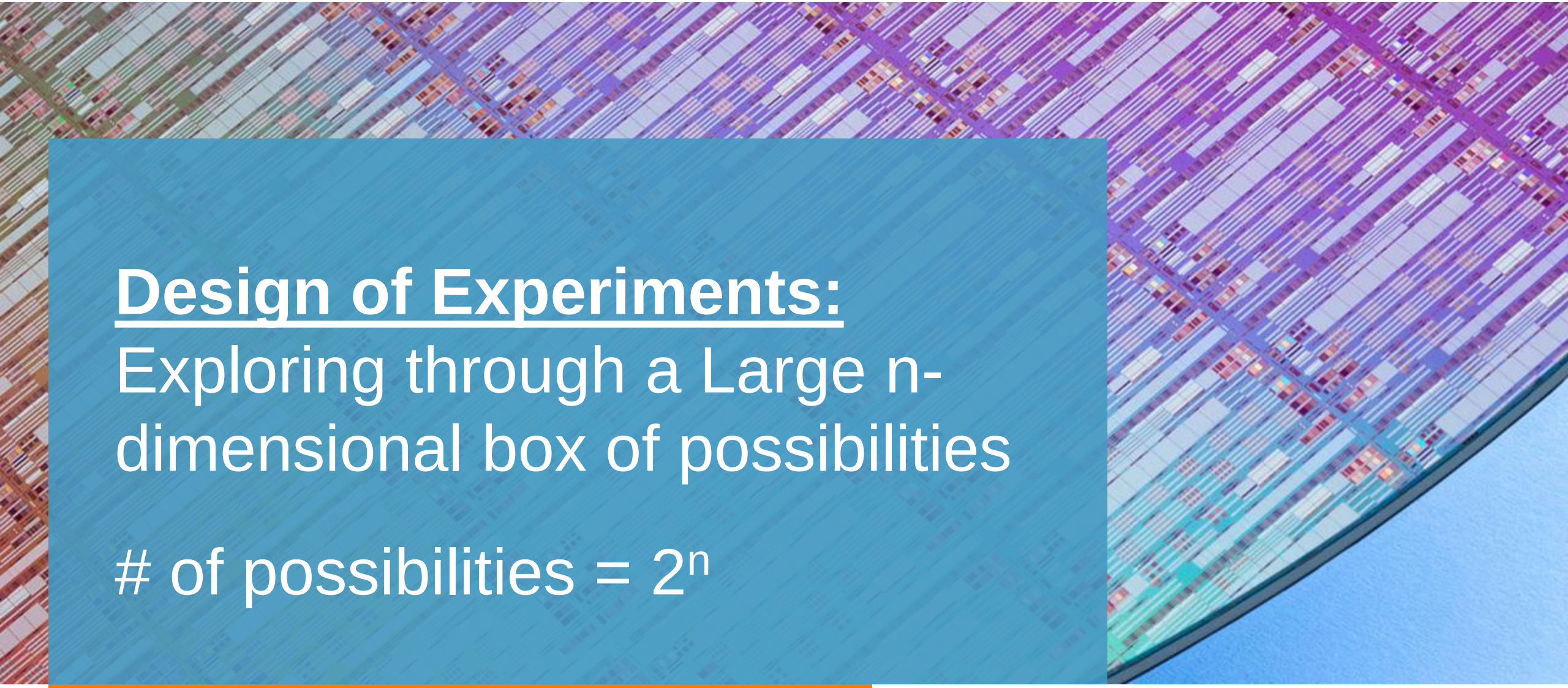
Polish Rate



9 Factors found to be statistically significant out of 26 possibilities

http://blog.minitab.com/blog/applying-statistics-in-quality-projects/a-doe-in-a-manufacturing-environment-part-1

Empirical Problem Solving Method

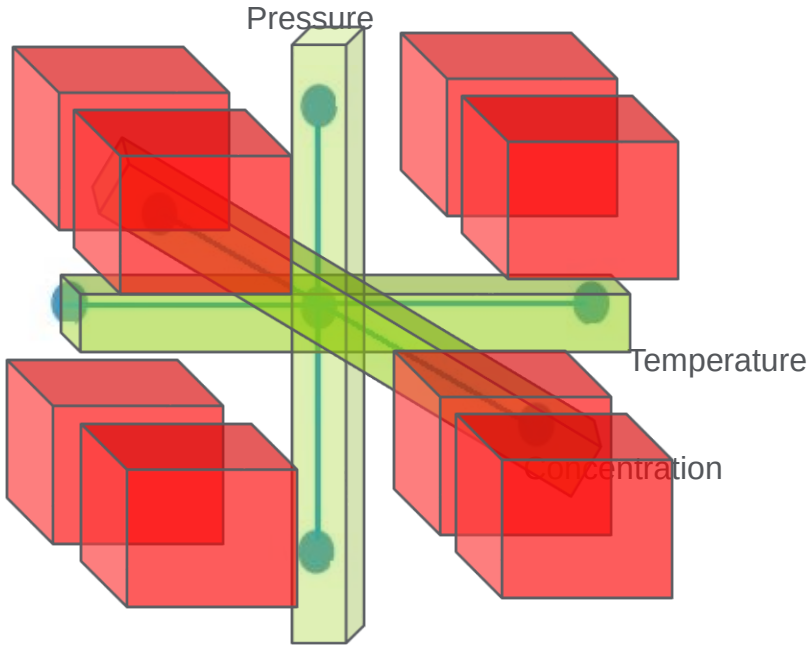


<u>Design of Experiments:</u>

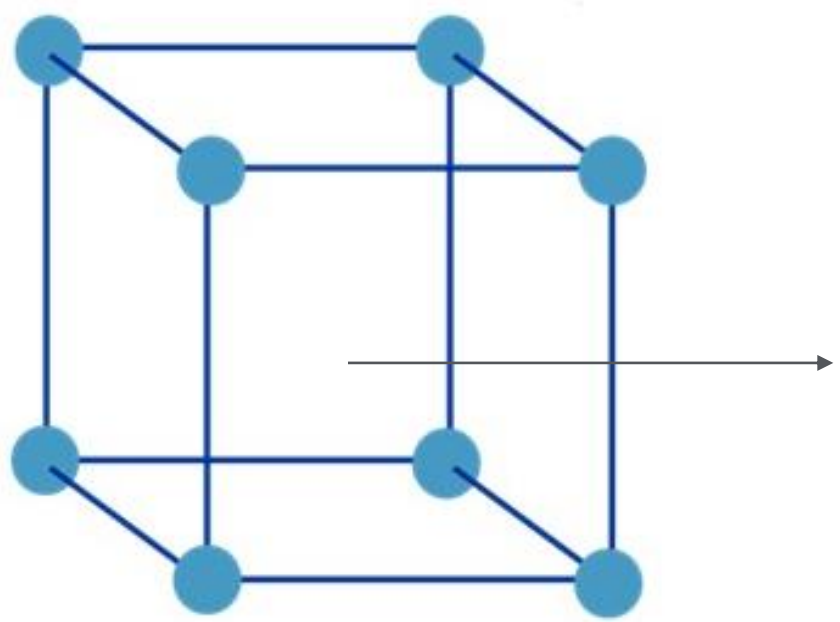
Exploring through a Large n-dimensional box of possibilities

# of possibilities = 2^n

One Factor At Time (Scientific Method) vs DOE Laying out your X-factors in Experiment



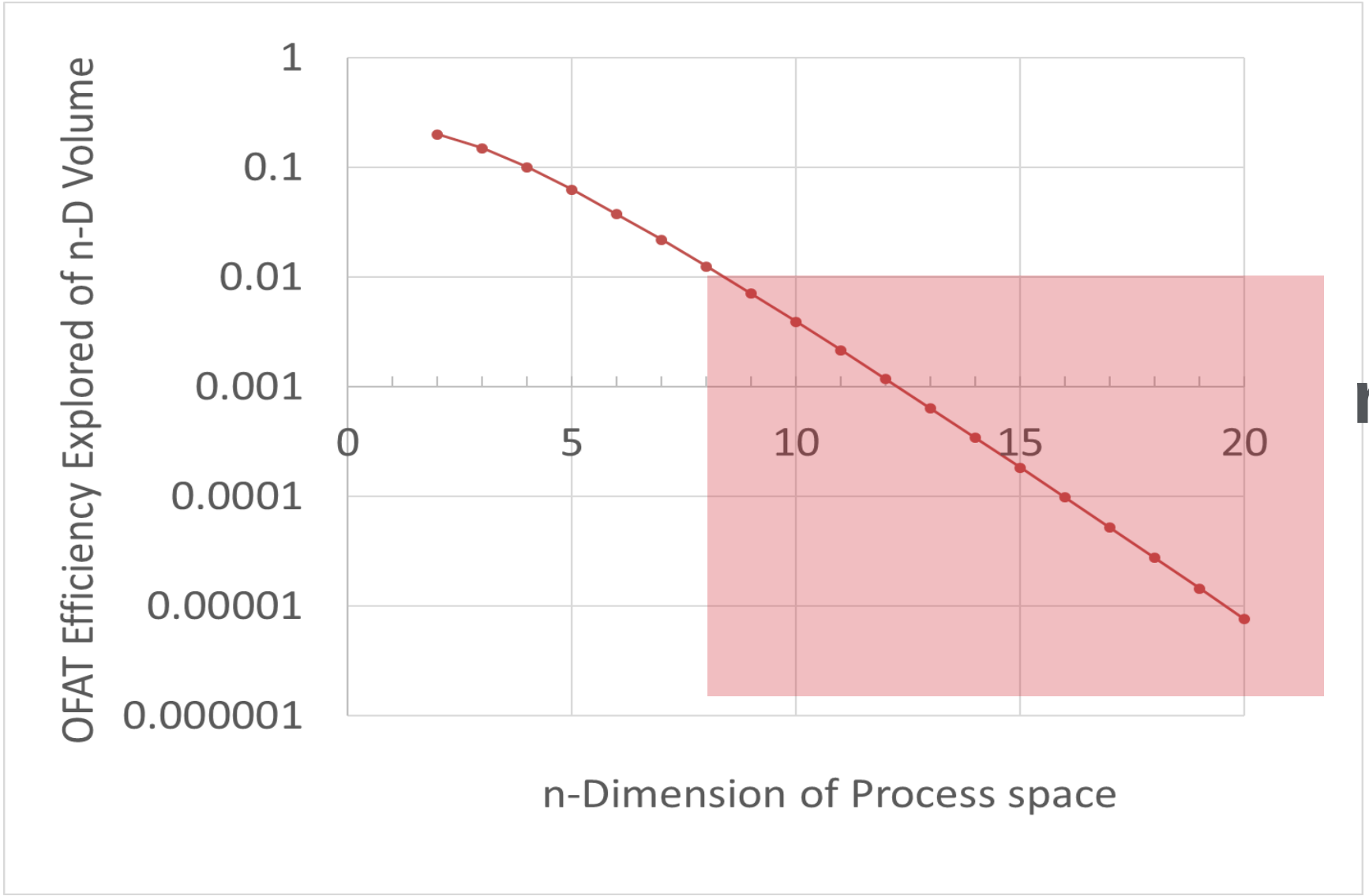
Scientific Method fails to explore the RED quadrants



DOE is 5x or 400% more efficient in exploring a volumetric space

"Algebra used to backout Solution: Solving for this case is like 2 equations , 2 unknowns"

Exploration with scientific method is Poor n > 5 x-factors



99.9% of the Space is Unknown with Scientific Method at >8-D Process Space

2 Types of Design of Experiments

- **Screening**: their purpose is to determine the important variables (“x”s) that affect the response (and separate them from the trivial ones)

n > 6 x-terms

- DOEs: Partial factorial, Custom, **Definitive screening**, Fractional Factorial

# of samples of DSD = 2*n

- **Optimization**: they try to find the levels of the vital factors that optimize the performance of the “y” (by influencing its variation, position or both)

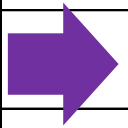
n < 6 x-terms

- BKM identification: Full factorial, space filling

# of samples of FF = 2^n

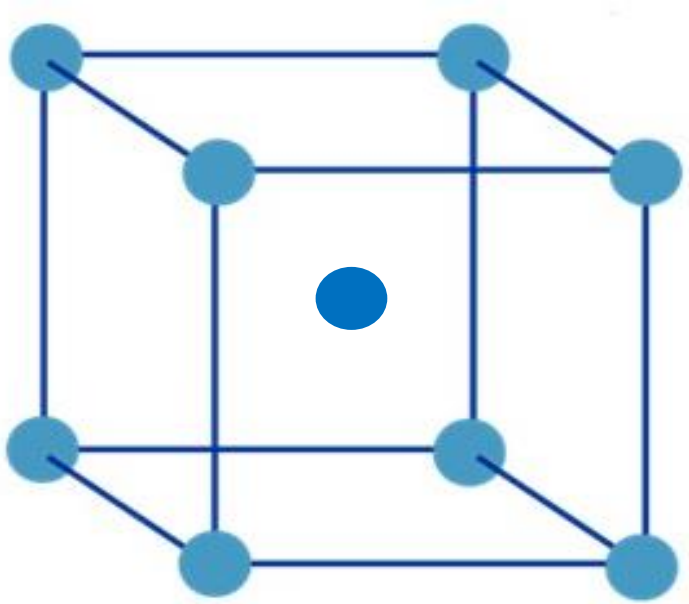
When to Switch DOE Experimental Type

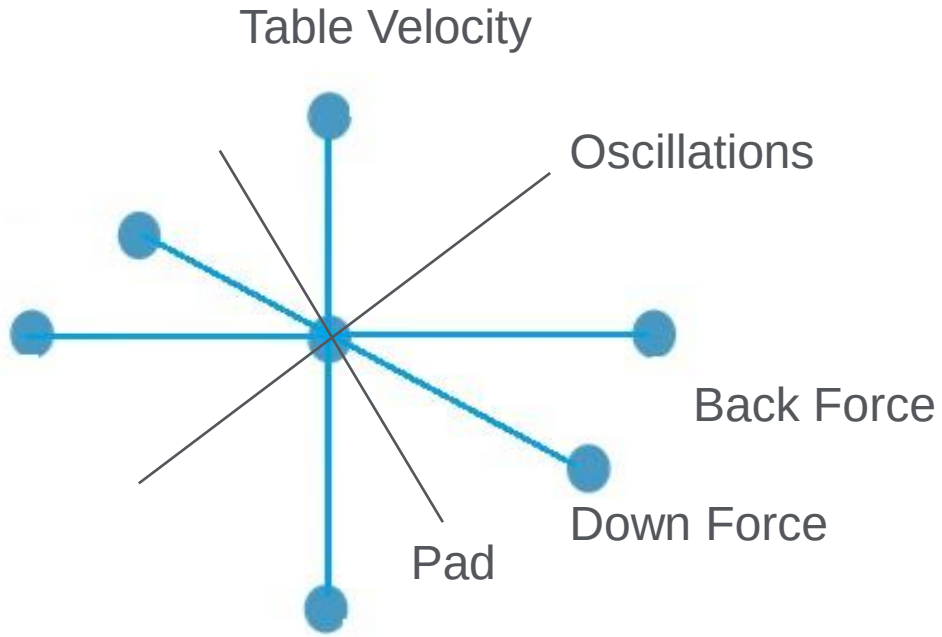
Box of n-Dimensions	Full Factorial DOE (# of Wafers)	DSD DOE (# of Wafers)
2	5	5
3	9	7
4	17	9
6	65	13
8	257	17
10	1025	21
12	4097	25
14	16385	29
16	65537	33
18	262145	37
20	1048577	41



Laying out Experimental Data points

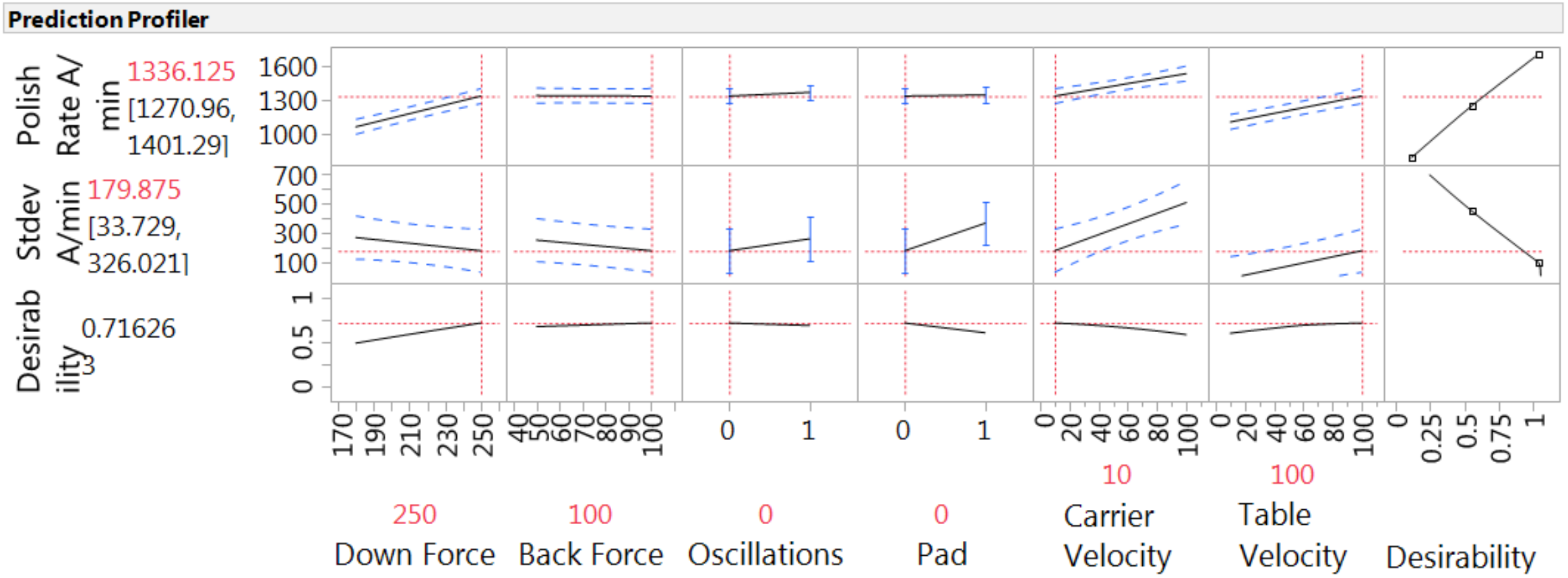
of possibilities = 2^6=64 tests





DOE runs the minimal experimental points and uses algebra and statistics to backout sensitivities and cross term coefficients

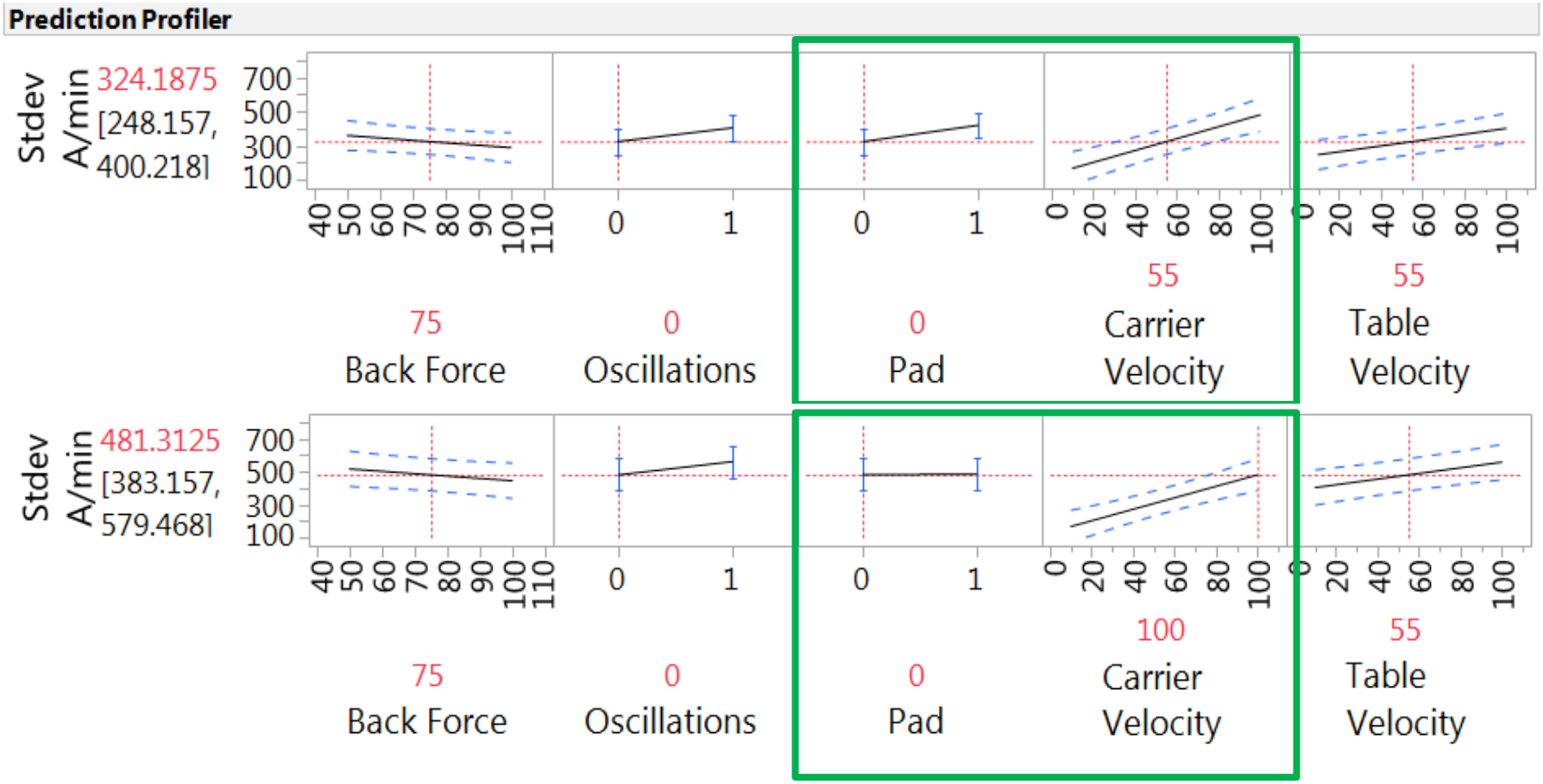
Dual Y Model Optimizing for High Polish Rate

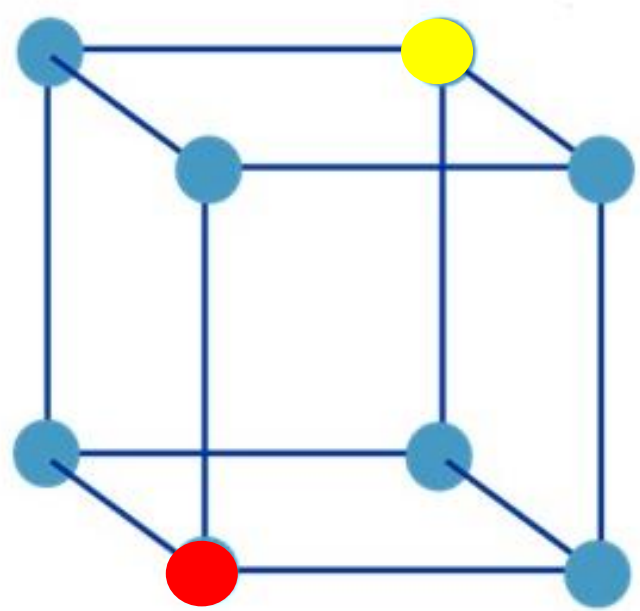


1. Solution found with only 16 runs in out of 300 possible options
2. Multiple Y factor optimization in 6 X-factor space while taking into account Cross-term Interactions

http://blog.minitab.com/blog/applying-statistics-in-quality-projects/a-doe-in-a-manufacturing-environment-part-1

Non-Uniformity (Stdev): Mapping a 6-D Box allows Conclusions to be location specific





The Scientific Method conclusion matters where you are in the n-D Solution space

People Team collaboration

1. **Safe Communication** (ok to disagree with Boss);
2. **Active Listening & Concise** communication (everyone speaks & listens)
3. Clear **Roles & Responsibility**; yet **Good ideas come from anyone**;
4. **Peer to Peer Initiate collaboration** across entire team rather than through the Boss

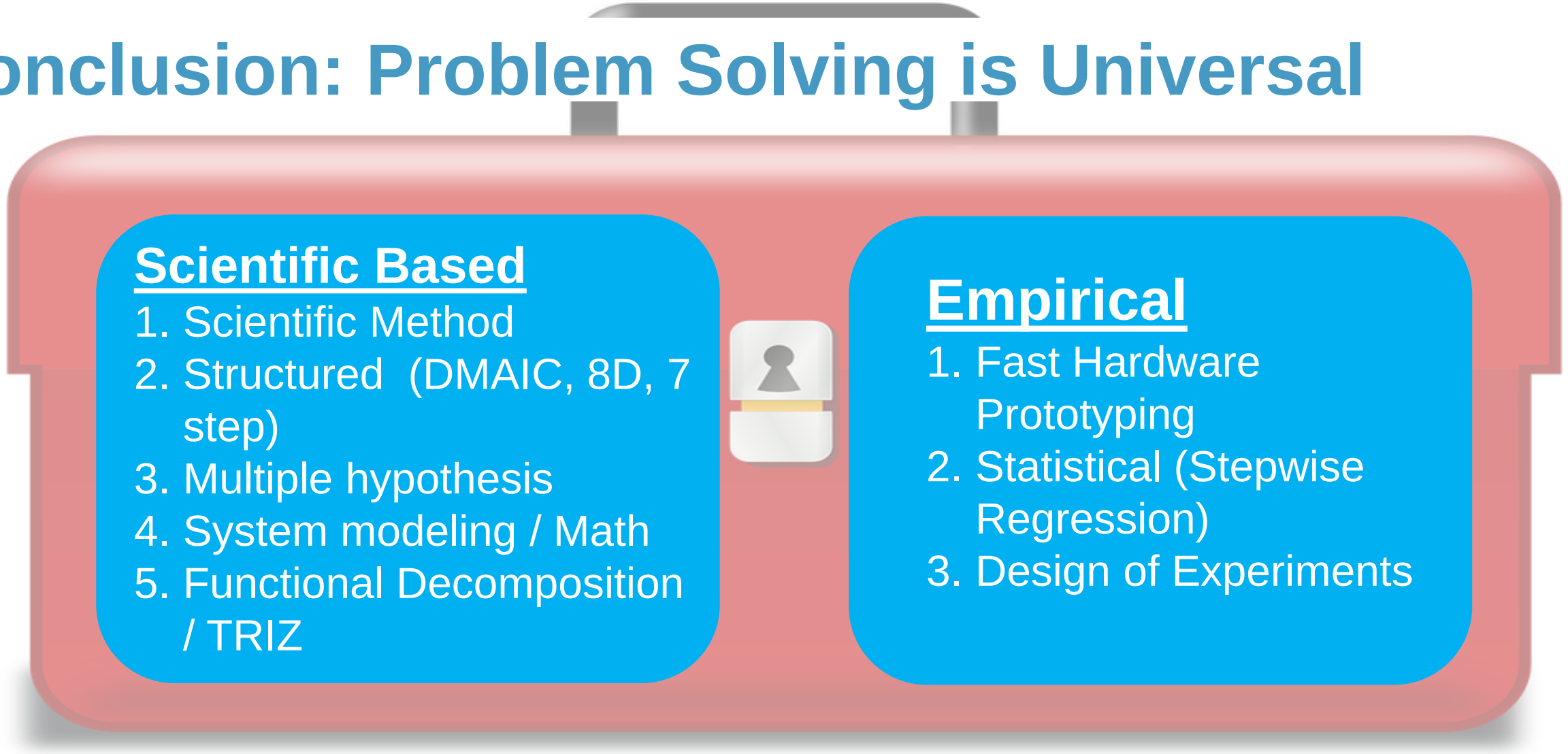
Systematic Problem Solving Template

Problem Statement	
Success Criteria	
Observations	1. 2.

Potential Root Causes	Action/ Test to Prove / Disprove	Estimated Completion Date
C1:	T1:	
C2:	T2:	
C3:	T3:	
C4:	T4:	

Safe communication where the team is open to alternate hypothesis, i.e., you can disagree with your boss openly & your boss (Professor) is ok to be wrong

Conclusion: Problem Solving is Universal



Scientific Based

1. Scientific Method
2. Structured (DMAIC, 8D, 7 step)
3. Multiple hypothesis
4. System modeling / Math
5. Functional Decomposition / TRIZ

Empirical

1. Fast Hardware Prototyping
2. Statistical (Stepwise Regression)
3. Design of Experiments

The Greatest Teams, listen, willing to be wrong, consider multiple root causes, and switch back and forth between Scientific and Empirical Tools

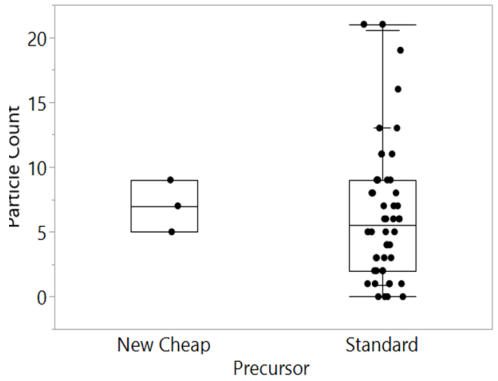
Career Recommendations

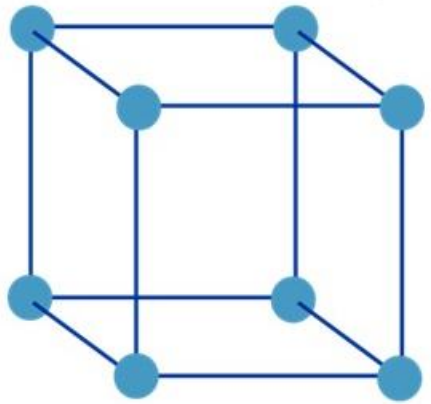
- Make yourself a Structured Problem Solving Template in Powerpoint
  - Lean Statistics as a Tool
    - P-value, T-test
    - Stepwise Regression
    - Go to www.jmp.com/learn
  - Categorize the complexity of your R&D project experimental X factors > 5; consider Design of Experiments

Step 5: Test per Root Cause Hypothesis

Problem Statement	
Success Criteria	
Observations	1. 2.

Potential Root Causes	Action/ Test to Prove / Disprove	Estimated Completion Date
C1:	T1:	
C2:	T2:	
C3:	T3:	
C4:	T4:	



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