

# FUN*da*MENTALS of Design

**Creating Ideas  
Concepting  
(ME 481, Fall 2021)**

# FUN*da*MENTALS of Design

## Introduction

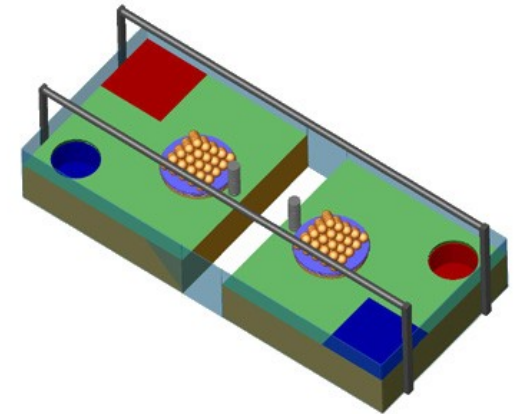
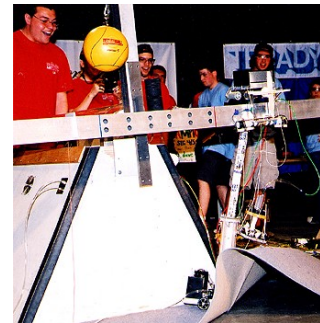
# ♥Passion♥ LOVE to Create



*"Enthusiasm is one of the most powerful engines of success. When you do a thing, do it with all your might. Put your whole soul into it. Stamp it with your own personality. Be active, be energetic, be enthusiastic and faithful and you will accomplish your object. Nothing great was ever achieved without enthusiasm"*

Ralph Waldo Emerson

- Use ♥Passion♥ as a catalyst to make ideas become reality:
  - Never stop asking:
    - “Is this really the best I can do”
    - “Can the design be made simpler”
  - Create, never stagnate
  - Do you see machines in ink blots?



Ink-Blot milling machine by Peter How





Henry Maudslay

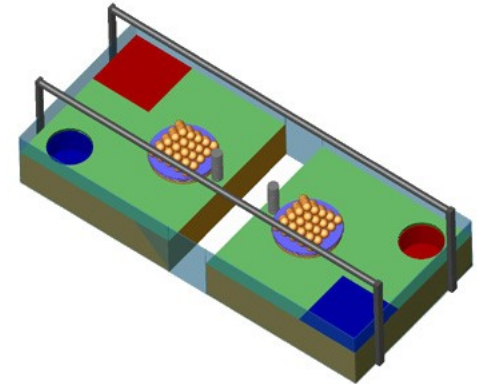
from J. Roe English and  
American Tool Builders, ©  
1916 Yale University Press

## ***♥Passion♥ FOCUS!*** ***Keep Your Eye on the Prize***

*“You can’t always get what you want But  
if you try sometimes well you might find  
You get what you need”*

Mick Jagger & Keith Richards 1969

<http://lyrics.all-lyrics.net/r/rollingstones/letitbleed.txt>



***Get a clear notion of what you desire to accomplish, then you will probably get it***

***Keep a sharp look-out upon your materials: Get rid of every pound of material  
you can do without. Put yourself to the question, ‘What business has it there?’***

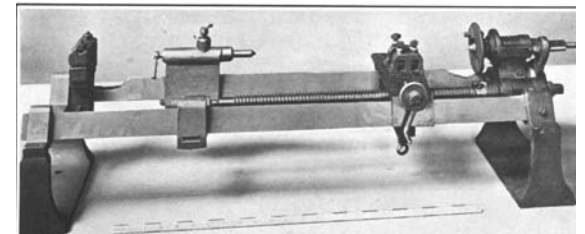
***Avoid complexities and make everything as simple as possible***

***Remember the get-ability of parts***

Henry Maudslay’s Maxims (1700’s, a father of modern machine tools)

Maudslay’s screw cutting lathe

from J. Roe English and American Tool Builders,  
© 1916 Yale University Press



# Design is a Series of Steps Blended Together

- Follow a design process to develop an idea in stages from **coarse** to **fine**:
  - **First Step:** Take stock of the resources that are available
  - **Second Step:** Study the problem and make sure you have a clear understanding of what needs to be done, what are the constraints (rules, limits), and what are the physics of the problem!
    - Steps 1 & 2 are often interchangeable
  - **Third Step:** Start by creating possible **strategies** (*ways to approach the problem*) using words, analysis, and simple diagrams
    - Imagine motions, data flows, and energy flows from start to finish or from finish back to start!
    - Continually ask “Who?”, “What?”, “Why?”, “Where”, “How?”
    - Simple exploratory analysis and experiments can be most enlightening!
    - Whatever you think of first, others will too, so think about how to defeat what you think first!
  - **Fourth Step:** Create **concepts** (*specific ideas for machines*) to implement the best **strategies**, using words, analysis, and sketches
    - Use same methods as for **strategies**, but now sketch specific ideas for machines
    - Often simple experiments or analysis are done to investigate effectiveness or feasibility
    - Select and detail the best **concept**...
  - **Fifth Step:** Develop **modules** (*sub assemblies of parts*) using words, analysis, sketches, and solid models
  - **Sixth step:** Develop **components** (*individual elements*) using words, detailed analysis, sketches, and solid models
  - **Seventh Step:** Detailed engineering & manufacturing review
  - **Eighth Step:** Detailed drawings
  - **Ninth Step:** Build, test, modify...
  - **Tenth Step:** Fully document process and create service manuals...





# First Step: *Resource Assessment*

Before even thinking about potential solutions to a problem, one has to first take stock of the available resources:

## – What time is available?

- When is the project due?
- How many person-hours a week can be spent on the project?
- What are the hours of operation for support facilities (library, shop, computers...)
- **Designer engineers are often way too ambitious!**

## – What materials and components are available?

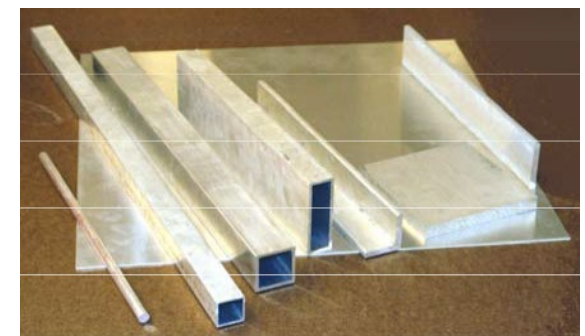
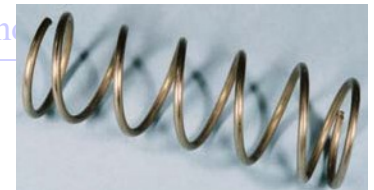
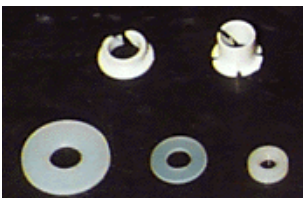
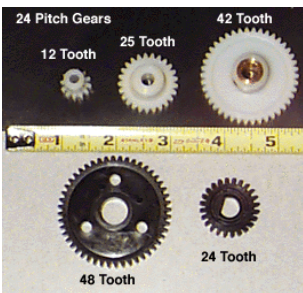
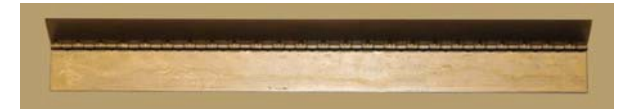
- Lay out all the materials you have (physically or catalogs) in front of you and play with them, let them talk to you, what are their limits, how have others used them...
- Look through hardware magazines
- Check the Web: <http://pergatory.mit.edu/2.007>, <http://www.efu>
- Look at other machines and search patents
- Knowing your hardware is a POWERFUL design catalyst

## – What manufacturing processes are available?

- You may not have access to a wire EDM, nor the time to send out the parts!
- You may not have the time to have a casting made!

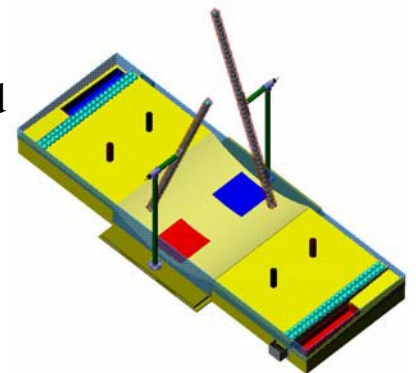
## – What people are available?

- Engineering?
- Manufacturing?
- Management?
- Marketing....?



## Second Step: Understanding the *Problem (Opportunity!)*

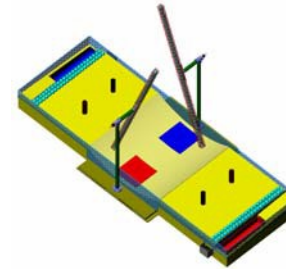
- Any problem can be dissected and understood by establishing a starting point, and then analyzing the system and its elements
  - It is like creating a design in reverse
- Study a problem and then define it in terms of its energy storage and dissipative elements, and its geometry and materials:
  - **Simple physical models**
    - Physically play with the kit and contest table: Let the hardware talk to you....
    - A *sketch model* made from simple materials enables you to play with the problem
  - **Simple drawings**
    - A simple hand-drawn isometric figure helps you to pattern the problem into your bio neural net
    - A simple solid model can also be very useful, particularly when later seeking to test your solid model solution on the problem
  - **Physics: First-Order-Analysis**
    - Words to describe the physics
    - Simple analysis with guestimates of realistic numbers (spreadsheets)
  - **Words** (in a table or bulleted list) to describe what problem must be solved
    - What must be accomplished? (e.g., tip a balance...*functions, events*)
    - What are the constraints? (e.g., rules, cost, size, time)



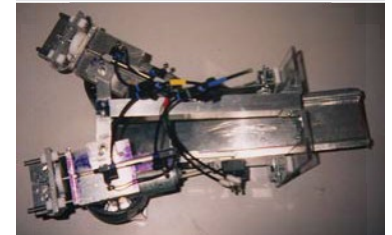
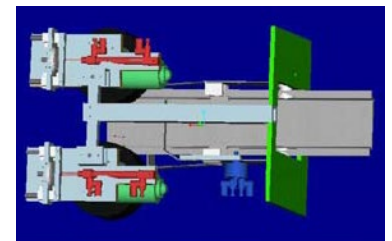
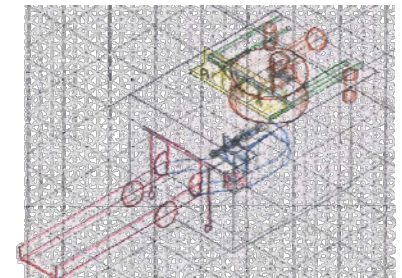


## Third Step: *Developing Strategies*

- A **strategy** is a general approach to a problem, and there may be many different actually ways of implementing it (i.e., many different concepts).
- **Strategies** are developed by:
  - Playing
    - Play with the contest table and the kit parts
    - Create simple experiments
  - Drawing
    - Sketch all the motions that might occur (use arrows to indicate motions)
    - *ROUGH* Sketch potential concepts (just stick figures)
    - Overlay sketches and search for patterns and AHAs!
  - Reading
    - Study past 2.007 contests
    - Study construction equipment, websites of mechanisms and other robot contests
  - Writing
    - Write a story about how the contest was won.....imagine the future!
    - The FRDPARRC Table is a fantastic catalyst
  - Arithmetic (analysis)
    - Analyze the effectiveness of different scoring methods with a sensitivity study
    - Create time/motion studies of the table and study geometric packaging options
    - Sketch free-body-diagrams to understand how the forces flow within the system
    - **Create a preliminary power budget (see page 7-26 and *Power\_budget\_estimate.xls*)**
  - Load your mind with information
    - let your bio-neural-net create images of what gets the most done with the least effort



Alex Sprunt's 2.007 machine development





## Fourth Step: *Developing Concepts*

- A **concept** is a specific vision of how one could actually accomplish the **Strategy**:

- Words to describe what the concept must do, and how it will work

- Ideally in simple tabular form, like a FRDPARRC Table

- Brain Storming & Simple sketch

- A simple hand-drawn isometric figure of the machine often suffices
- A simple solid model can also be very useful
- A sketch model made from simple materials can also be very useful

- First-Order-Analysis

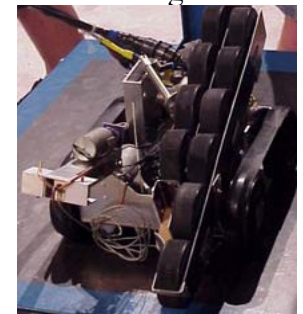
- Spreadsheet-based time and motion study
  - More detail based on better estimates of machine size...
- Preliminary power, accuracy, or stress calculations
  - More detail based on better estimates of machine weight...

- **Refine the power budget to ensure your idea can be powered by the batteries (see page 7-26)**

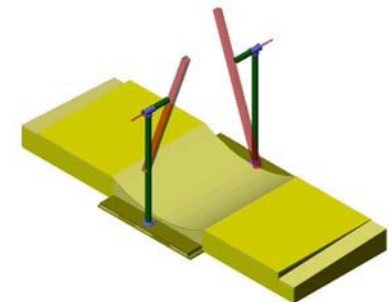
- The design engineer needs to take care to propose a concept in just enough detail to be assured that it could indeed be implemented

- Example: **Concepts** for **Gather pucks and balls and deposit in goal Strategy**

- **Concept A** for **Strategy 1**: Drive around picking up pucks and balls and deposit them into the goal one-by-one, so as to avoid complexity or jamming
  - After scoring with objects, the vehicle could go and actuate the pendulum
- **Concept B** for **Strategy 1**: Gather pucks and balls using a combine-like harvester that collects them and dumps them into a bin, and then drives over and raises the bin and dumps it into the scoring goal
  - After scoring with objects, the vehicle could go and actuate the pendulum



1999's *MechEverest!*

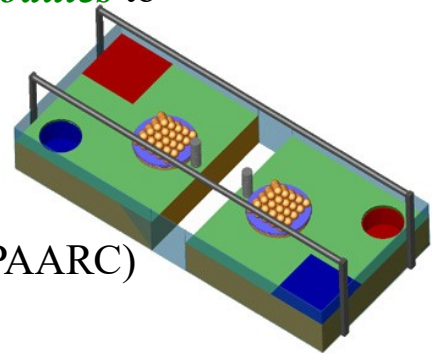


# Fifth Step: *Developing Modules/Subsystems*

- A **module** is a subassembly that has a defined envelope and specific inputs and outputs that can be engineered, built, and tested and then assembled with other **modules** to implement the **concept**



- Pick any **module**, and you will also get **sub-modules**
  - Example: Powertrain: Transmission, Motors, Crawler tracks
  - Hence the term “**module**” implies a *granularity* of detail

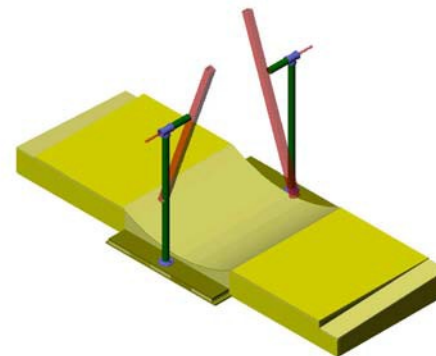


Words to describe what the **module** must do, and how it will work (FRDPAARC)

- Drawings
  - Initially a simple hand-drawn isometric will suffice
    - There may be many different ways of designing the **module**
      - » The process of **strategy**, **concept**, **module**, **components** can be applied again!
  - A solid model (layout drawings) will eventually need to be created
- First-Order- and Detailed-Analysis
  - Motion, power, accuracy, stress...
  - Greater detail as the module detail increases
- Developing **modules** is the first part of what some called the “**embodiment**” phase of design



- Example: **Modules** for the **Harvester Concept**
  - **Module 1** for **Concept B**: Gatherer
  - **Module 2** for **Concept B**: Bin
  - **Module 3** for **Concept B**: Deposit mechanism
  - **Module 4** for **Concept B**: Vehicle



## Sixth Step: *Developing Components*

- **Modules** are made from **components**, **sub-assemblies** or **machine elements**:



- Words to describe what the **component** must do, and how it will work

- Ideally in simple tabular form, like a FRDPARRC Table



- Drawings

- Initially a simple hand-drawn isometric will suffice

- There may be many different ways of designing the **component**

» The process of **strategy**, **concept**, **modules**, **components** can be applied again!

- A solid model (part drawing) will eventually need to be created

- Detailed engineering analysis

- Motion, power, accuracy, stress, corrosion...

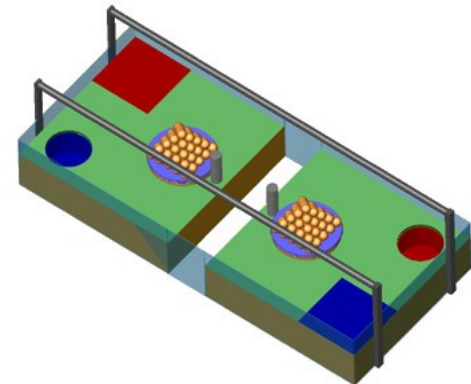
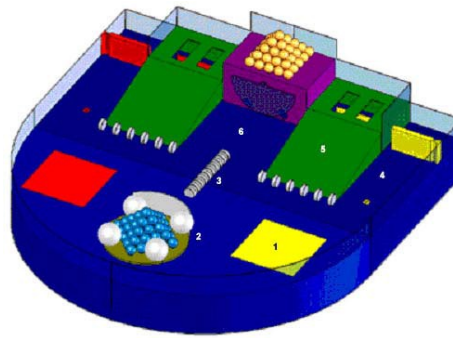
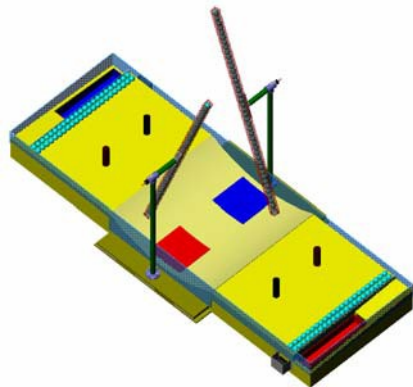
- This is the super detailed phase of design

An advertisement for Alpha Cymex software. The top half shows a diver in a black wetsuit and yellow fins standing on a sandy beach, looking out at the ocean. The bottom half is a blue background with white text. The text reads: "AS FRANK SOON FOUND OUT, CHOOSING MOST OF THE RIGHT COMPONENTS IS NOT EXACTLY THE SAME AS CHOOSING ALL OF THE RIGHT COMPONENTS." Below this, it says: "ALPHA'S REVOLUTIONARY CYMEX SIZING SOFTWARE LETS YOU PINPOINT THE PERFECT COMBINATION OF GEARHEADS AND SERVOMOTORS FOR EVEN THE TRICKIEST APPLICATIONS. CALL FOR YOUR FREE COPY TODAY. AND BREATHE EASY. Visit us at the Design Show, booth #1059". At the bottom, there is a logo for "alpha" and a table with the following information: 99.86% RELIABILITY, 5 YEAR WARRANTY, and 1-888-534-1222. Below the table, it says "ENGINEERED TO BE THE BEST. GUARANTEED TO STAY THAT WAY."

# Patterns from the Process:


*Repeats* *Repeats* *Repeats* *Repeats*

- Notice how each *Strategy's* Functional Requirements will each generate one or more *Design Parameters (Concepts)...*
  - Notice how each *Concept's Functional Requirements* will each generate one or more *Design Parameters (Modules)...*
    - Notice how each *Module's Functional Requirements* will each generate one or more *Design Parameters (Components)...*
- Executing a systematic design process can help you develop a *rapid design reflex*:
  - Rapidly and effectively solve design problems with a minimum of floundering!
- *As you take more and more trips around the sun, the design process and a rapid design reflex becomes hard-wired into your bio-neural-net!*





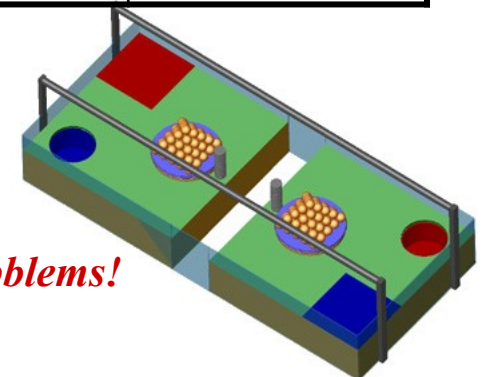
# Deterministic Design: *FRDPARRC* (*Functional Requirements Design Parameters Analysis References Risks Countermeasures*)



<b>Functional Requirements (Events)</b> <i>Words</i>	<b>Design Parameters (Idea)</b> <i>Words &amp; Drawings</i>	<b>Analysis</b> <i>Experiments, Words, FEA, Equations, Spreadsheets...</i>	<b>References</b> <i>Historical documents, www...</i>	<b>Risk</b> <i>Words, Drawings, Analysis...</i>	<b>Countermeasures</b> <i>Words, Drawings, Analysis...</i>
A list of independent functions that the design is to accomplish. Series (1,2,3...) and Parallel (4a, 4b..) FRs (Events) can be listed to create the <i>Function Structure</i>	Ideally independent means to accomplish each FR. AN FR CAN HAVE SEVERAL POTENTIAL DPs. The “best one” ultimately must be selected	Economic (financial or maximizing score etc), time & motion, power, stress... EACH DP’s FEASIBILITY MUST BE PROVEN. <b>Analysis can be used to create DPs!</b>	Anything that can help develop the idea including personal contacts, articles, patents, web sites....	High, Medium, Low (explain why) risk of development assessment for each DP	Ideas or plan to mitigate each risk, including use of off-the-shelf known solutions

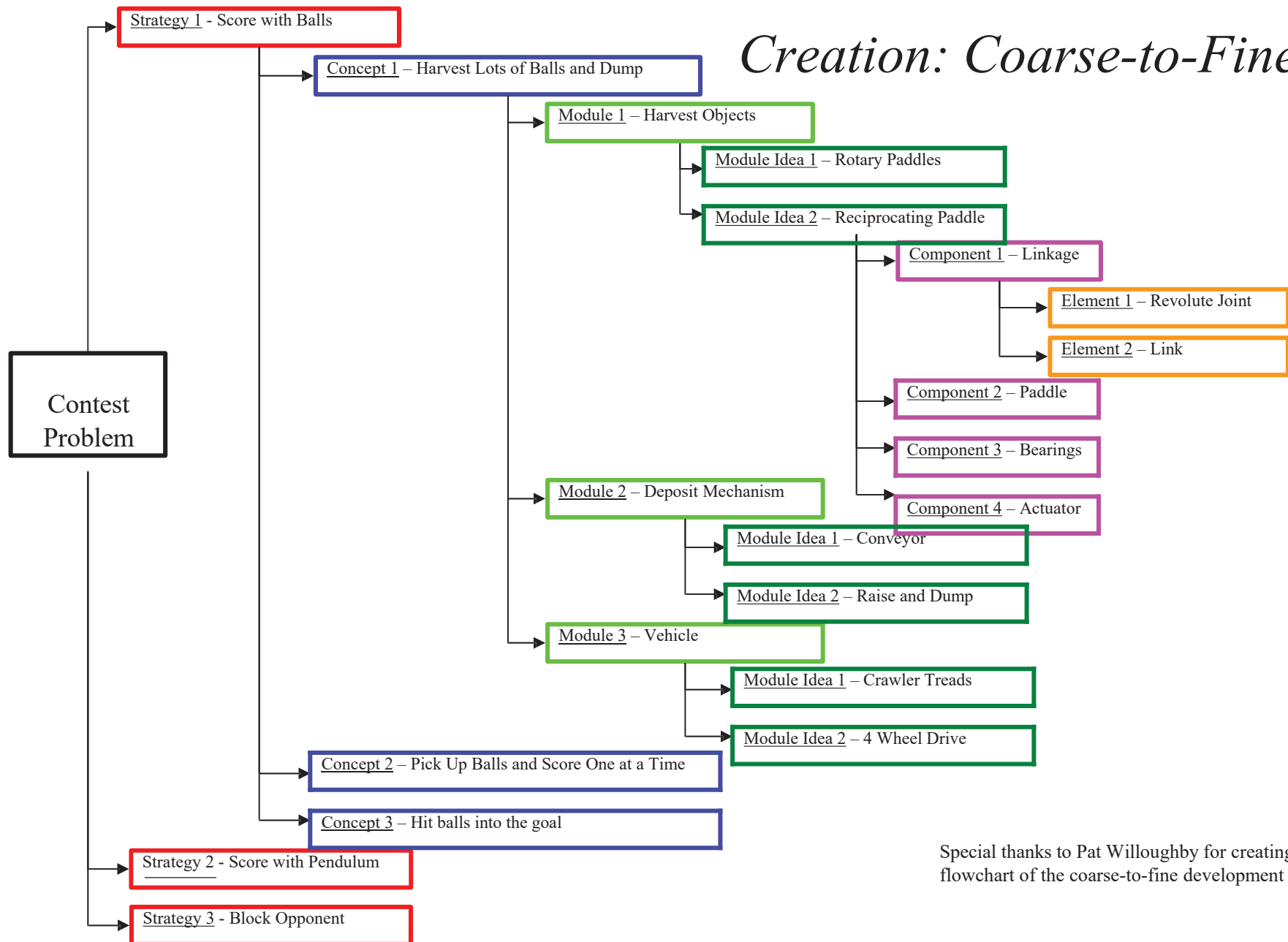
- To actually use the FRDPARRC Table:
  - Create one actual table that becomes your development roadmap
  - Dedicate one sheet to each FR/DP pair

***The FRDPARRC table is an exceptional catalyst to help you identify opportunities for applying reciprocity to uncover new ideas and solve problems!***





## Creation: Coarse-to-Fine

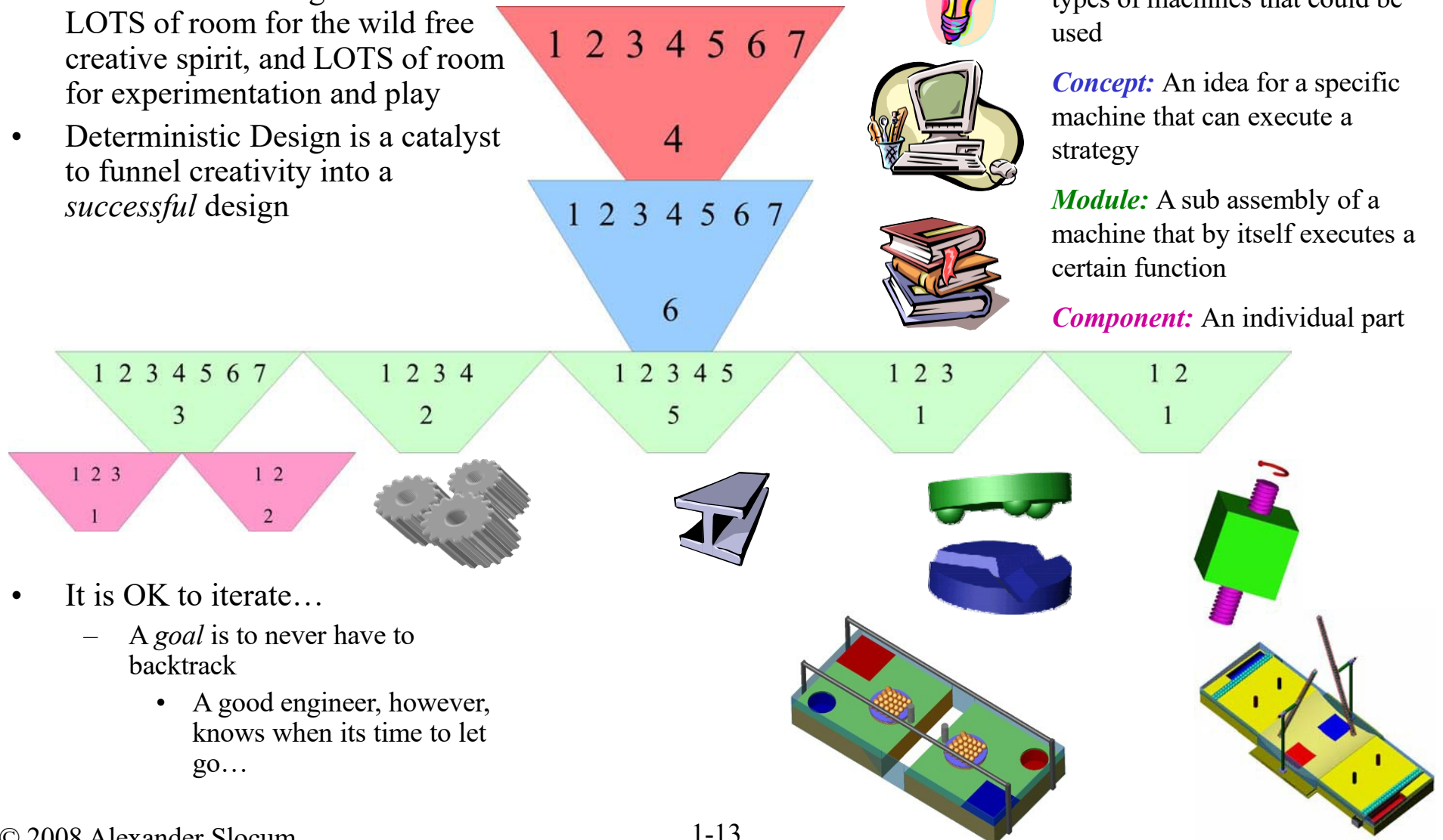


Special thanks to Pat Willoughby for creating this flowchart of the coarse-to-fine development process

# Deterministic Design: *Coarse-to-Fine Funnels:*

**Strategies** Concepts Modules Components

- Deterministic Design leaves LOTS of room for the wild free creative spirit, and LOTS of room for experimentation and play
- Deterministic Design is a catalyst to funnel creativity into a *successful* design



**Strategy:** Plan or tactics to score but there may be many different types of machines that could be used

**Concept:** An idea for a specific machine that can execute a strategy

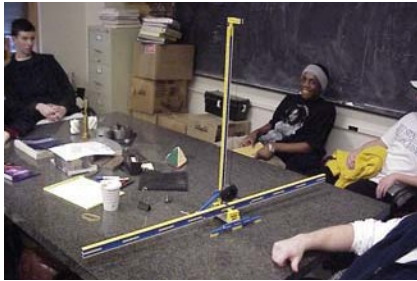
**Module:** A sub assembly of a machine that by itself executes a certain function

**Component:** An individual part

- It is OK to iterate...
  - A *goal* is to never have to backtrack
    - A good engineer, however, knows when its time to let go...

# FUN*da*MENTALS of Design

## Creating Ideas



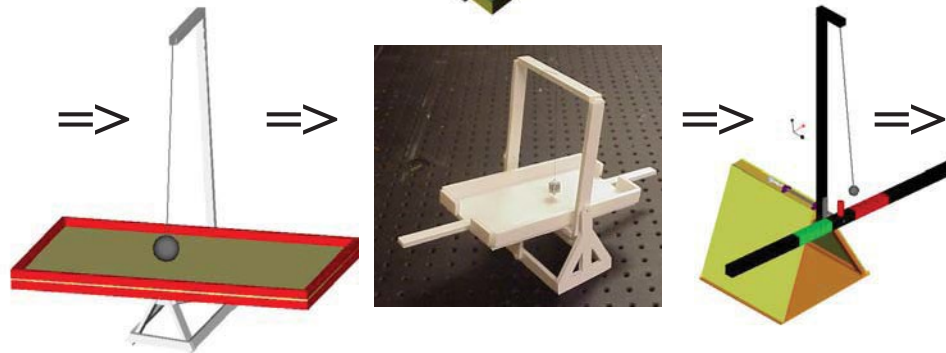
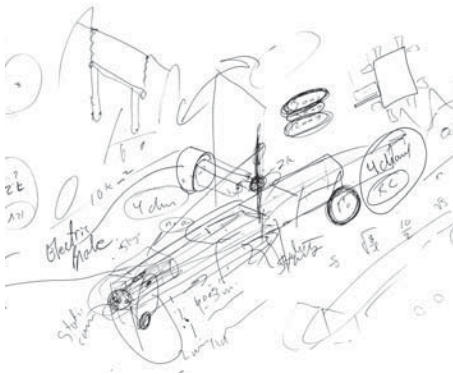
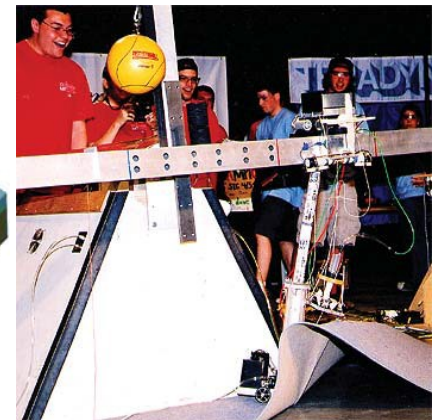
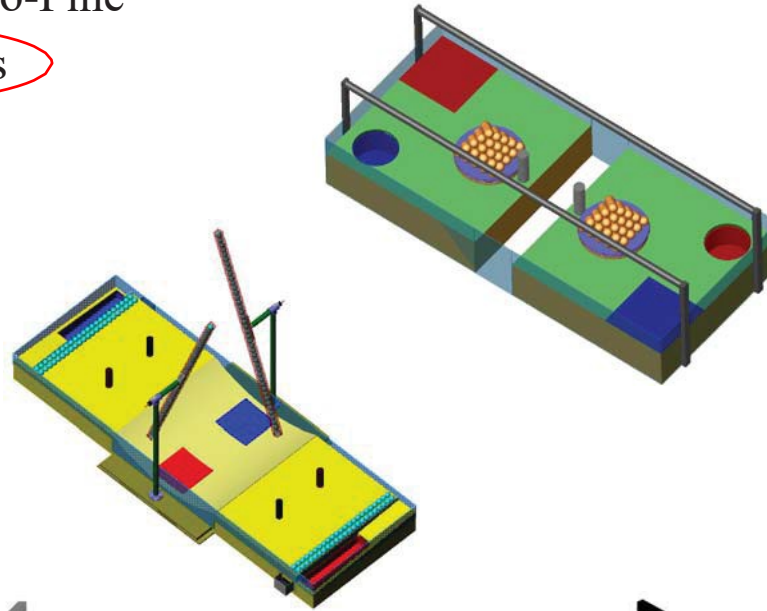
# Creating Ideas Concepting



## Topics

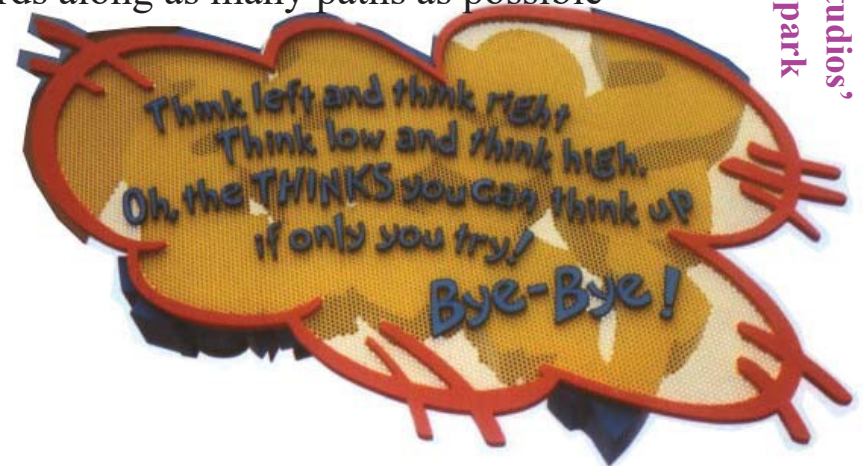
- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- Drawing
- Research
- Writing
- Analysis
- Evolving Ideas

*“Curiosity is one of the permanent and certain characteristics of a vigorous mind” – Samuel Johnson*



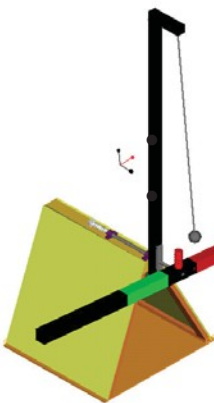
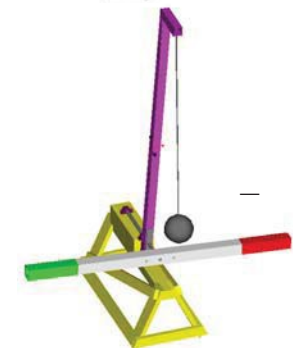
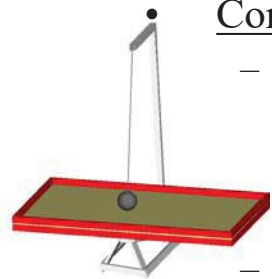
# Thought Processes

- **"Personal self-satisfaction is the death of the scientist. Collective self-satisfaction is the the death of research. It is restlessness, anxiety, dissatisfaction, agony of the mind that nourish science"** *Jacques-Lucien Monod*
- To help generate and create ideas, *thought processes* can be used as *catalysts*
  - Systematic Variation
    - Consider all possibilities
  - Persistent Questioning
    - Continually ask “Who?”, “What?”, “Why?”, “Where”, “How?”
  - Reversal: Forward Steps
    - Start with an idea, and vary it in as many ways as possible to create different ideas, until each gets to the end goal
    - Also called the *method of divergent thought*
  - Reversal: Backwards Steps
    - Start with the end goal and work backwards along as many paths as possible till you get to the beginning
  - Nature’s Way
    - How would nature solve the problem?
  - Exact Constraints
    - What are the minimum requirements



Dr. Seuss from Universal Studios?  
Islands of Adventure theme park





# Thought Processes: Systematic Variation

Consider all possibilities:

- Energy: How can it be applied, generated, stored?
  - Mechanical: springs, flywheels...
  - Hydraulic: piston, bladder, reservoir, propeller...
  - Electrical: line source, battery, capacitor, magnet, optical...

– Material:

- State: solid, liquid, gas
- Behavior: rigid, elastic, plastic, viscous...
- Form: bar, sheet, powder...

– Motions:

- Type: fixed, linear, rotary
- Nature: uniform, non-uniform, transient
- Direction & Magnitude

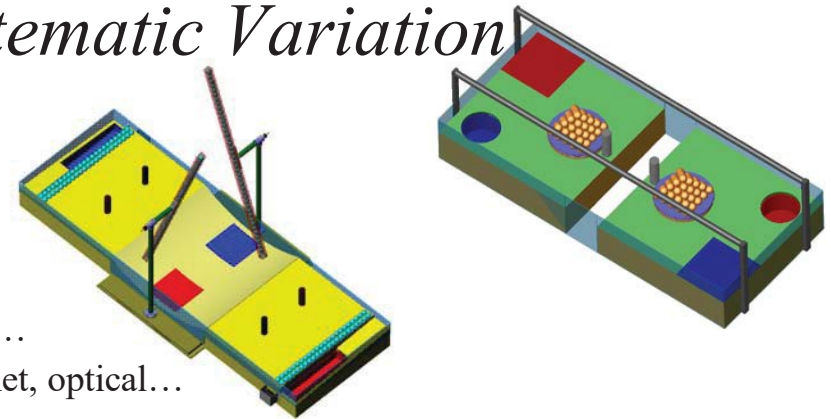
– Controls:

- Passive
- Active

AND all combinations of the above!

Analytical models of systems are invaluable

Sensitivity studies can be easily conducted



**Schwings!** → no machine-machine interaction

The playing field consists of two opposing swing sets. The game begins with two robots at rest in their respective swings. Robots are not allowed to push off or otherwise interact with anything but the cables and seat of their swing. After sixty seconds, the winner is the robot who has swung the greatest cumulative distance, as measured by an optical encoder. To generate a little instability in the system (and keep the crowds happy), place the swing sets close enough so that there is some overlap in the arcs.

*Physics & like it, but what could we use besides a fan?*

*I love this very raw & original*

*What about the other robot's swing?*

*machine*

*rigid, not cable to encode could read → or instrument itself*

*maybe add some means of getting yourself to swing?*

*let them interact with this wall*

**Egg Drop Soup**

The game begins with one dozen fresh AA grade eggs in a bowl at one end of the playing field. Two robots compete to gather the eggs, and deliver them to their own marked bowls without damage. ....

*SOME INTERESTING PLAYING FIELD.*

*BASIC GATHERING CHALLENGE*

*This could be a mess by the third round unless we booted eggs*

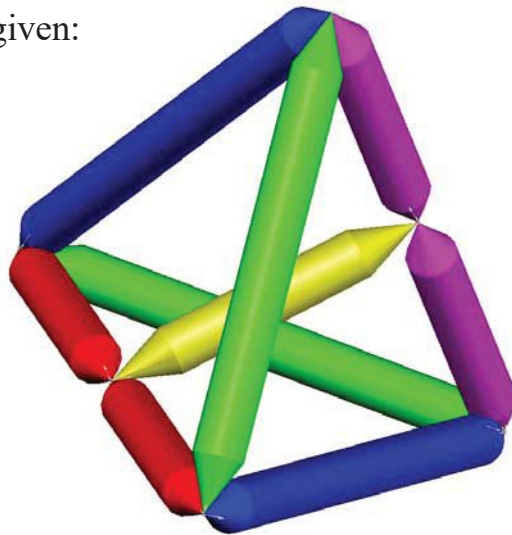
*That's such a waste of food. Couldn't we use bad eggs?*

*how to judge damage*

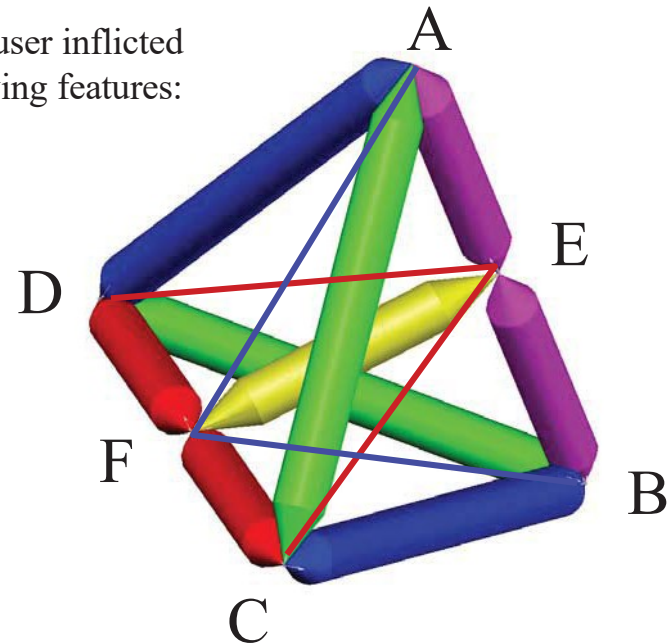
## Thought Processes: Reversal

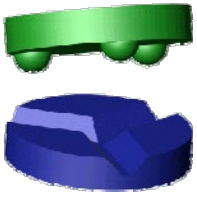
- When an element has a risk, a countermeasure is often the inverse of the element
  - When a naysayer in a design review points out a weakness (risk) bring them onto your side by saying “that’s a good observation, lets make sure we consider 1/weakness”
- Being able to rapidly switch between the methods of Forward Steps and Backward Steps is an invaluable skill
  - Example: Given length equalities indicated by the colored pointy end cylinders, prove that the yellow cylinder is the perpendicular bisector of the purple and red cylinders?
    - Never be afraid to add your own sketching to a problem that is given you
      - The thin red and blue lines and vertex labels were added!
    - If you do not rapidly see how to move forward, try going backwards!

As given:

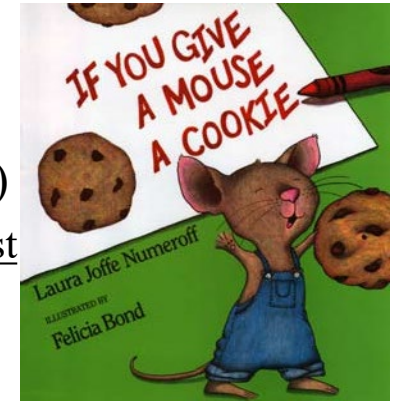


After user inflicted  
clarifying features:

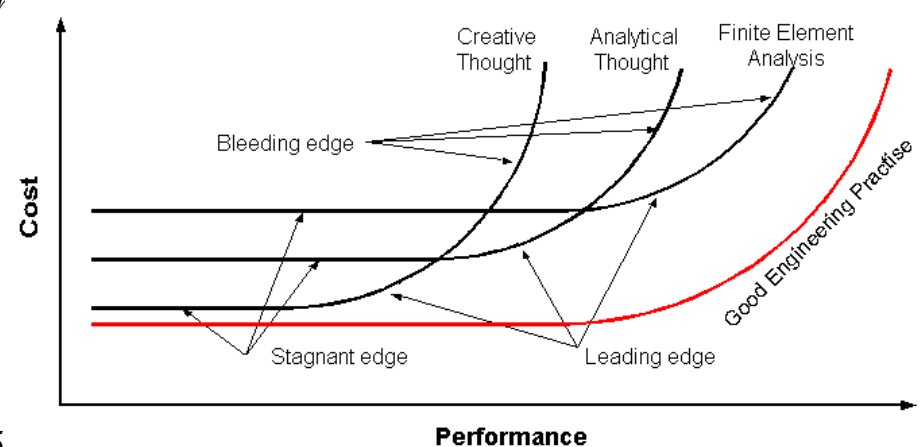
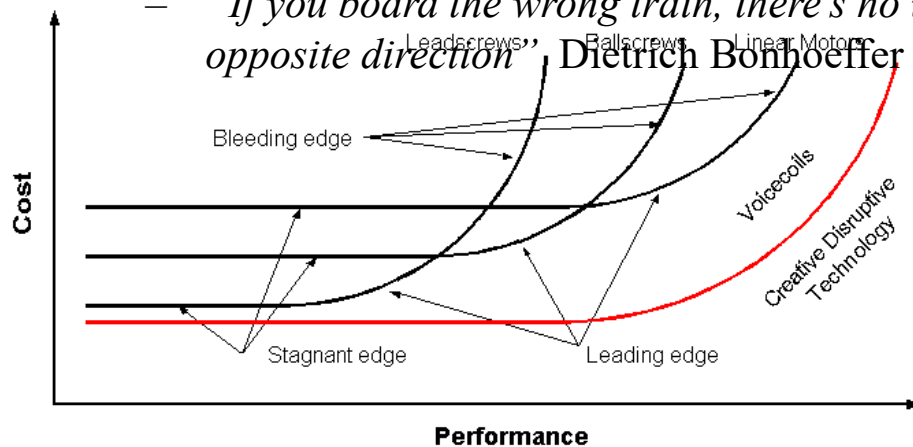
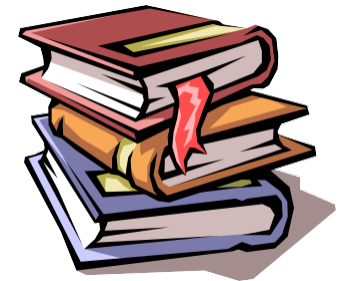




# Deterministic Design



- Everything has a cost, and everything performs (to at least some degree)
  - If you spend all your time on a single tree, you will have no time for the forest
  - If you do not pay attention to the trees, soon you will have no forest!
  - You have to pay attention to the overall system and to the details
- Successful projects keep a close watch on budgets (time, money, performance)
  - Do not spend a lot of effort (money) to get a small increase in performance (90%-10% Rule)
    - “Bleeding edge” designs can drain you!
  - Do not be shy about taking all the performance you can get for the same cost!
- Stay nimble (modular!) and be ready to switch technology streams
  - It is at the intersection of the streams that things often get exciting!
  - “If you board the wrong train, there’s no use in going in the opposite direction” Dietrich Bonhoeffer





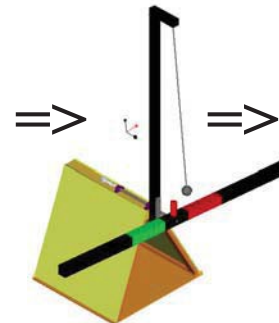
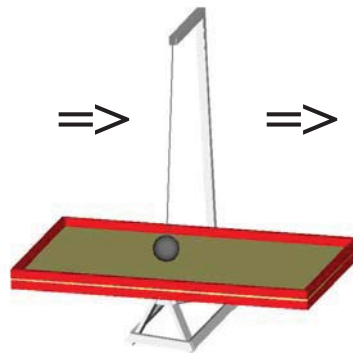
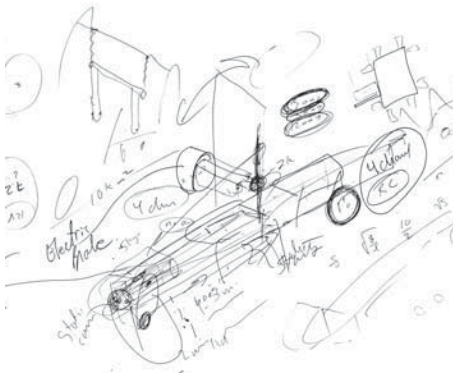
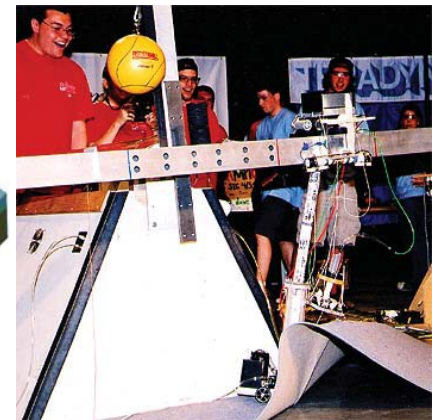
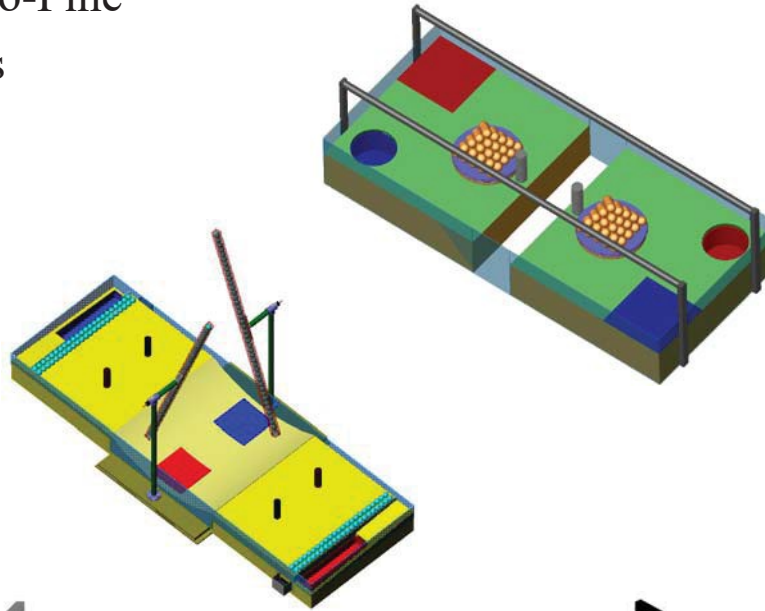
# Creating Ideas Concepting



*"Curiosity is one of the permanent and certain characteristics of a vigorous mind" – Samuel Johnson*

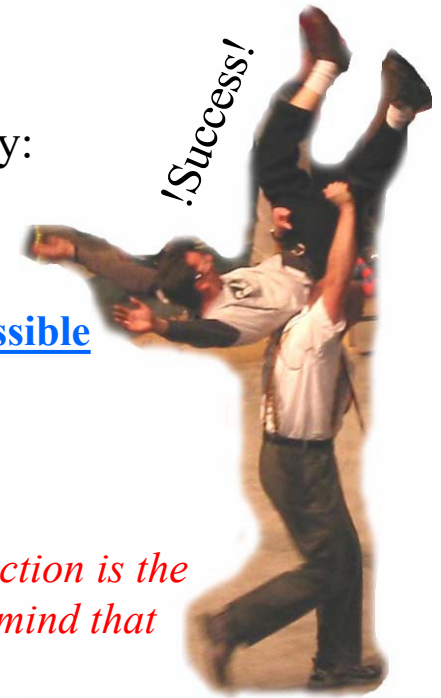
## Topics

- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- Drawing
- Research
- Writing
- Analysis
- Evolving Ideas

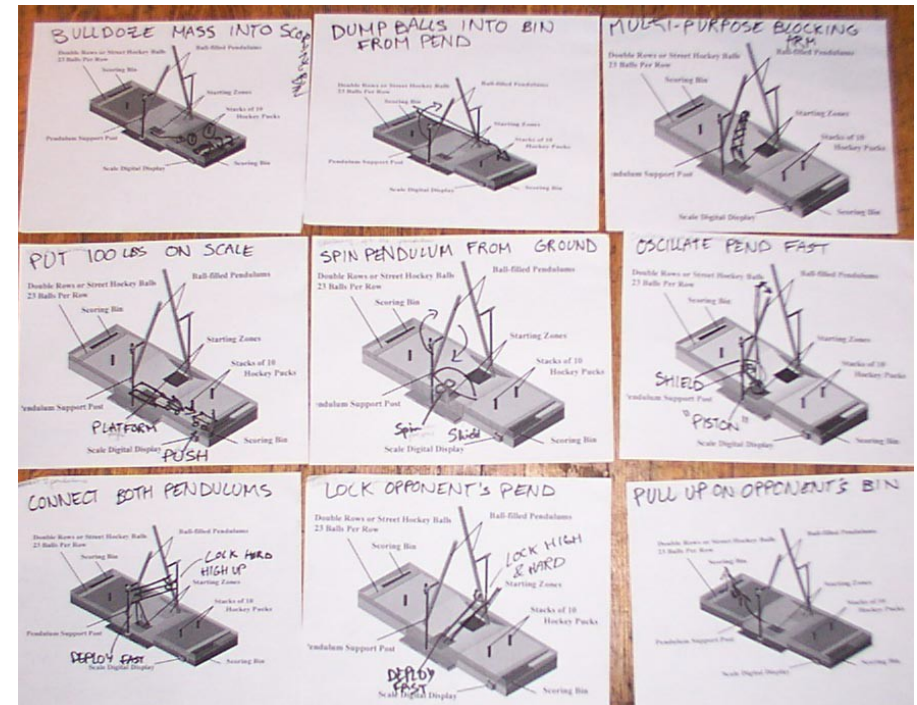


# Deterministic Design: Play!

- Engineering is often a tactile, visual, verbal, cerebral, and physical activity:
  - Play with the table and the kit parts
  - Sketch ideas
  - Create physical & analytical models to identify opportunities and test possible strategies
  - Detail the machine using all the engineering skills and tools at your disposal
  - Build & test your machine!
  - *“Personal self-satisfaction is the death of the scientist. Collective self-satisfaction is the death of the research. It is restlessness, anxiety, dissatisfaction, agony of the mind that nourish science” Jacques-Lucien Monod*



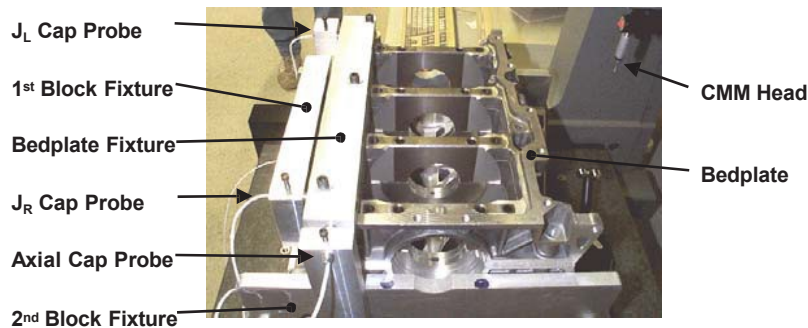
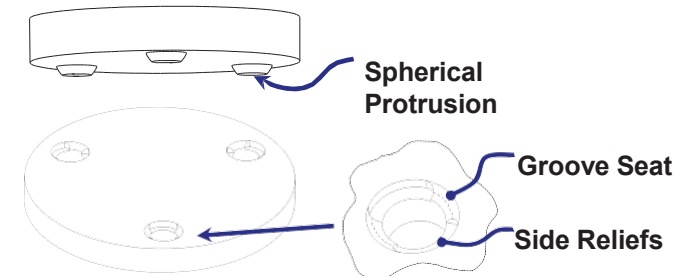
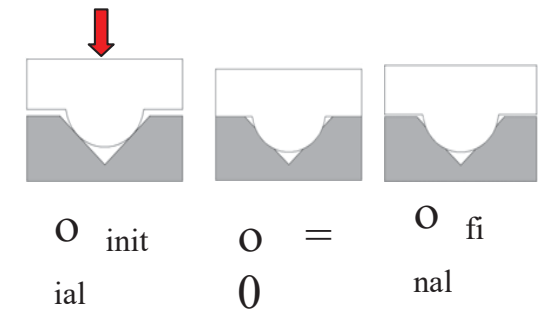
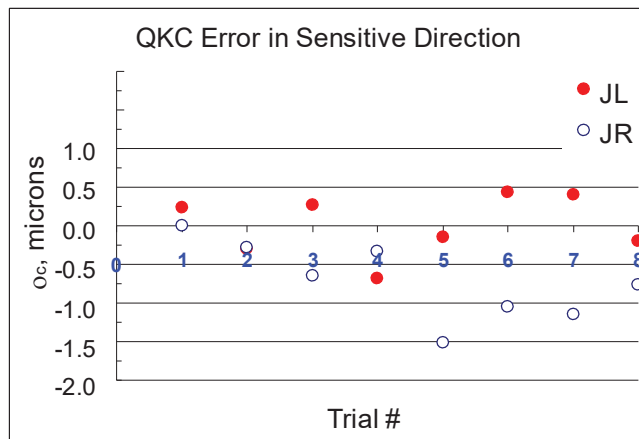
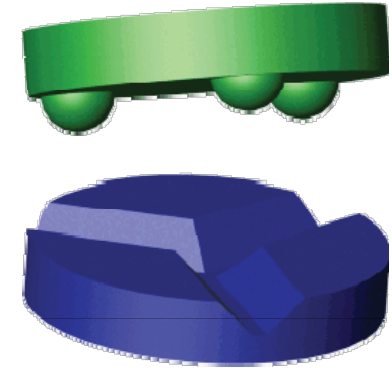
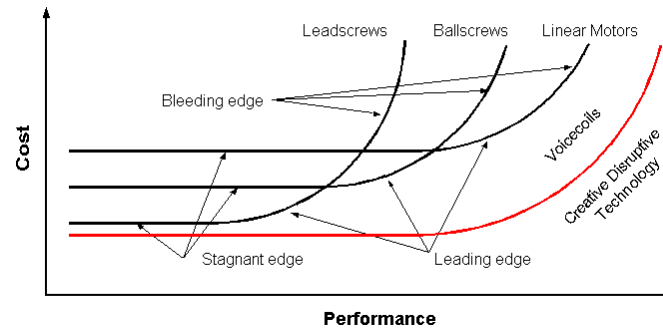
Martin Jonikas' high scoring machine and idea evolution.  
Can you figure out how it works (Reverse Engineering)  
and create an even better machine?





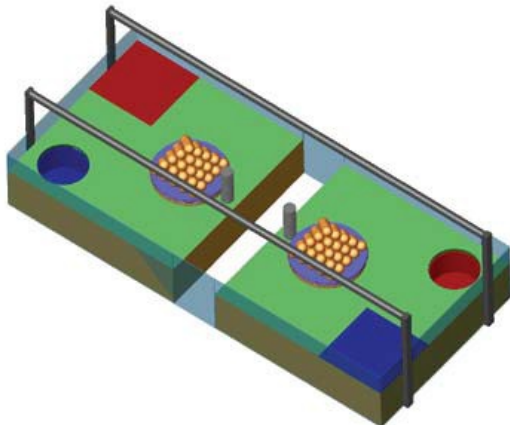
# Experimentation with Prototype/Model

- Playing With Parts
- Sketch Models
- Bench Level Experiments
- Bench Level Prototypes
- Identifying Risky Ideas



# Experimentation: *Playing with Parts*

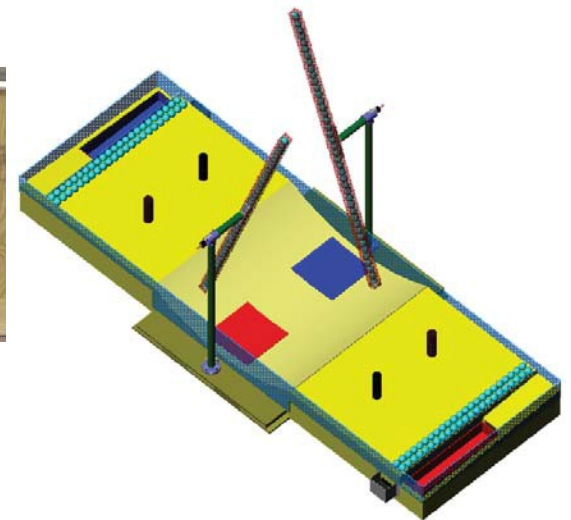
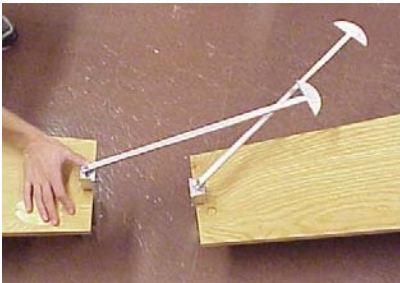
- Lay out all the materials you have (physically or information sheets) in front of you and play with them, let them talk to you, what are their limits, how have others used them...?
  - Place components amongst each other on the contest table to obtain a physical feel for how they might work and fit.....
  - Move the table and feel its motions....
- With a “competing” partner “drive” imaginary machines with your hands to feel how things might move in competition
  - Mock competitions can help create and evolve *strategies*





## Experimentation: Sketch Models – Rapid Prototyping

- Sketch models are made from simple materials (e.g., cardboard, foam, hot-melt- glue, tape, string) and they allow you to literally “play” with potential strategies
  - Later, when you have a *concept* developed, they enable you to “test drive” your machine *concept* around the table
    - In the “real world” where designs are often very complex, sketch models are still often important “proof of *concept*” aids
      - They can be invaluable sales tools!
- A *Sketch-Model-Derby* is an invaluable way to test ideas, with minimal risk of time and materials
  - See <http://me.mit.edu/lectures/sketch-modelling/2.2-examples.html>
  - Evolution of *The MIT and the Pendulum*:



# Experimenting: *Bench Level Experiments of Physical Models*

- Experiments to test function, force, friction, and speed, are a vital part of the design process

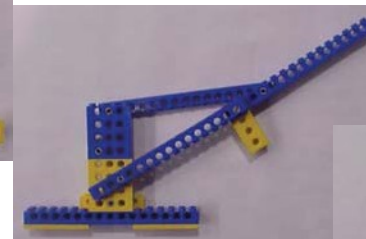
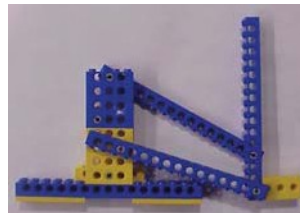
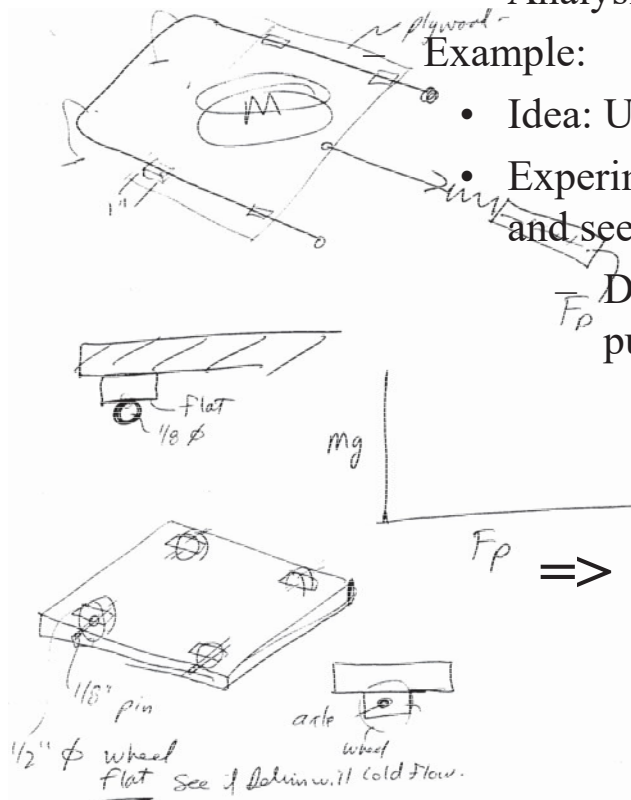
- Analysis is potentially the quickest way to verify an idea
- Remember, to be thorough! However, ....
- Analysis inexperience or uncertainty can lead to *analysis paralysis*

- Analysis paralysis is most often relieved by a simple experiment

Example:

- Idea: Use a winch to pull the pendulum back and forth?
- Experiment: Tape a motor to the beam and tie a string around the pendulum and see if the motor shaft can wind the string up and pull the pendulum over

Does the motor's distance from the pendulum affect how far over it can pull the pendulum?



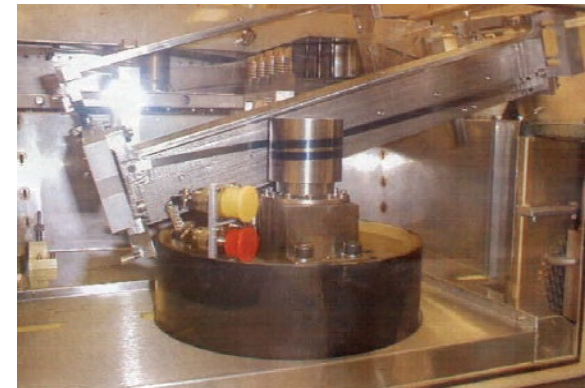


# Experimenting: *Bench Level Prototypes*

- Once you get to the *concept* phase, you may have a risky idea, which if it works, would be awesome
  - A Bench Level Experiment is performed to prove the principle of an idea, but it is not a potentially functional part of the machine
- A Bench Level Prototype is designed to ideally be an actual *module* to test a risky concept
  - Design it well, and if it works, it could be a ready-to-use *module* for your machine!
  - It often shows what works and what must be fixed in a *module* (like the software!)
  - A robot contest BLP would be to create a vehicle to test its speed and controllability
    - Use modular *components*, so you can change them to optimize performance
    - E.g., change the gear ratio on a vehicle's drive train



*Oops! Software crashed it again!*



*Programmers are not that innocent!*



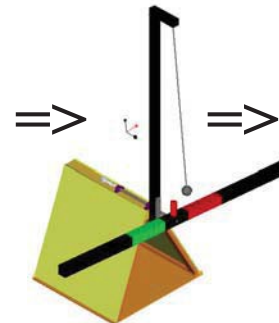
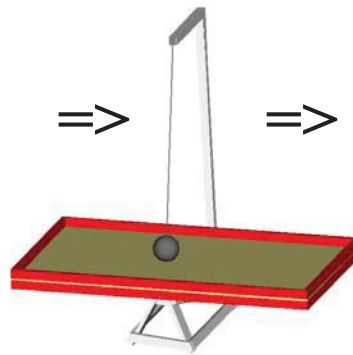
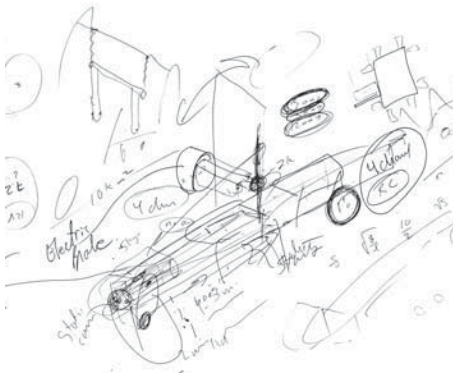
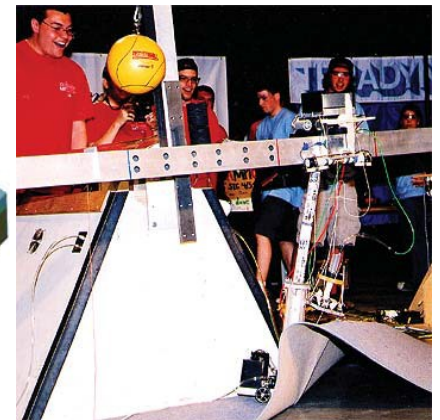
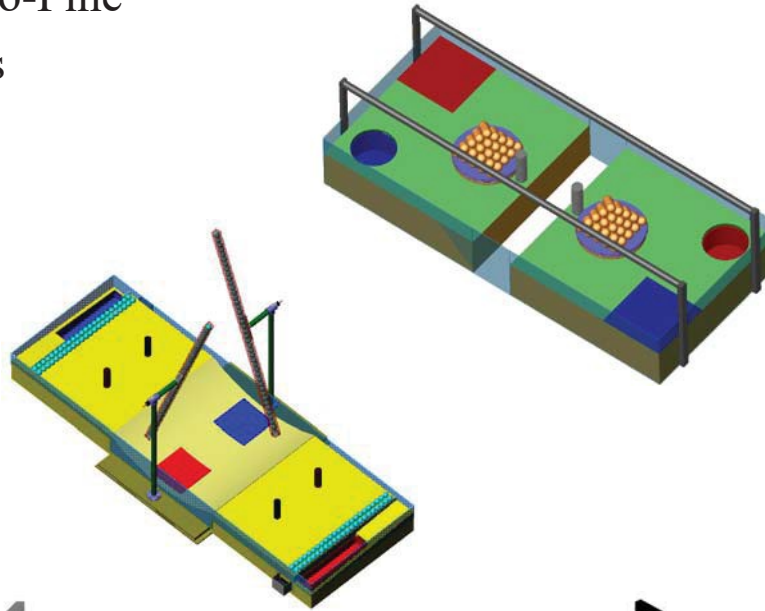
# Creating Ideas Concepting



## Topics

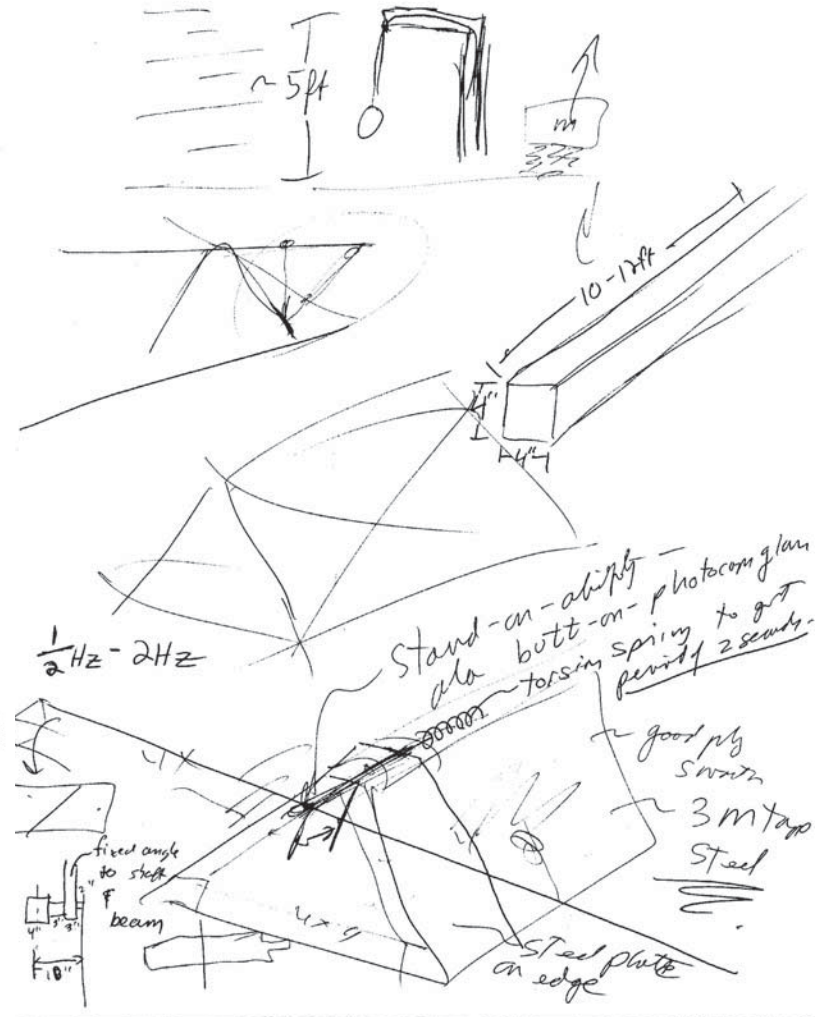
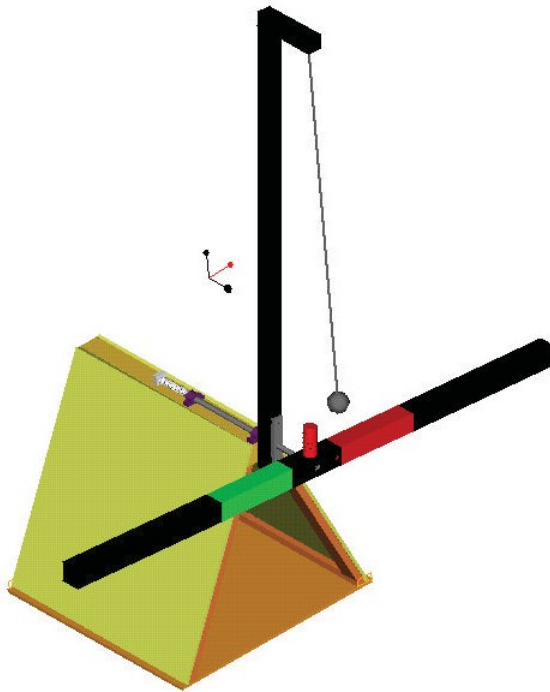
- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- **Drawing**
- Research
- Writing
- Analysis
- Evolving Ideas

*“Curiosity is one of the permanent and certain characteristics of a vigorous mind” – Samuel Johnson*



## A 3x3 grid of green circles. There are 9 circles in total, arranged in 3 rows and 3 columns. Each circle is green with a black outline.

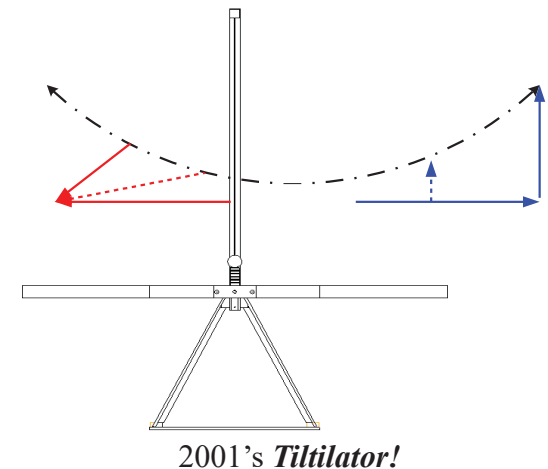
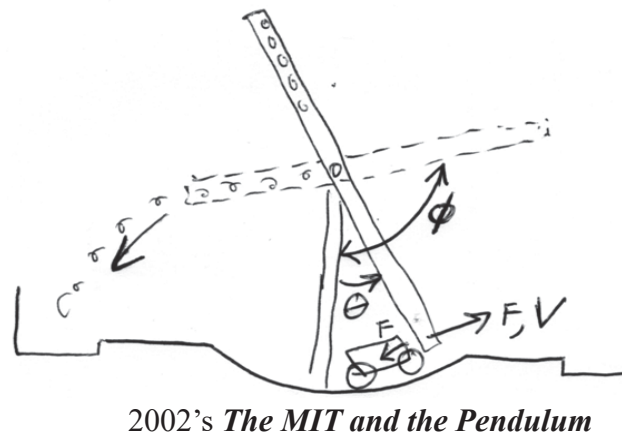
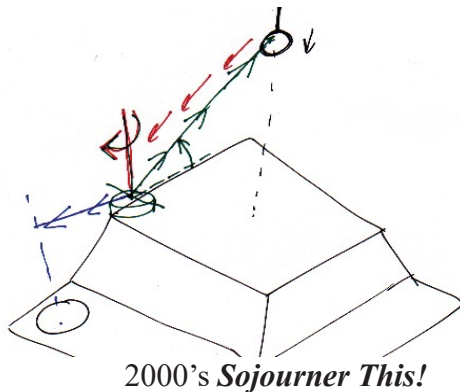
- 



# Drawing: Motion & Force Diagrams Free Body Diagram (Statics & Dynamics)



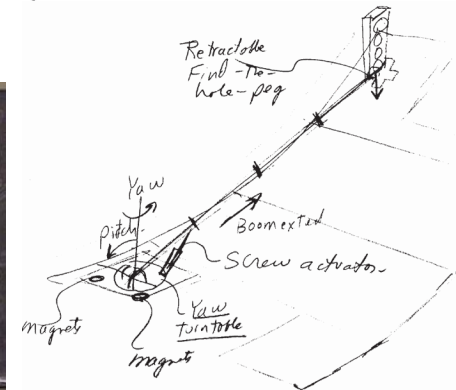
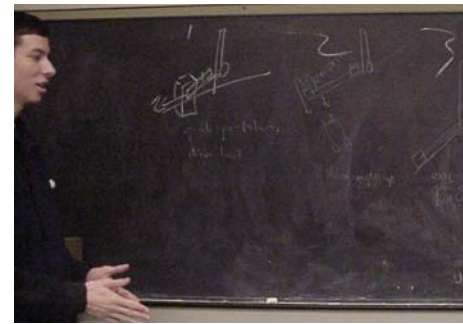
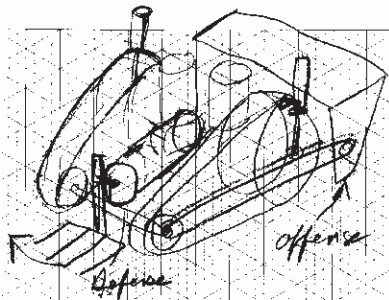
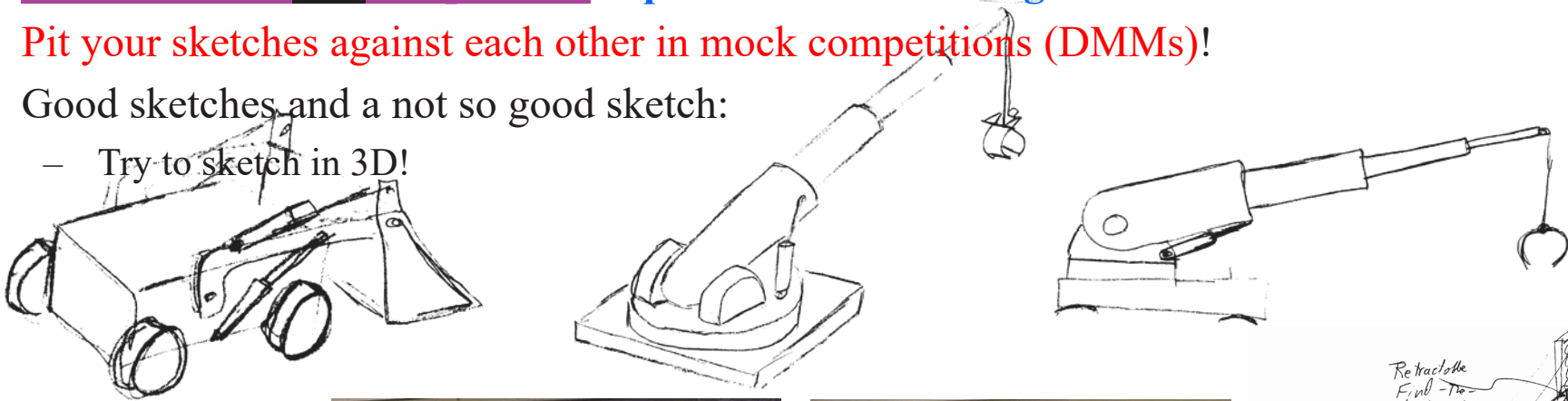
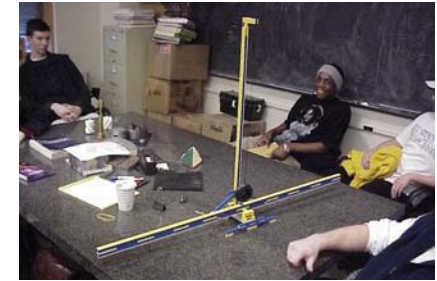
- It is important to sketch the idea of a **strategy** without including any mechanical detail:
  - Just use arrows to indicate directions of motions
    - Illustrating the motion with mechanism implies a concept
    - Use different colors!
  - You do not want to start implying specific **concepts** because this could lead you to spend time developing it before you explore enough **strategies**
    - Time is precious
    - For an illustrative reference, read *If You Give a Mouse a Cookie*
  - **Use your motion and force diagrams to help create a preliminary power budget!**





# Drawing: Sketches

- **Strategies (Design)** are sketched with simple arrows to indicate motions
- **Concepts (Brain Storming)** are sketched showing overall design intent via possible mechanisms and blocks representing modules
- **Modules (Subsystems)** are sketched showing basic types of components
- **Subassemblies** and **Components** capture detail and design intent
- Pit your sketches against each other in mock competitions (DMMs)!
- Good sketches and a not so good sketch:
  - Try to sketch in 3D!

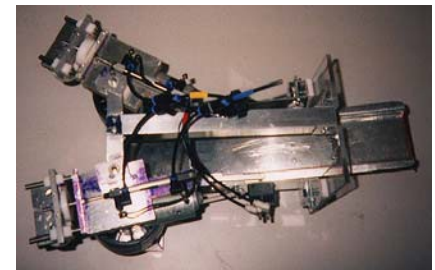
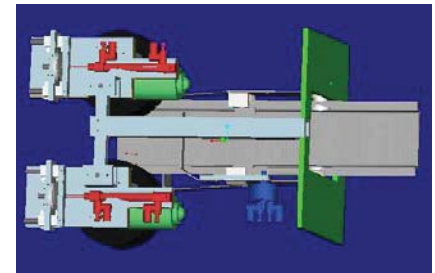
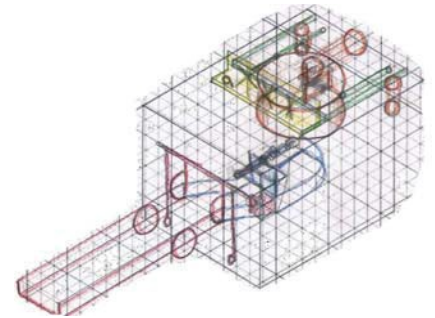




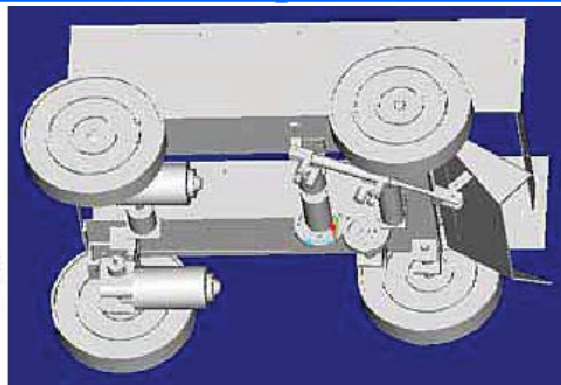
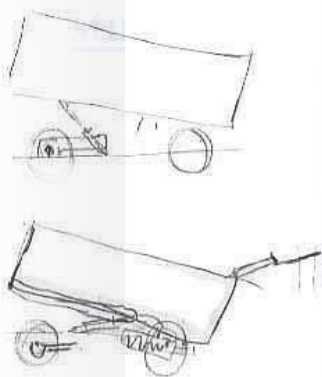
## Drawing: *Solid Models*

- Creating a solid model of the environment (e.g., Contest table!) helps you build a solid model of your machine, to make sure it will fit!
  - A solid model of the environment lets you make measurements outside of the lab, to make sure your mechanism will fit
- A solid model of a *concept* starts with simple parametric shapes, that will essentially define volumes into which *modules* must fit
  - Detail is added as the design progresses
  - Use *Tools/Equations* to add relations between dimensions
    - When you change a primary dimensions, all other dimensions related by equations automatically change too!
      - The design "morphs" automatically
    - The true power of solid modeling: You do not have to track down and change umpteen different dimensions in different parts!
- Analysis of a solid model can serve as a *Bench Level Experiment*, to illuminate problems and help guide sensitivity

Alex Sprunt's machine



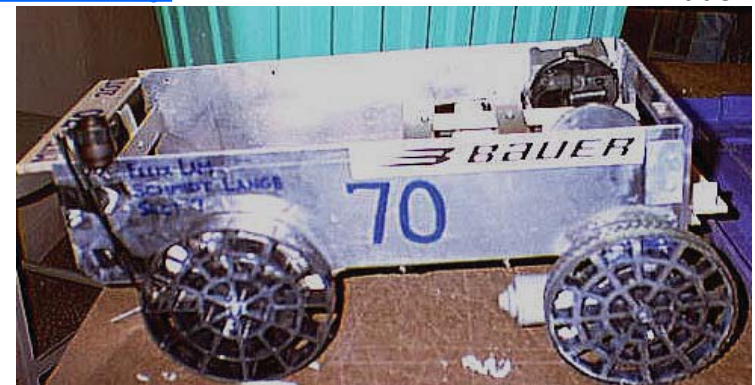
1/1/2008



2-14

33/56

Felix Lam's machine



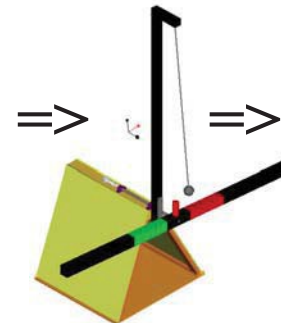
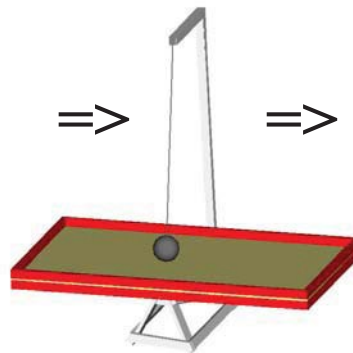
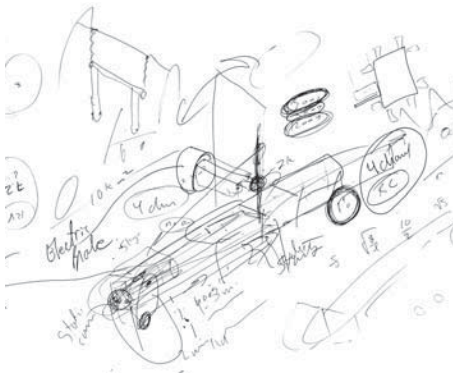
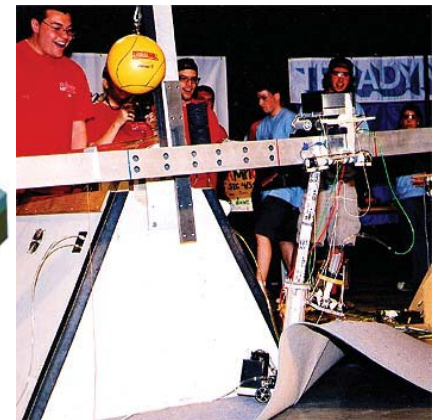
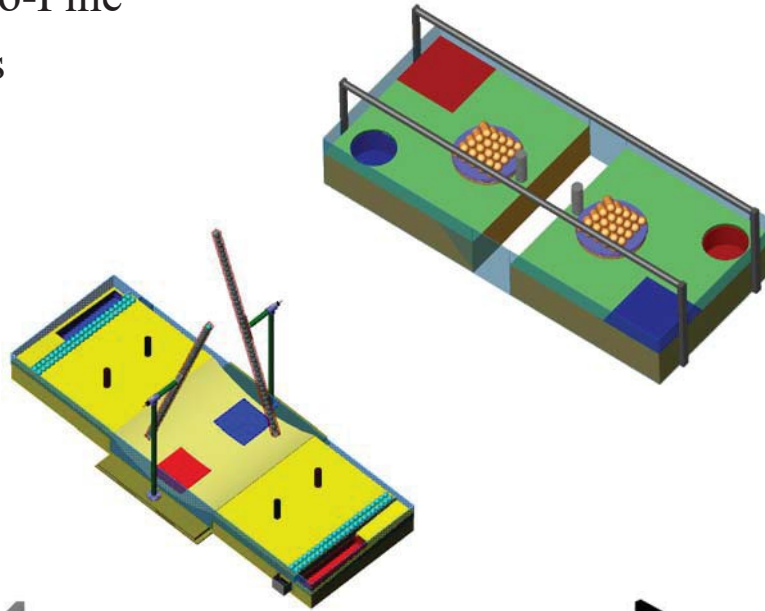
# Creating Ideas Concepting



*"Curiosity is one of the permanent and certain characteristics of a vigorous mind"* – Samuel Johnson

## Topics

- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- Drawing
- **Research**
- Writing
- Analysis
- Evolving Ideas



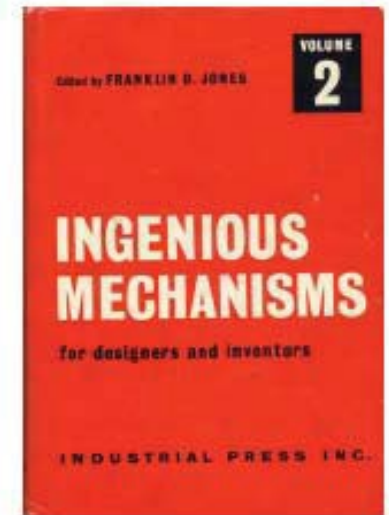




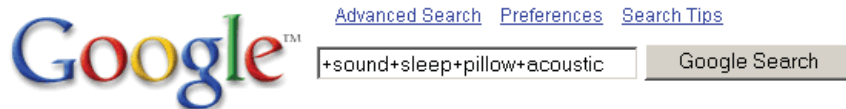
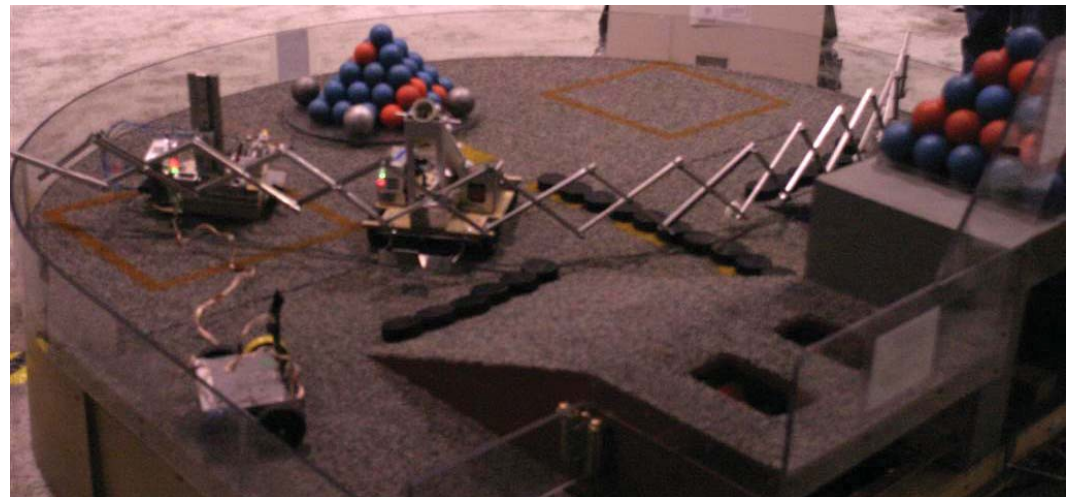
[www.bobcat.com](http://www.bobcat.com)

## Research

*Go to your local museum of science, as they likely have a neato mechanisms room!*



- [Books, journals, trade magazines...](#)
- [Past events](#)
  - Show guides, competitor catalogs
  - Previous contests!
- [The Internet](#)
  - Popular search engines
  - Engineering and scientific databases!
  - University technical library



[Sound Spa Deluxe Acoustic Relaxation Machine with LCD Alarm ...](#)



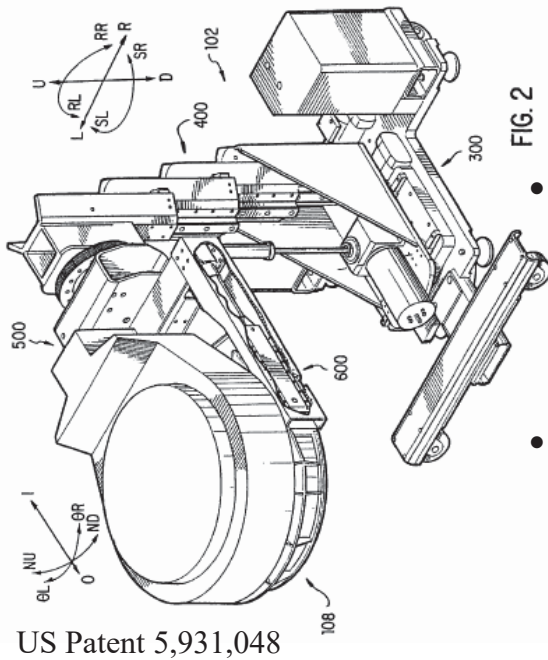


FIG. 2

US Patent 5,931,048

#### Publication Types

#### Patents at MIT

#### Where to Search

- ♦ Utility and design patents
- ♦ Biotechnology and chemistry patents
- ♦ Aggregate analysis of patents

#### How to Search

- ♦ Search strategy
- ♦ Guides for searching

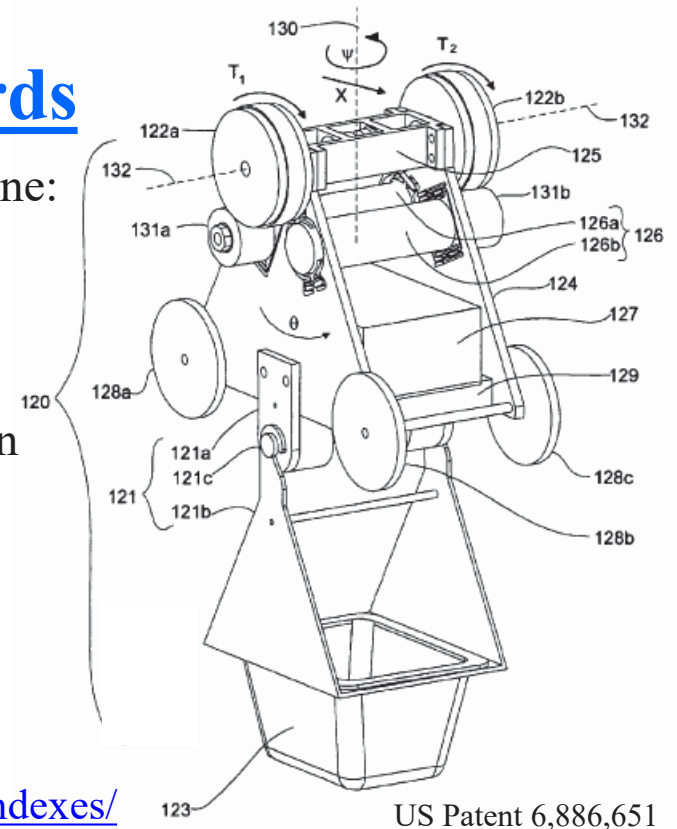
## Patents & Standards

- Patent searches can be done online:

- Library databases
- [www.uspto.gov](http://www.uspto.gov)
- [www.freepatentsonline.com](http://www.freepatentsonline.com)

- Standards contain information on “how to do things right”!

- [www.nssn.org](http://www.nssn.org)
- [www.ansi.org](http://www.ansi.org)
- [www.astm.org](http://www.astm.org)
- [www.iso.org](http://www.iso.org)
- <http://www.normas.com/DIN/indexes/>



US Patent 6,886,651

US patent 5,176,454

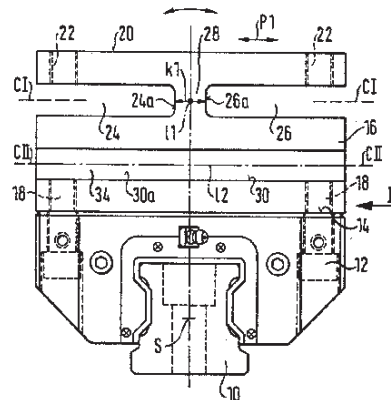
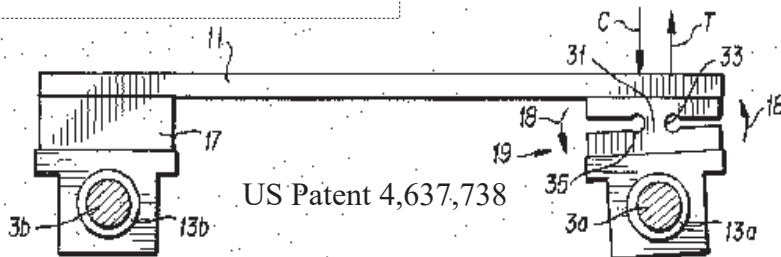


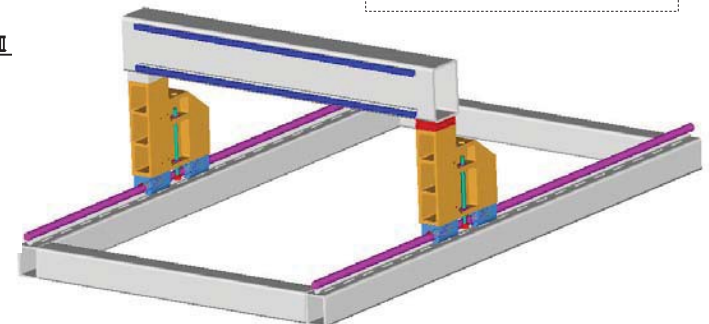
FIG. 3

US Patent 4,637,738



#### BRITISH STANDARD

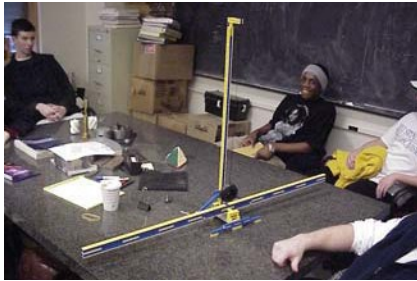
Specification for  
motors for battery  
operated vehicles



2-16

36/56





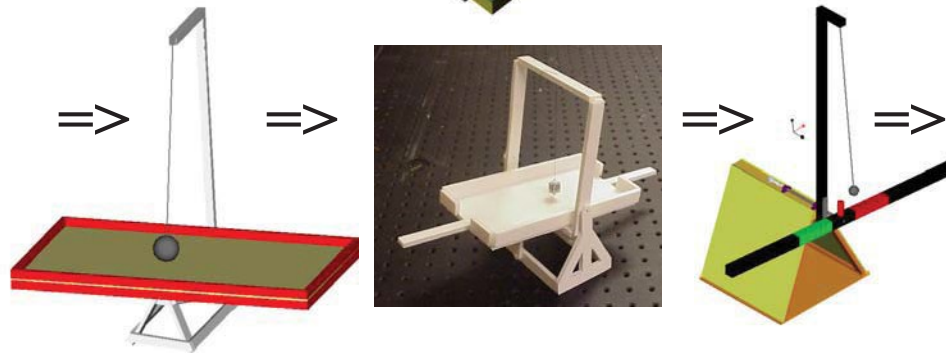
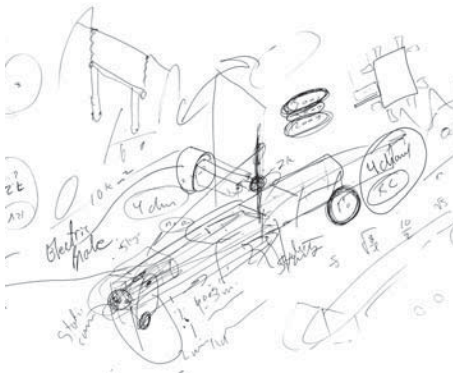
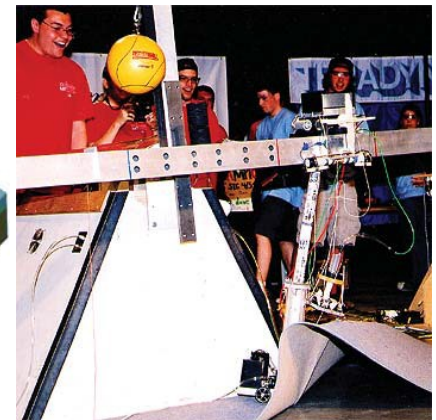
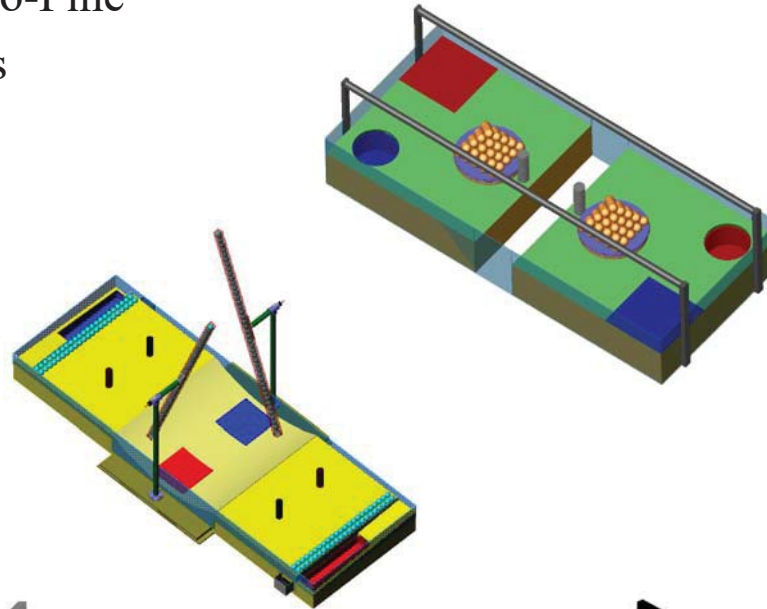
# Creating Ideas Concepting



## Topics

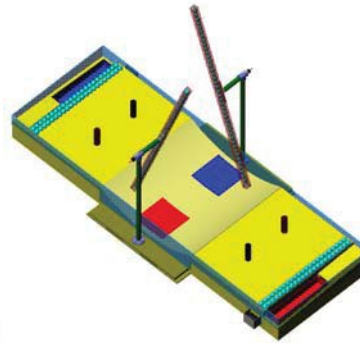
- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- Drawing
- Research
- Writing
- Analysis
- Evolving Ideas

*“Curiosity is one of the permanent and certain characteristics of a vigorous mind” – Samuel Johnson*



## Writing

- **Putting it in your own words....**
- **Lists, Figures, and Tables**
- **Narratives**
- **Poems, raps, ballads...**



### PROJECT STATUS UPDATE: NOFER TRUNIONS

Work has been proceeding in order to bring to perfection the crudely conceived idea of a machine that will consistently refragicate Nofer Trunions. The current design concept, known as a Turbo Encabulator, supplies inverse reactive current to unilateral phase detractors and thus is capable of automatically synchronizing its internal Cardinal Grammers.

The original machine has a base plate of pre-fabulated amulite surmounted by a malleable logarithmic casing in such a way that the two sperving bearings are co-linear with the pentrametric fan. The main winding is of the normal Lotus-O-Delta type, placed into patedermic semi-blode slots in the stator with every seventh conductor being connected by a non-reversible tremic pipe to the differential girdle spring at the upper end of the grammeter. 41 (yes, 41!) manestically spaced grouting brushes are arranged to feed into the rotor slip stream a mixture of high S value phenolbitatol benzene and 5% ruminative tetra tyliodol hexamine. Both these liquids have a specific pericosity given by:

$$P = 2.5 Cn^{6.5}$$

where n is the diethetical retribute of temperature phase disposition, and C is Colomondole's annual grilliage constant. Initially, n was measured with the aid of a metapolar diffractive pilfrommeter, but to date nothing has been found to equal the transcendental hopper dactascope.

Undoubtedly, the Turbo Encabulator has reached a high level of technical development. It has been successfully used to produce sucraactively modified Nofer Trunions in large volumes. In addition, whenever a bardensen scorn motion is required, it may be employed in conjunction with a drawn reciprocating dingle arm to reduce sinusoidal depeneration in the Nofer Trunions' bifurdangled hipniscorn.

*Believed to be written decades ago by a long-forgotten soul at Phi Kappa Tau fraternity, Rensselaer Polytechnic Institute*

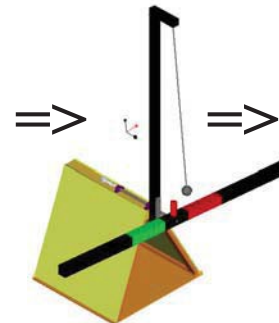
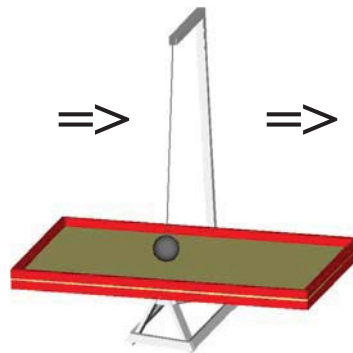
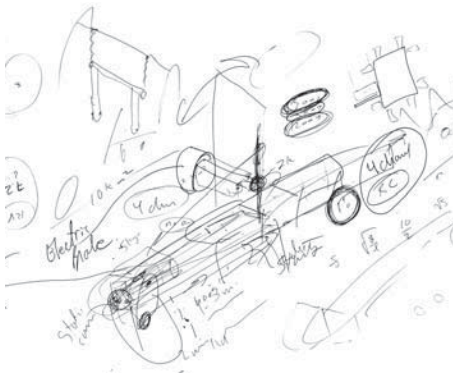
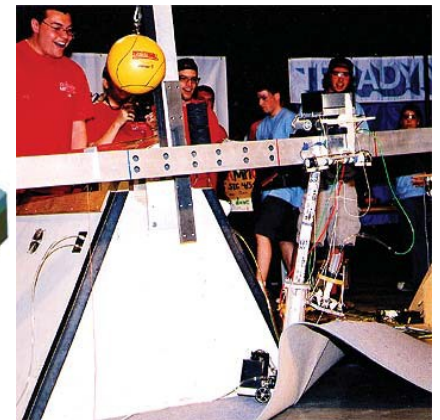
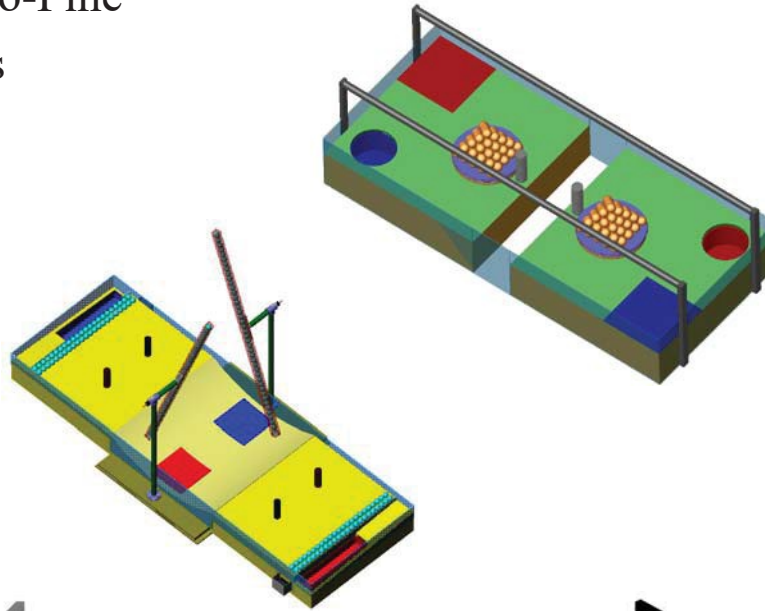
# Creating Ideas Concepting



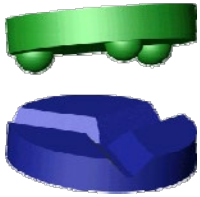
## Topics

- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- Drawing
- Research
- Writing
- **Analysis**
- Evolving Ideas

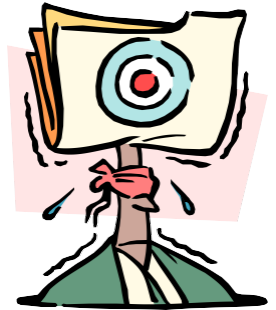
*“Curiosity is one of the permanent and certain characteristics of a vigorous mind” – Samuel Johnson*



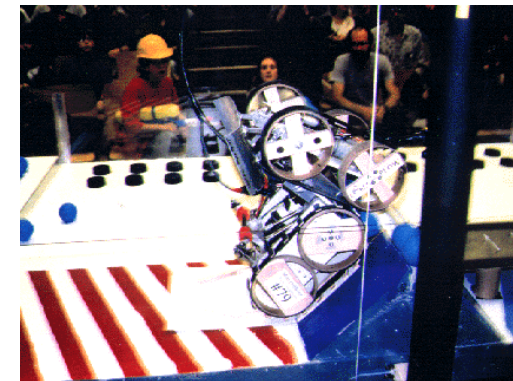
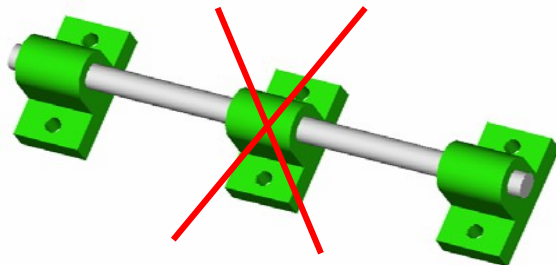




# Deterministic Design: Risk Management



- The key to deterministic design is risk management
- For every idea, risk must be assessed
  - Ask yourself which ideas and analysis (physics) are you most unsure of?
    - Which element, if defined or designed wrong, will neutralize the machine?
  - For every risk identified
    - Estimate the probability of occurrence (High, Medium, Low)
    - Identify a possible countermeasure (i.e., Risk Mitigation)
  - Prioritize your risk and continue to do analytical, computational, or physical Bench Level Experiments (BLEs) to test ideas before you move forward!
  - Good Engineering Practice continually applies!
    - Prayer is for your personal life!
    - Determinism is for design!



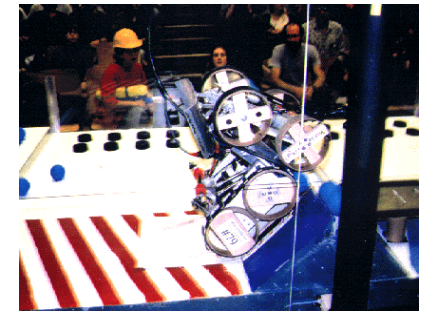
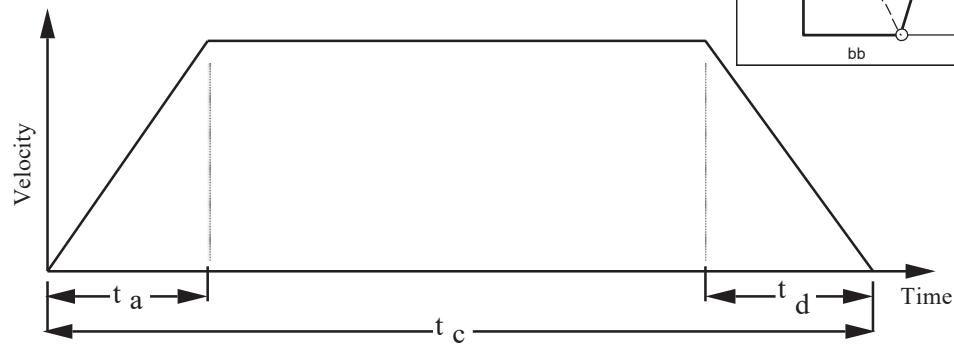
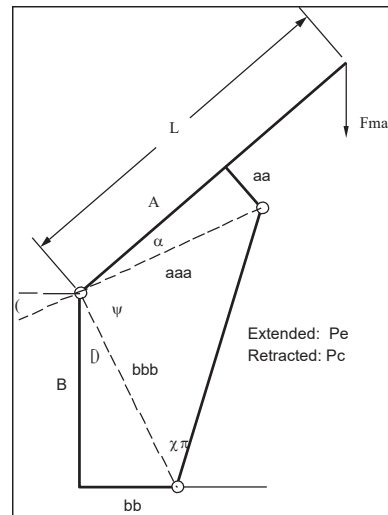
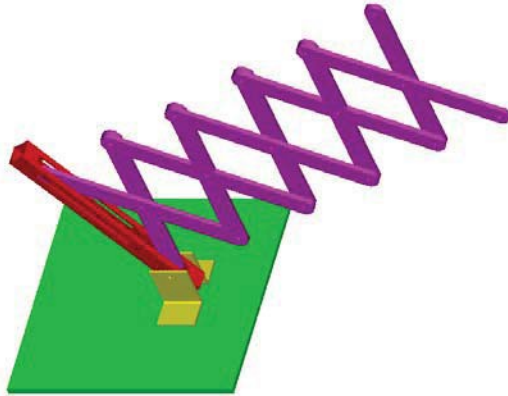


# Analysis

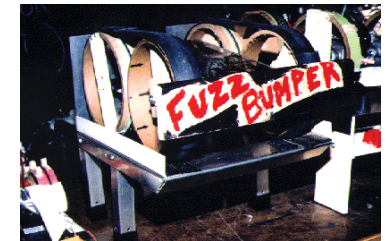
- Appropriate Analysis
  - *Ratiocinator emptor*
- Scoring Sensitivity
- Geometry, Time & Motion
- **Energy, Momentum, Mass, & Strength**



Sir Isaac Newton (1642 - 1727 )



Tim Zue

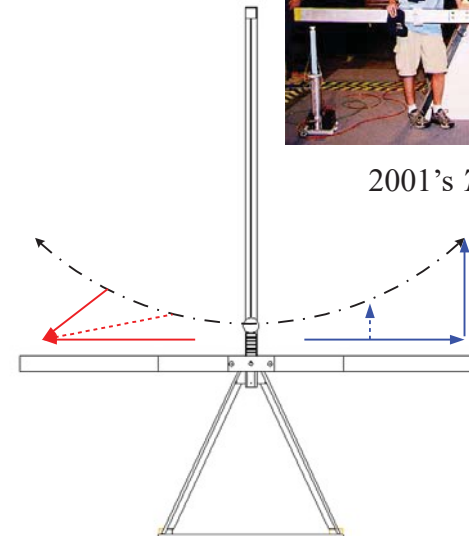


1997's *Pass The Puck!*

Will Delhagen & Alex Jacobs



2001's *Tiltulator!*



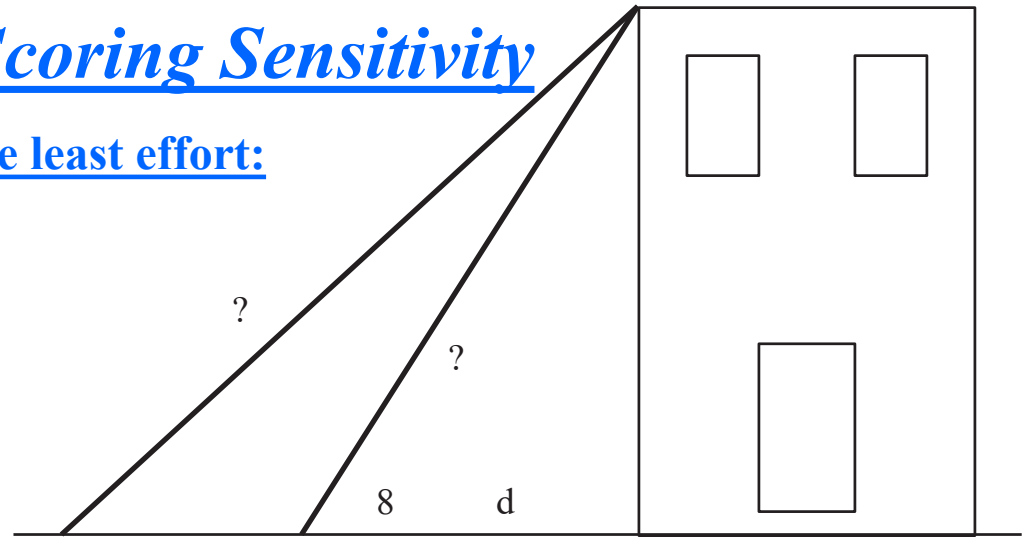
## Analysis: Scoring Sensitivity

- What gives the greatest score for the least effort:

- Pendulum?
- Hockey pucks?
- Balls?

- What variables affect the score?

- Ball and puck weight
- Pendulum travel?
- ?



- Answer these questions by writing the equations, and then investigating which are the most sensitive parameters

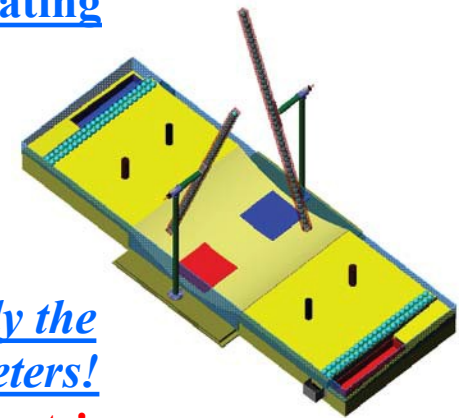
- Ask yourself: *How can I affect each of these parameters?*

- Physics is an AWESOME catalyst to help your brain generate ideas

- Analysis is an awesome lens for focusing effort!

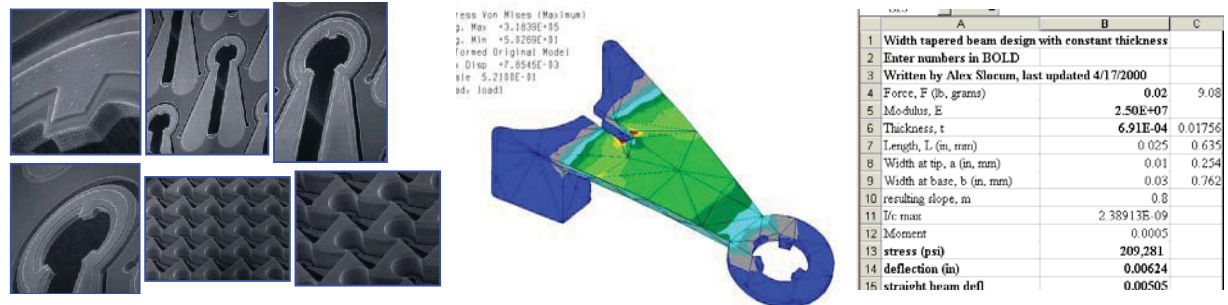
- The MOST critical thing you can do in a robot design contest, is study the scoring algorithm and determine which are the most sensitive parameters!

- This will direct your efforts for the development of strategies and concepts!



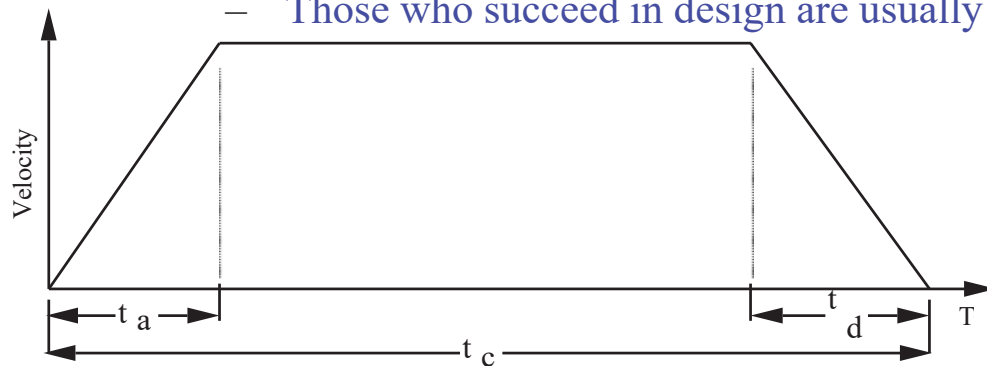
# Analysis: *Appropriate Analysis*

- Appropriate Analysis is a CRITICAL part of defining a problem's bounds and generating creative concepts!
  - If  $F = ma$  will answer the question, do NOT bother with relativity!
  - Spreadsheets, MATLAB, FEA....use whatever works best for you to yield an informative and insightful answer in the least amount of time
  - Remember to use analysis to design experiments, and experiments to answer questions when analysis is too difficult
    - If you spend your time pushing on a rope, you will buckle from the strain!
- “Back-of-the-envelope” calculations are a critical part of the early conceptual design phase!
  - Kinematic constraints
  - Beam stresses
  - Power required
  - Tractive force
  - Tipping angle
  - ...
- Too many designers put-off analysis until its too late. Detailed Analysis must be done prior to freezing the Design
- Always check your solutions to see if they pass the “Sanity Check”, using your Engineering Sense & Knowledge



# Analysis: Geometry, Time, & Motion

- The contest only lasts for N seconds, so do you have the time (and the power!) to do what is needed?
  - Maximum motor power is generated at 1/2 the motor's no-load speed!
- A simple spreadsheet can help answer these questions
- Check out *garmotor\_move.xls* and its discussion in Topic 7
  - Those who succeed in design are usually explorers...!



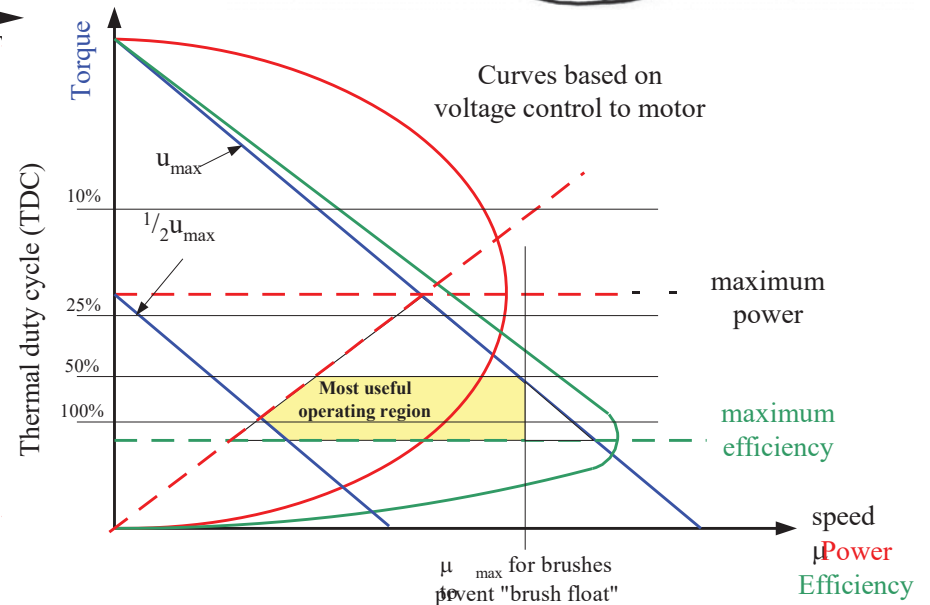
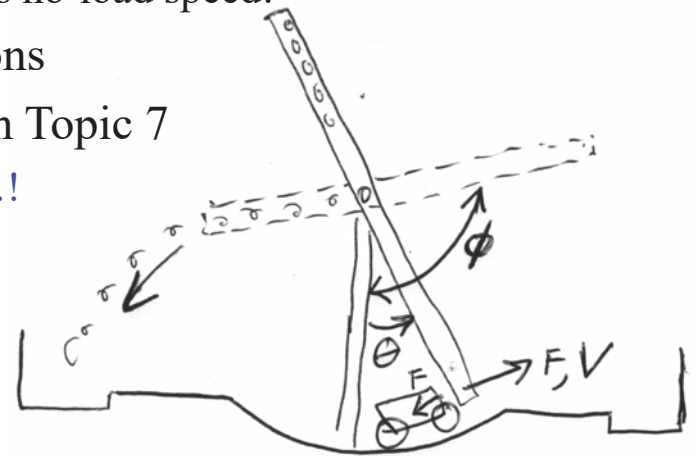
$$D = \frac{a_{\max}}{2} \left( \frac{t_c}{3} \right)^2 + \left( \frac{a_{\max} t_c}{3} \right) \left( \frac{2t_c}{3} \right) + \frac{a_{\max}}{2} \left( \frac{t_c}{3} \right)^2$$

$$a_{\max} = \frac{9D}{2t_c^2}, \text{ maximum acceleration (m/s}^2 \text{ or rad/s}^2\text{)}$$

$$v_{\max} = \frac{3D}{t_c}, \text{ maximum velocity (m/s or rad/s)}$$

$$X_{car} = F_{\max} \left\{ \frac{\lambda}{2} \frac{M}{s} + \frac{s}{M} t + \frac{1}{2!} \frac{s}{M} t^2 + \frac{1}{3!} \frac{s}{M} t^3 + \dots + \frac{1}{s^2} \frac{M}{s} t \right\}$$

$$X_{car} \text{ for } st/M \ll 1 \left\{ \frac{s}{F_{\max} M} \right\}^2 \left\{ t \sqrt{\frac{2MX_{car}}{F_{\max}}} \right\}$$

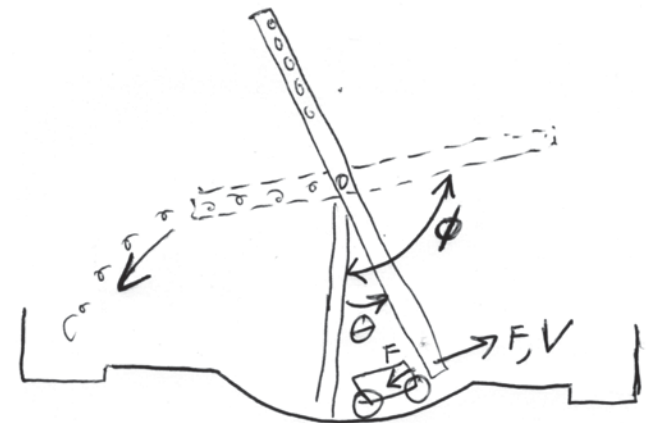
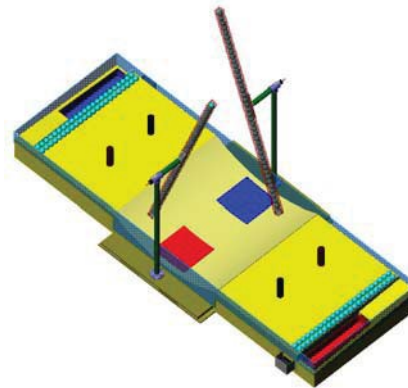
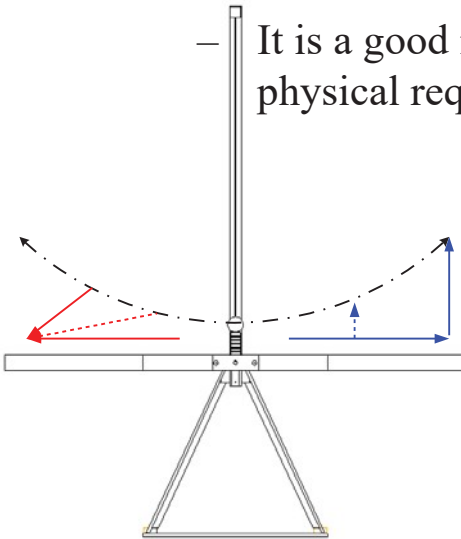




# Analysis: Energy, Momentum, Mass, & Strength

- 1<sup>st</sup> check for the feasibility of a design: Is available Power<sub>available</sub> > Power<sub>required</sub>?
  - Example: Can I raise the pendulum through a 30 degree arc in 1 second using energy stored in constant force springs?
    - $mgh < FL_{\text{extension}}$
- 2<sup>nd</sup> check for the feasibility of a design: Is  $\sigma_{\text{yeild}}$  > applied stress? i.e., is FOS > 1 ?
  - Example: Can I hold M kg extended out L m on a telescoping truss with H m cross section made from D mm welding rod?

- It is a good idea to be aware of the physical capabilities of the kit materials, and the physical requirements of the scoring methods...



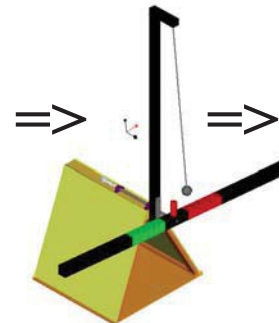
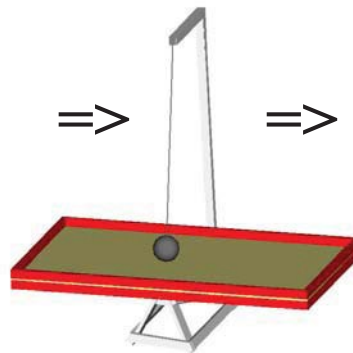
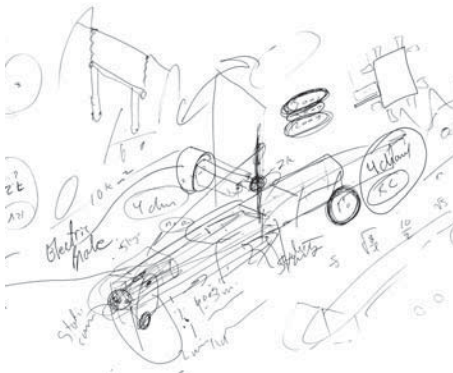
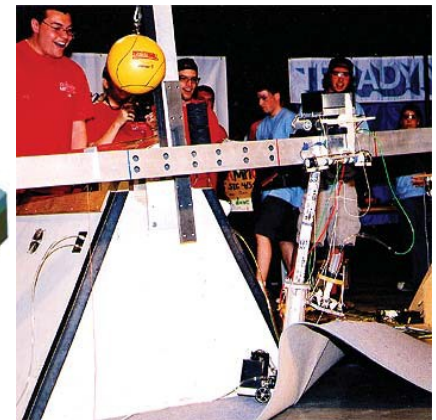
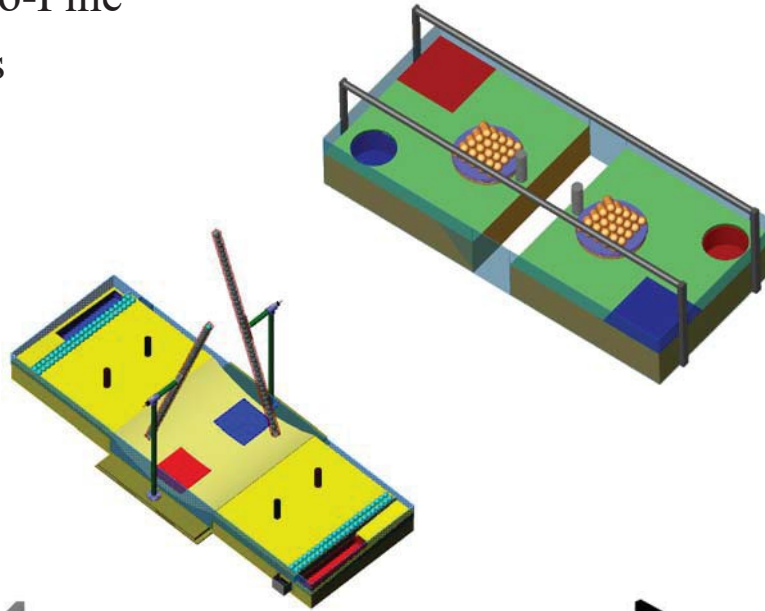
# Creating Ideas Concepting



*"Curiosity is one of the permanent and certain characteristics of a vigorous mind" – Samuel Johnson*

## Topics

- Creation: Coarse-to-Fine
- Thought Processes
- Experimentation
- Drawing
- Research
- Writing
- Analysis
- **Evolving Ideas**



# Evolving Systems

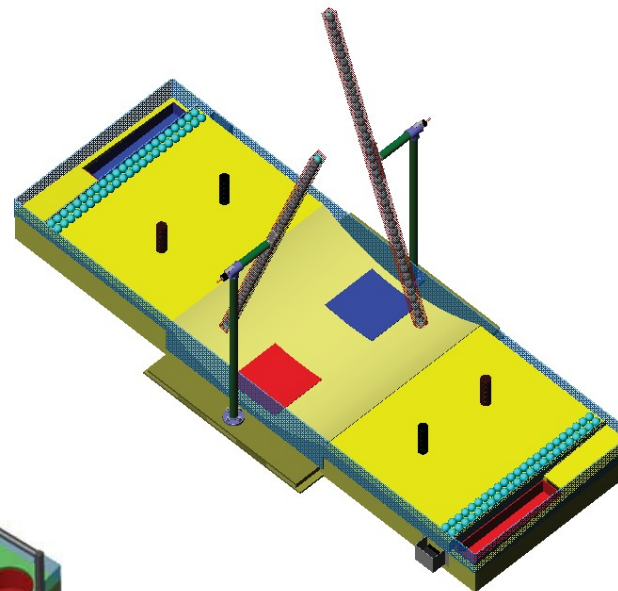
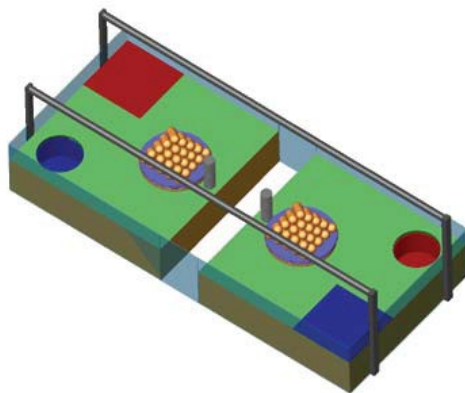
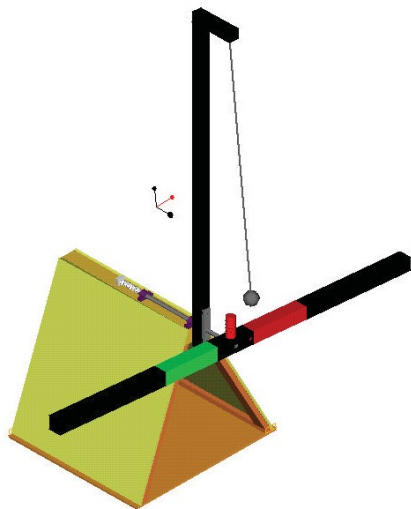
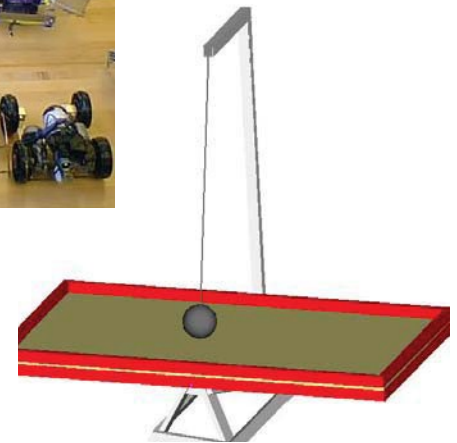
- Individual Thought
- Peer Review
- Brainstorming
- Comparing Designs



Colin Bulthap



1998's *Ballcano!*

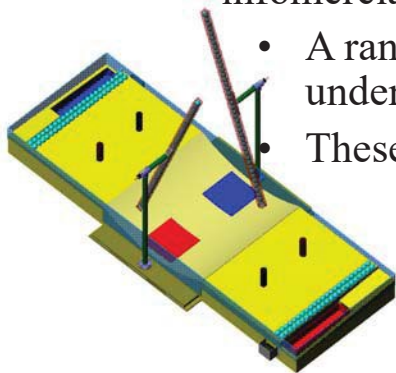




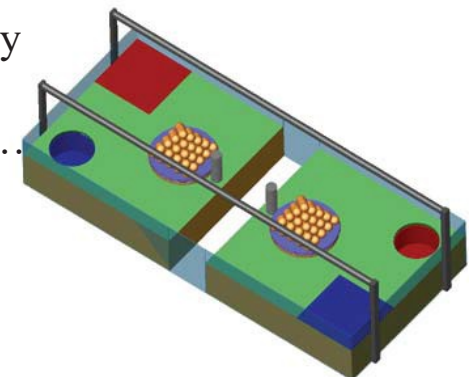
# Evolving Systems: *Individual Thought*



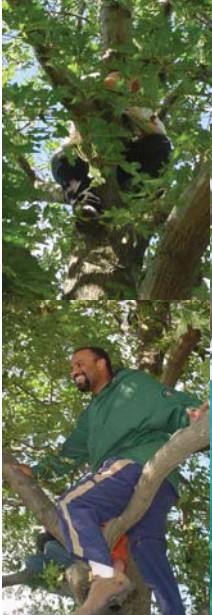
- Individual thought is often the most creative
  - Do leisurely things (e.g., long walks) that inspire creative thought
  - Look at what other people have created
    - Look in your home, stores, www, patents
  - Get out of traffic and take alternate routes
  - Sketch ideas and the ideas' principal components
  - Cut out the principal components and pretend they are modular elements
    - Like toy building blocks, try different combinations of components to make different products
  - Pit one idea against another and imagine strategies for winning
    - Take the best from different ideas and evolve them into the best 2 or 3 ideas
- Group Brainstorming is often the most effective for Concepting Alternatives
- Update the FRDPARRC table and create a *Milestone Report* or *Press Release* for your favorite ideas
  - The FRDPARCC Table (ONE DP per FR) and a large annotated sketch makes an effective infomercial



- A random person should be able to read your *press release* and fully understand your idea without your having to explain it to them
- These sheets will be shared with your teammates in the next stage...

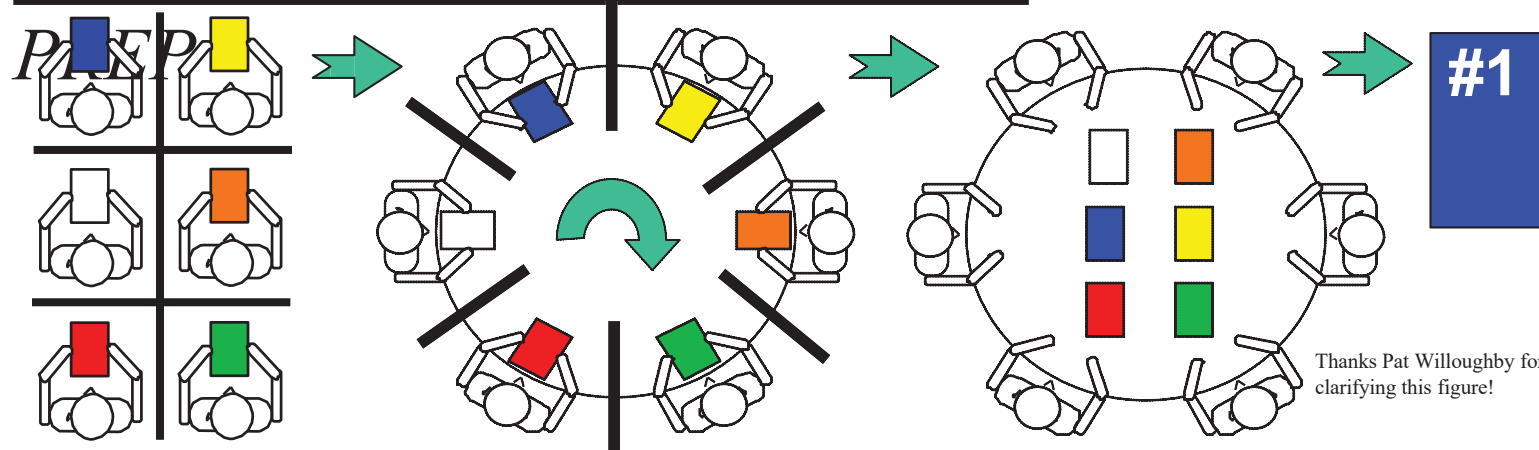






# Peer Review Evaluation Process:

***"Passion"***



- There is no such thing as just an individual/Teams are made up of individuals
- Any design process must make the best use of resources: *individuals* and *teams*:
  - Give individuals pride of ownership:
    - Privately (think & create on their own, AND constructively evaluate the work of others)
  - Maximize the efficiency and effectiveness of teams and reduce apathy:
    - Do not have brainstorming meetings unless everyone is PREPared
    - Individuals must have thought of ideas and reviewed each other's ideas beforehand
    - Peer pressure will help correct non-performers and nay-sayers and reduce apathy

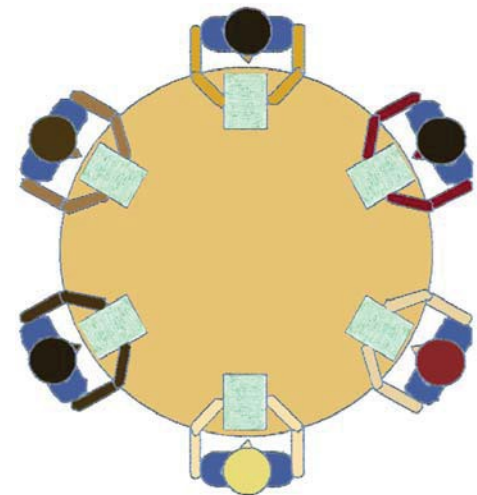
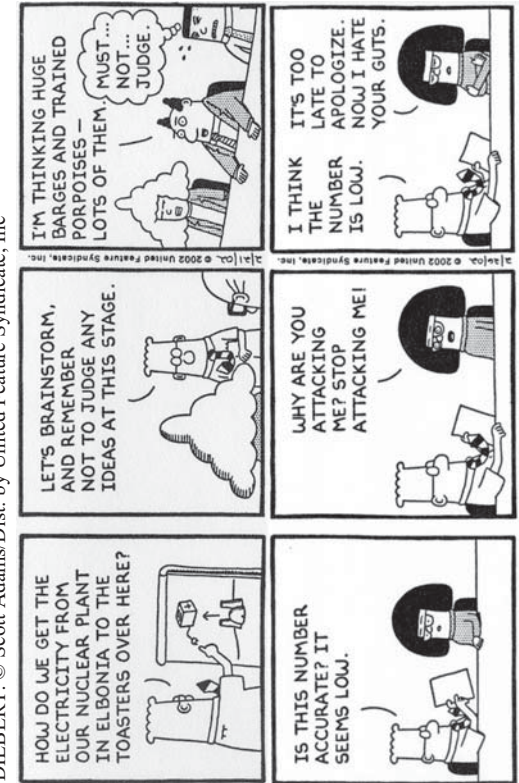
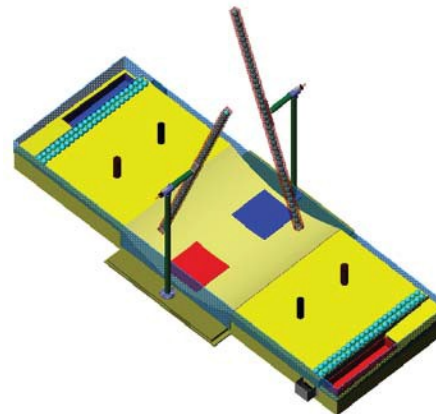
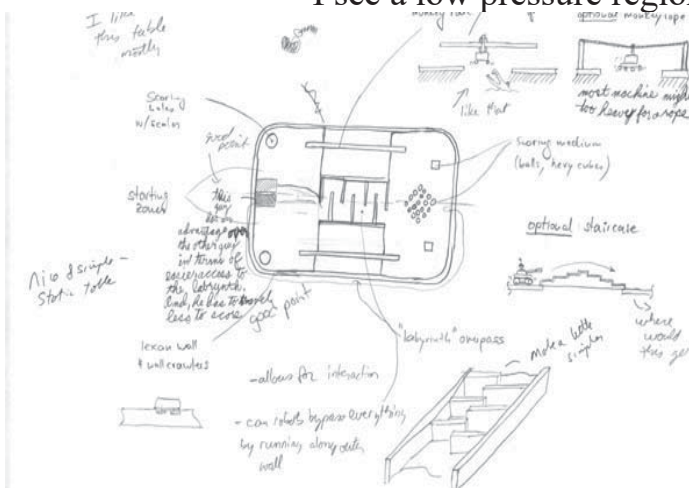


# Evolving Systems: Group Brainstorming

- Brainstorming helps teams solve personal creativity deadlocks and help to ensure something hasn't been overlooked
- Initially let everyone voice their suggestions, then distill ideas
- Group personality factors must be considered:
  - Shy individuals getting run over
  - Aggressive individuals always driving
- An individual's personality often has nothing to do with creativity
  - Careful to avoid conflicts over the issue of who first thought of the idea
  - The people in the group must be willing to take praise or scolding as a group
  - NO pure negatives, only observations with suggestions for improvement:

• “~~That design sucks!~~”

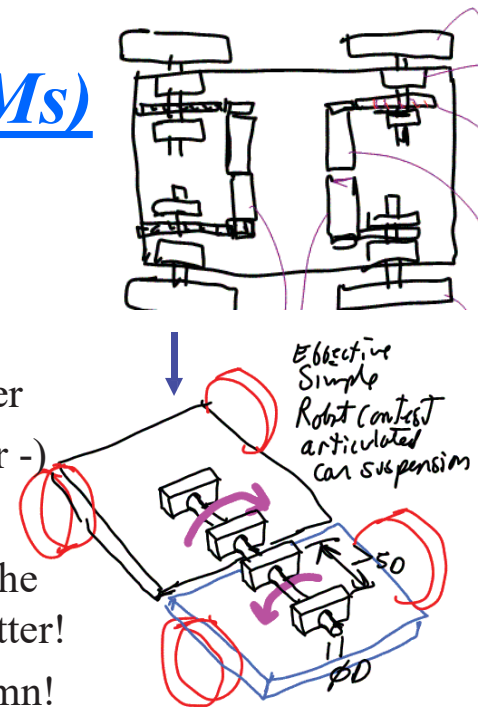
• “I see a low pressure region that can be alleviated by making it blue”



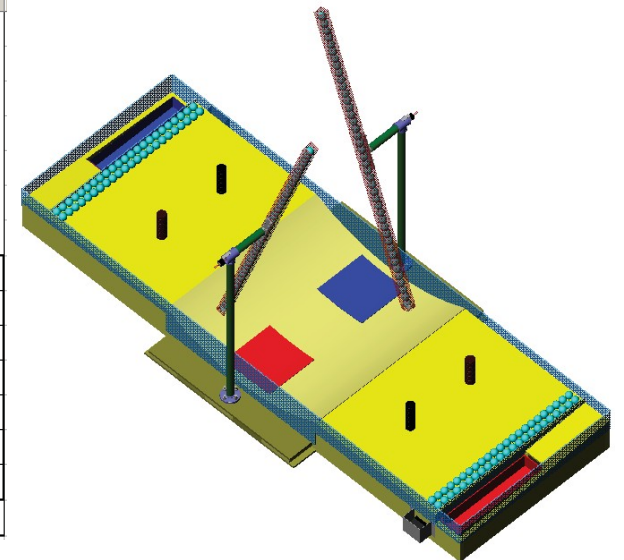


# Evolving Systems: Comparing Designs (DMMs)

- There are many methods available for evaluating design alternatives
  - The simplest method is a linear weighting scheme:
    - You may want to use the list of FRs as the evaluation parameters
      - Apply a relative importance weight to each evaluation parameter
    - Pick one design as a “baseline” (all zeros), and compare the rest (+ or -)
      - Easiest to use provided user bias can be minimized
    - When you find the “best” design, look at other designs and see how the + characteristics can be transferred to the “best” design to make it better!
  - A “Pugh” chart is similar, except that it does NOT use the weighting column!
    - A linear weighting scheme (+, -, 0 wrt a baseline design) will give equal weighting to attributes

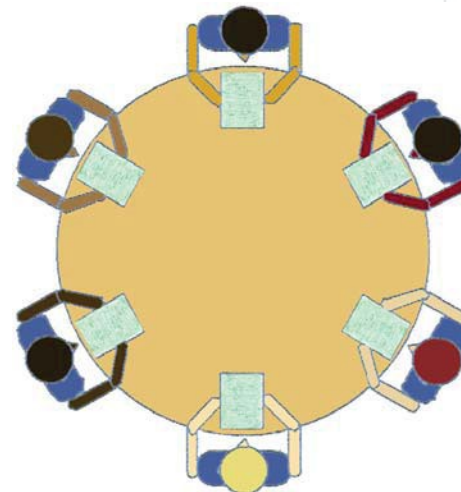
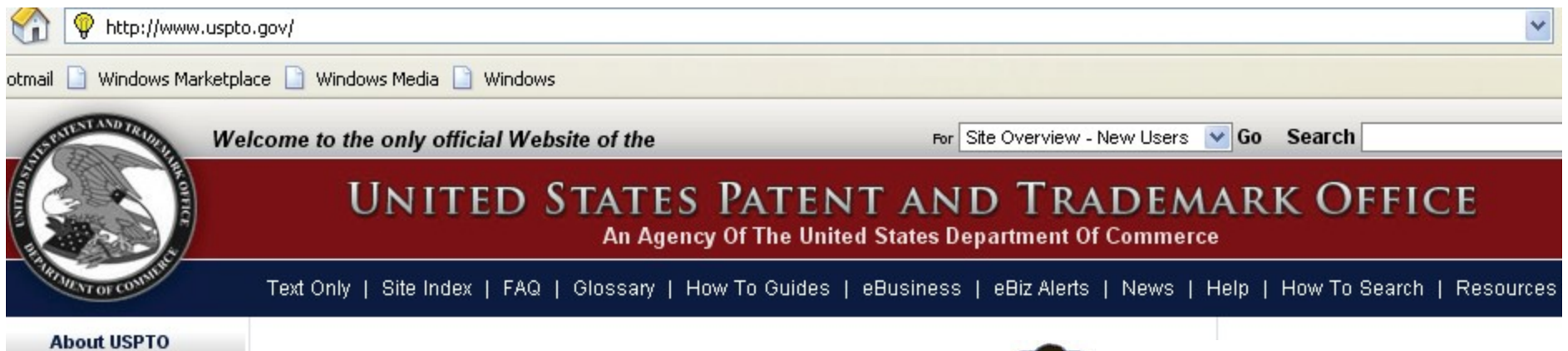


	A	B	C	D	E
1					
2					
3					
4					
5					
6					
7		Weight	Tilting Table	Peace Circle	Tilting Beam
8	Scoring variation	3	0	-1	0
9	Dynamic motions	2	0	0	1
10	Crowd appreciation	1	0	0	0
11	Manufacturability	1	0	1	0
12	Transportability	1	0	1	0
13	Scalability	2	0	0	0
14	Base for storage	1	0	1	0
15			0	0	2



# Intellectual Property

- [www.uspto.gov](http://www.uspto.gov) has lots of useful information, e.g.,:
  - Under the Paris Convention for the Protection of Industrial Property, a treaty that provides a number of important rights for innovators, a patent applicant may file an application in one Paris Convention member country (the priority document), and within 12 months, file corresponding applications in other member countries, while obtaining the benefit of the first application's filing date. This 12-month period allows applicants to make important decisions about where to file subsequent applications to seek protection for their inventions. Paris Convention filings are a critical component in many applicants' global business and patenting strategies and represent a substantial portion of worldwide patent activity.





# Professional & Personal Ethics and Moral Standards

- Professional ethics:
  - Work hard and try to help create an environment where others can also do their work
  - Practical jokes and humor at the expense of others are never in good taste
  - If you see a problem, try to offer help and do not turn a blind eye
  - Always try to offer constructive criticism: end each statement with a +
  - Document what you do, and if a problem is discovered, keep raising it until it is addressed.

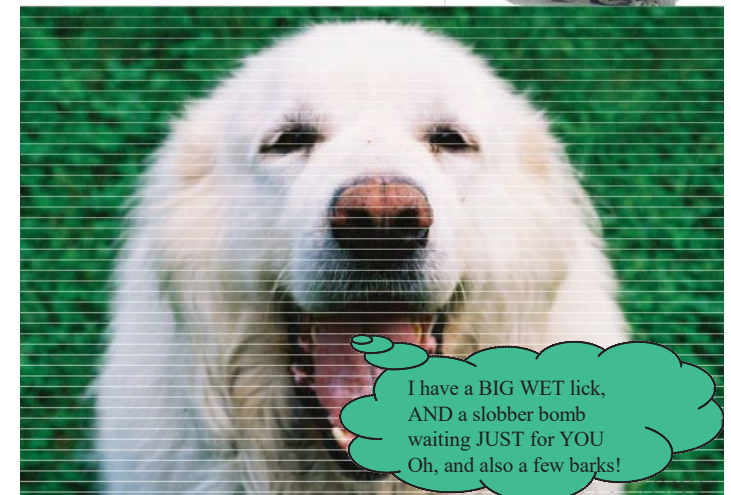


If you know who created this picture, please email [slocum@mit.edu](mailto:slocum@mit.edu) so appropriate credit can be given

- Personal ethics and Moral Standards
  - Assume what you do and your name will be on the front page of the newspaper...
  - Treat others with the same respect as you would like to receive
    - Brush your teeth, beware others' personal space...
  - Romance in the office can work, but ask what will happen if it ends...
    - Be discrete, perhaps ask a friend to enquire...NO means NO!
      - There should be no direct supervisory role, and not working on the same project
        - » Check company policy and tell your boss ASAP!

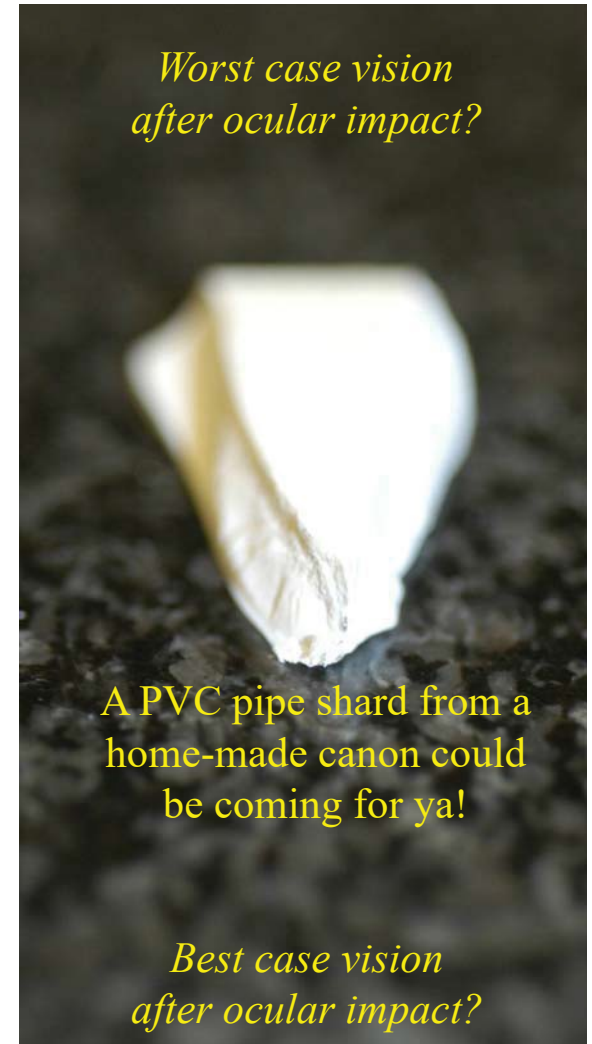


Look for happiness all around,  
and if you do not find it, create it!



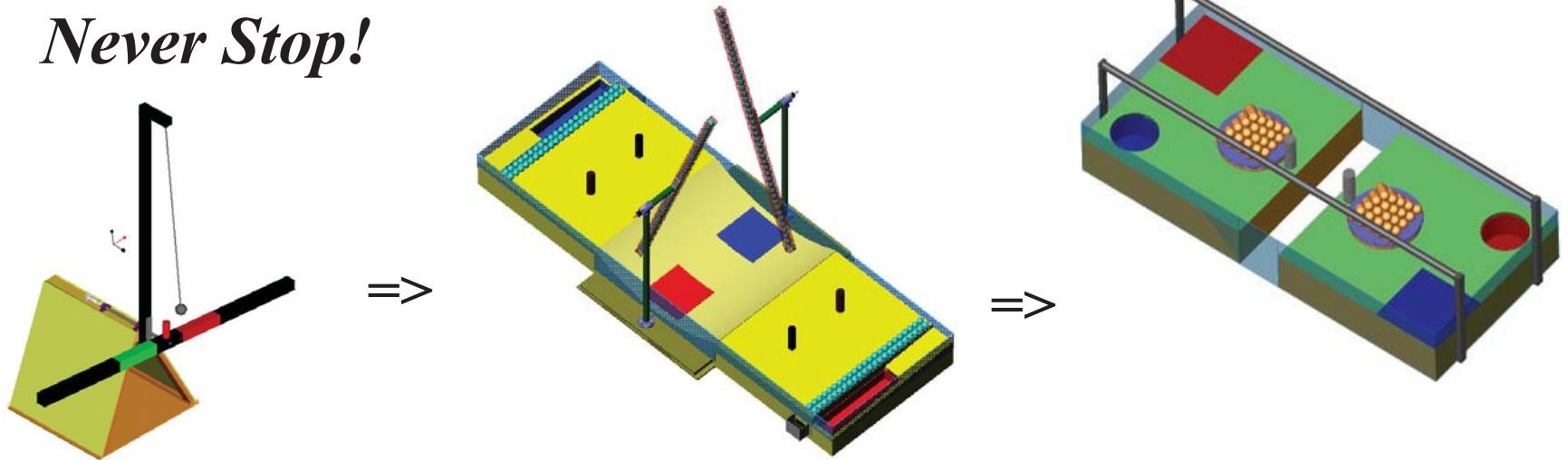
# Safety

- It should be obvious:
  - WEAR EYE AND EAR PROTECTION!
  - We each only have one set of body parts and one life to live
  - We all need to look out for each other
- The RISK column of FRDPARRC is also used to identify potential safety issues
- Humans are often defensive, and people will often make up what sounds like a reasonable excuse to justify their poor decision
  - It starts with kids:
    - “Dude, isn’t it dangerous to hold the pipe and fill it with match heads?”
    - “Nah, if the match heads start to go off, I will just throw the pipe away before it explodes”
  - It does not always end with adults:
    - “I am going to help my kid and his friends build a PVC potato canon like they saw on TV”
- Do for others as you would have them do for you

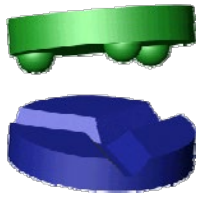


## Evolution: *It Never Stops*

- Physically experimenting with the hardware while thinking about all possible variations can produce many creative ideas
  - Sketching, drawing, and solid modeling are powerful creativity catalysts
  - Much has been done by others: Learn from others' failures and successes
  - Writing down your thoughts and dreams can help you to see solutions
  - Analysis can identify areas of high (low) sensitivity and rapidly ascertain feasibility
  - Ideas can evolve rapidly when they are compared to others
- *Stay Psyched and Passionate!*
- *Never Stop!*







# Deterministic Design: *Disruptive Technologies*

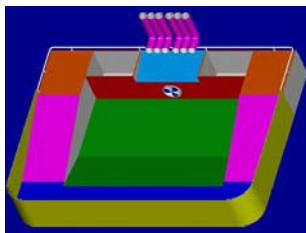


Hyoseok Yang



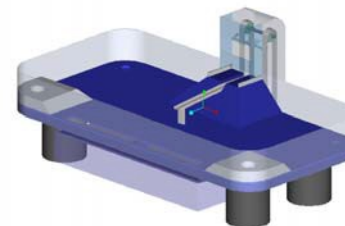
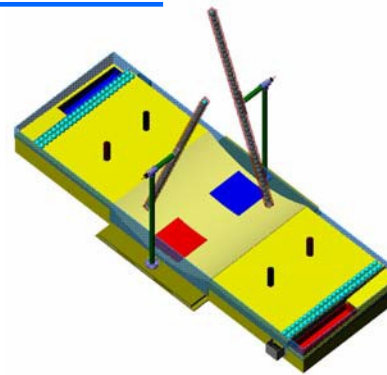
1995's *Pebble Beach!*

Sami Busch

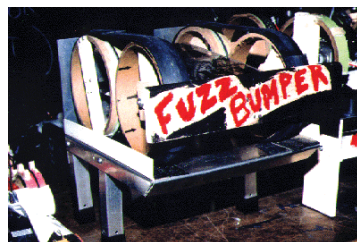


1996's *Niagara Balls!*

- Analysis is the lens which brings a problem into focus and lets you clearly see the best return on your investment
  - Value analysis of scoring methods
  - Physics of scoring methods
  - Risk analysis
  - Schedule analysis



Tim Zue



1997's *Pass The Puck!*

Colin Bulthap



1998's *Ballcano!*

Will Delhagen & Alex Jacobs



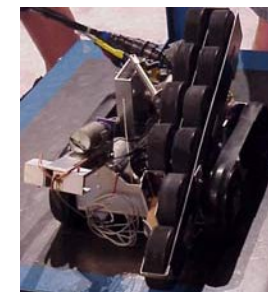
2001's *Tiltulator!*

Kevin Lang



2000's *Sojourner This!*

David Arguellis



1999's *MechEverest!*