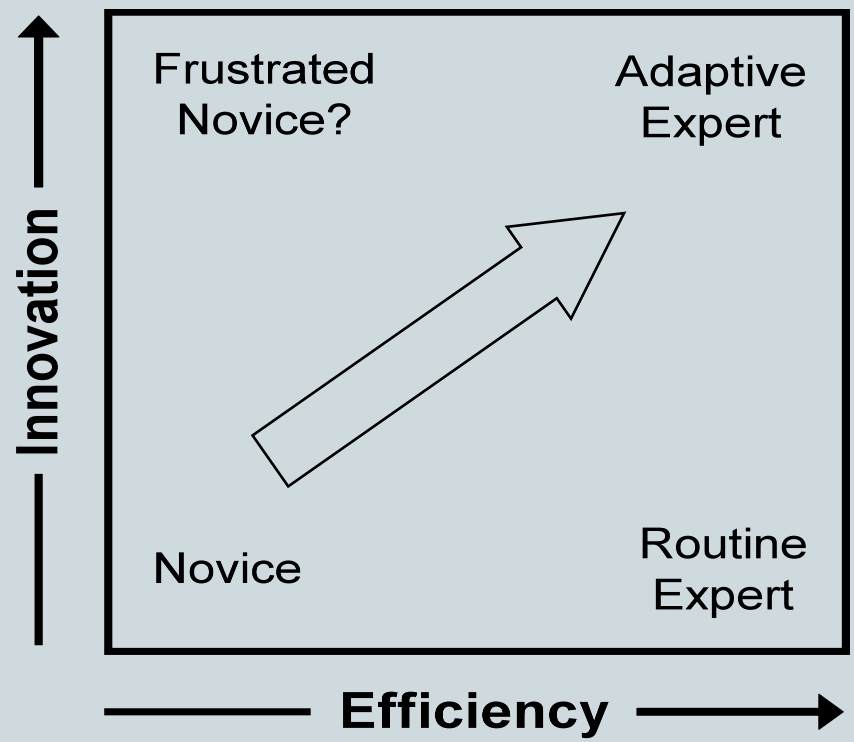
Knowledge Fluency in Design and Innovation

ANN F. MCKENNA

ARIZONA STATE UNIVERSITY
ENGINEERING EDUCATION GROUP
OCTOBER 22, 2010

Adaptive Expertise Framework



Schwartz, D.L., Bransford, J.D., and Sears, D., 2005, “Efficiency and Innovation in Transfer,” In Jose Mestre, *Transfer Of Learning: Research and Perspectives*, Information Age Publishing Inc., pp. 1-51.

Characteristics of Innovation and Efficiency

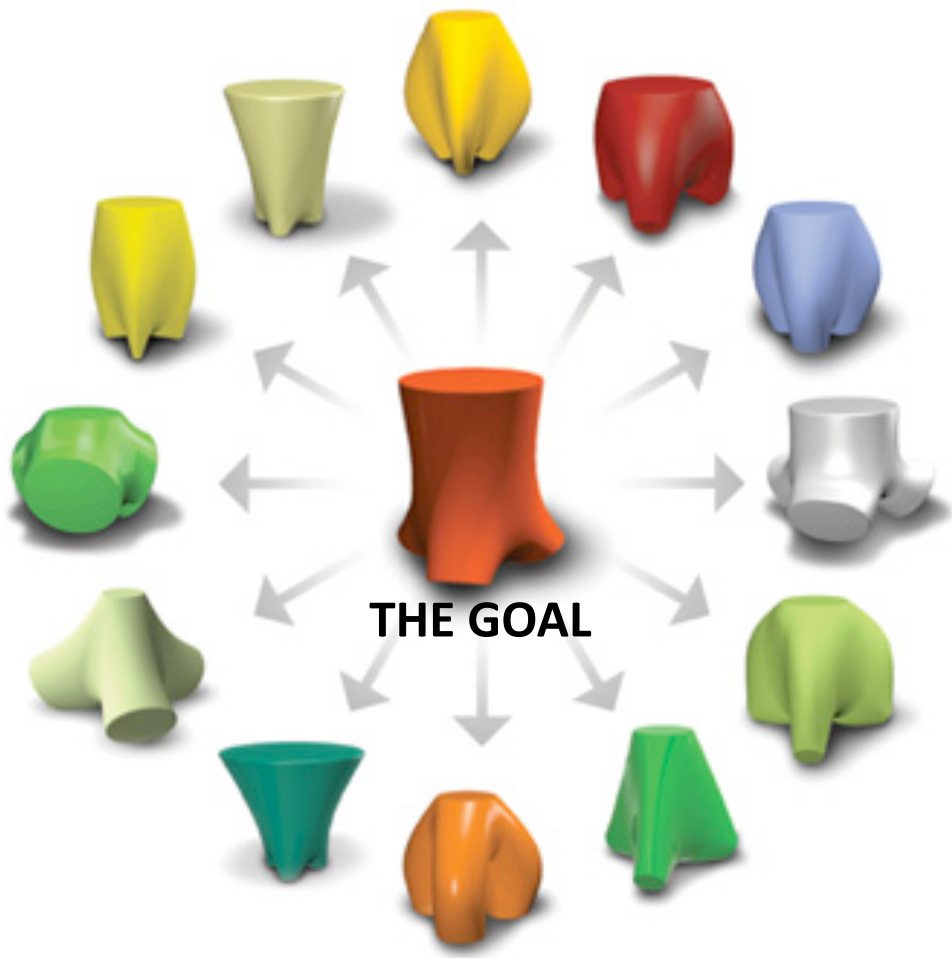
<u>Efficiency</u>

•emphasis on repeating behaviors for speed and accuracy
•can fluently apply knowledge and skills to complete activities one has significant experience performing
•have well organized knowledge structure

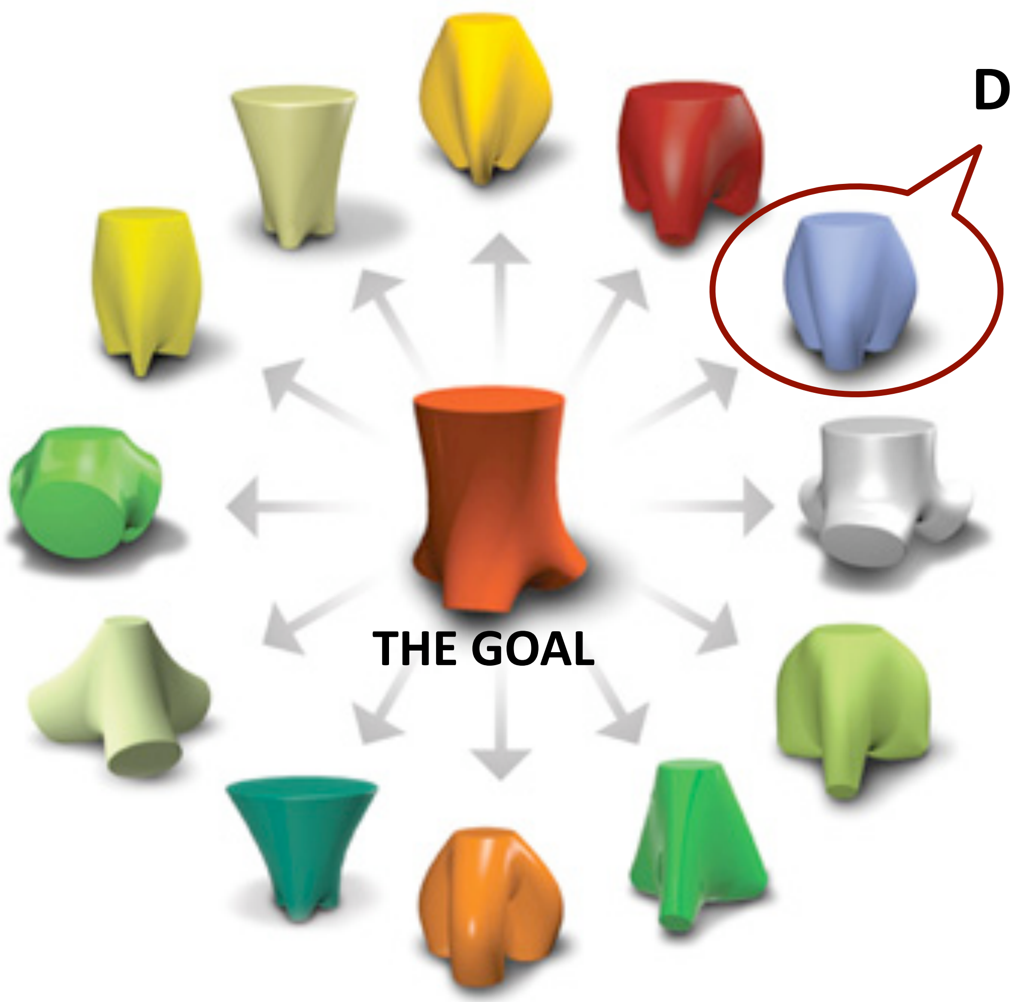
<u>Innovation</u>

•involves reaching beyond the immediately known
•possess a willingness to move away from being efficient and to challenge the status quo
•generate new knowledge that is useful for achieving a novel goal

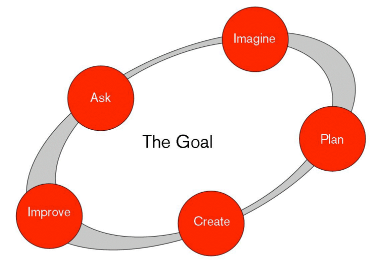
Efficiency in the context of engineering design: what are the components?



Efficiency in the context of engineering design: a starting point



Design Process Knowledge



- Identify need
- Generate ideas
- Build mock-up/prototype
- Perform user testing
- etc…

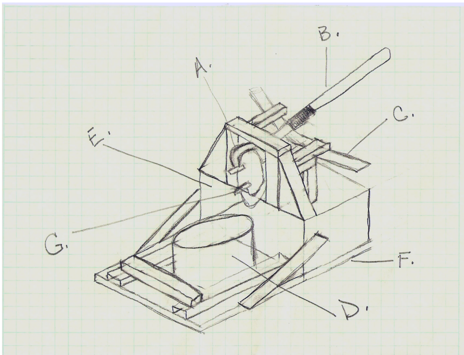
Context for design: example project

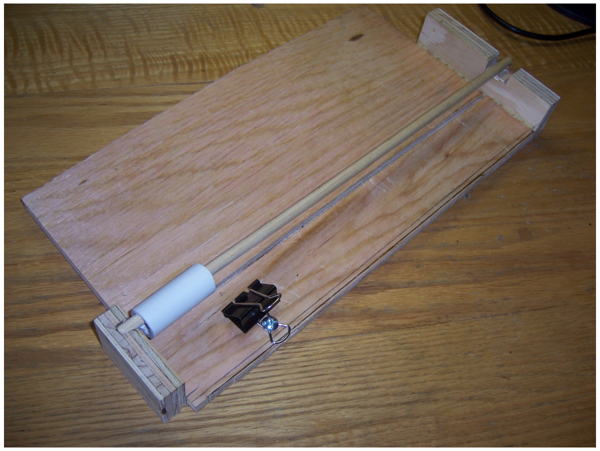
Client: Rehabilitation Institute of Chicago

Create a one-handed device that would open a snack bag

user observations

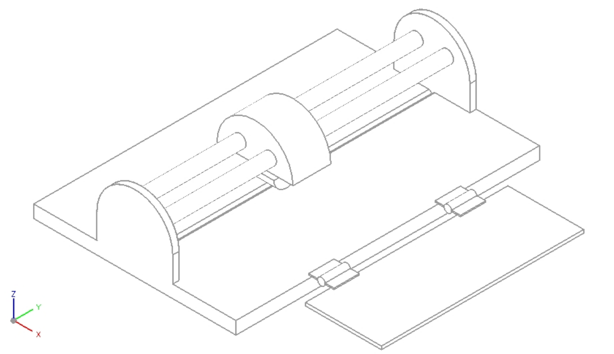
idea generation/sketching





building prototypes

modeling



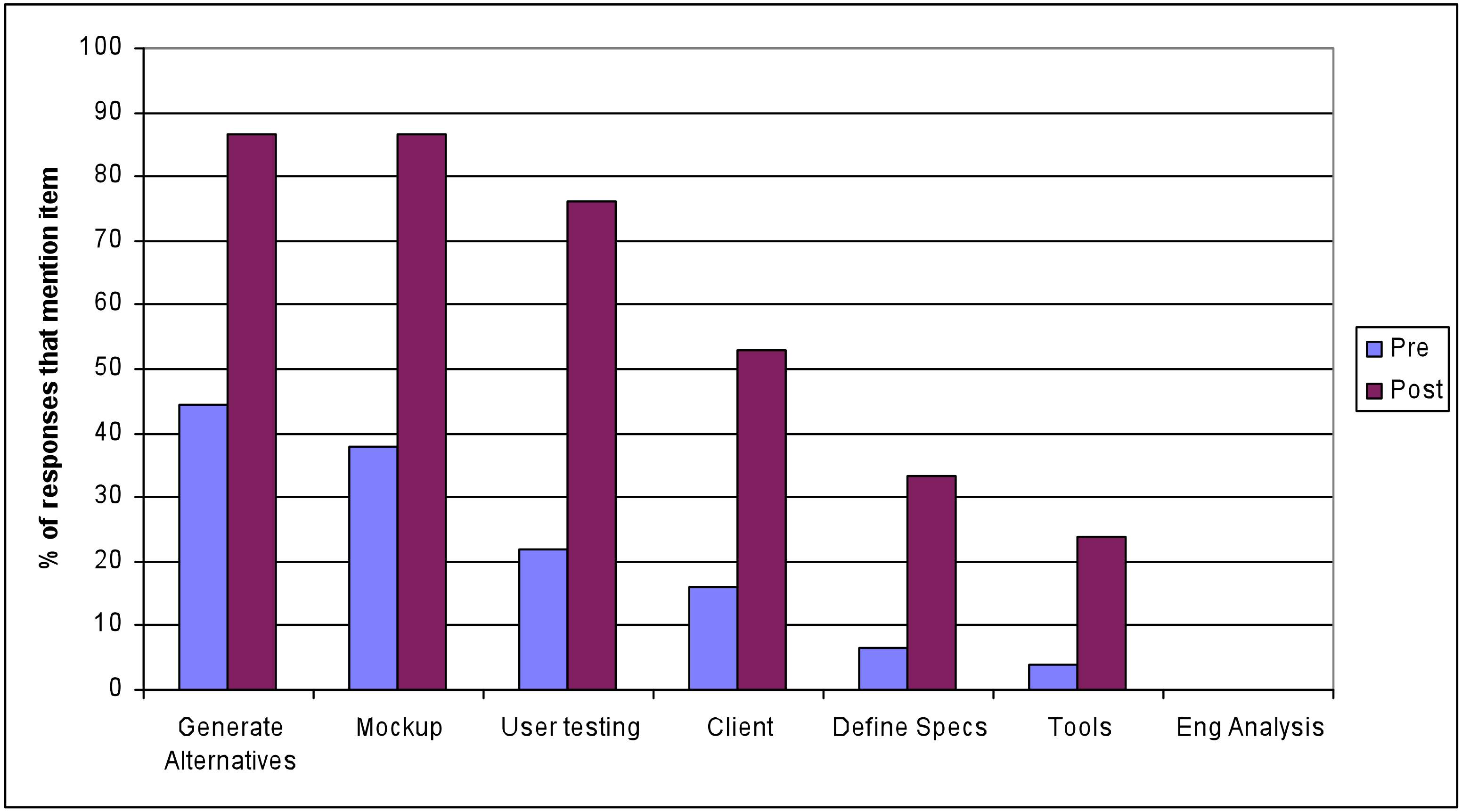
user testing

Design scenario data collection

- Assume that you are on a design team that has been hired by the Rehabilitation Institute of Chicago to design a new device to help stroke patients open doors. Many individuals who have had a stroke are unable to perform bilateral tasks, meaning they have limited or no use of one upper extremity (arm/shoulder). It is particularly difficult for these people not only to unlock and turn the knob, but also to push/pull the door open. Your design team has been asked to create a system that allows a person to unlock and open the door at the same time with one hand.

- Your design team accepts this challenge and goes to work. Map out a plan, describing how you intend to approach this project.

Results from 1st Year Course: Design Process Knowledge

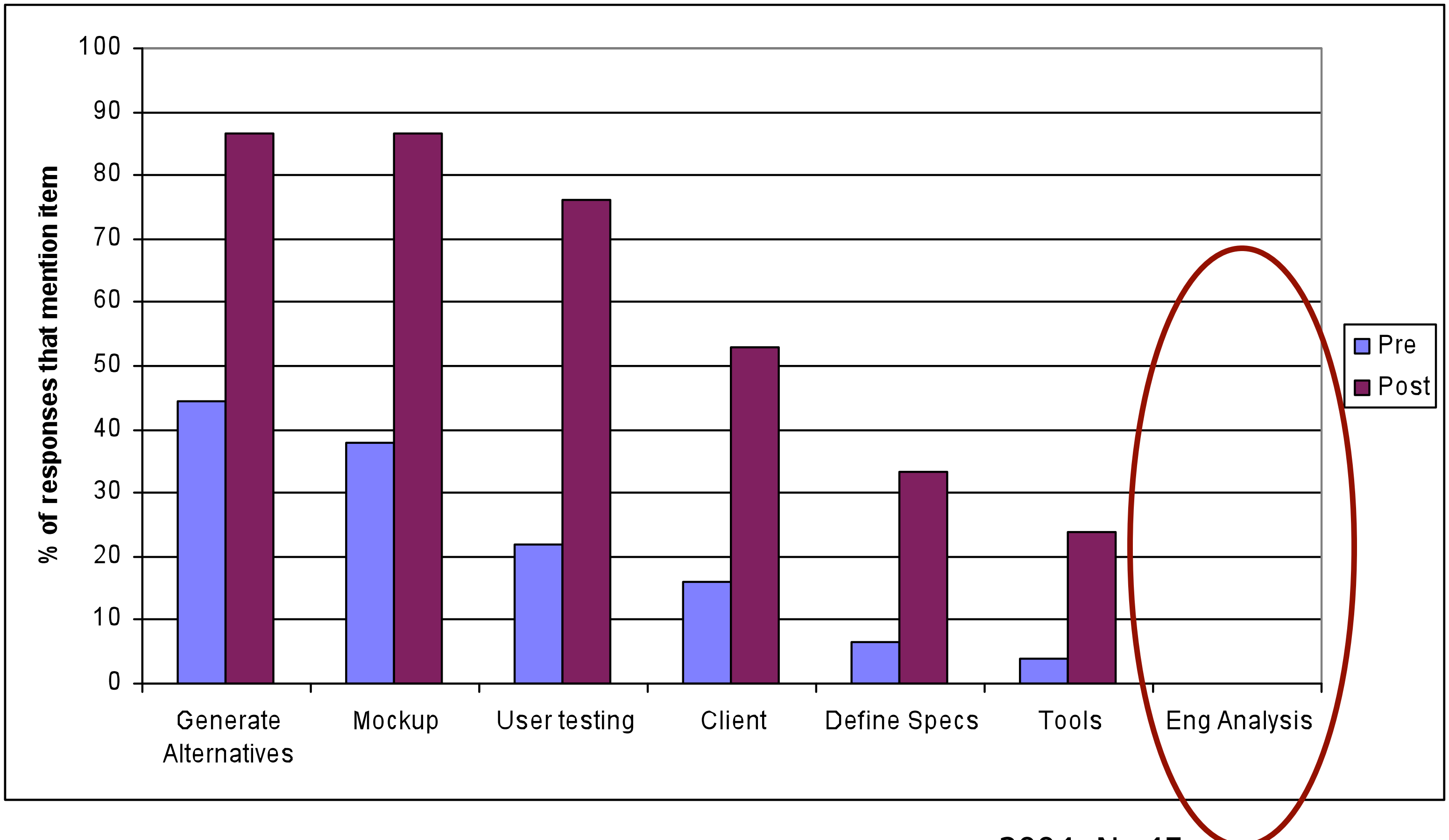


2004, N=45
All items stat. sig. at $p<0.01$ level

Data also show a shift in students' focus

	Emphasis	Example Response
PRE	*Solution-* focused	First, the **product would probably not sell** because many stroke patients usually retain the use of one side of their body…second, **this is a bad question** because it does not specify the type of lock…the **easiest but most expensive solution** would be to alter a pre-existing mechanism to open when unlocked…the **most economical way would** be to add a handle to the doorknob so that it would turn more easily because of torque…
POST	*Process-* focused	First my team would go down to the RIC and **conduct an interview of the client**…we would **watch the users**…we would **do research** and see if there are any existing products... Next, we would do a **brainstorming session**… we would cut down the ideas by using an **alternatives matrix**. The team would **create mock-ups**…to be used in **user testing.** After watching the users, the team would **re-evaluate the alternatives**, make changes to them, and then do more user testing. Based off of the user testing and client feedback the **team would choose a design direction and build a prototype**…

Results from 1st Year Course: Design Process Knowledge



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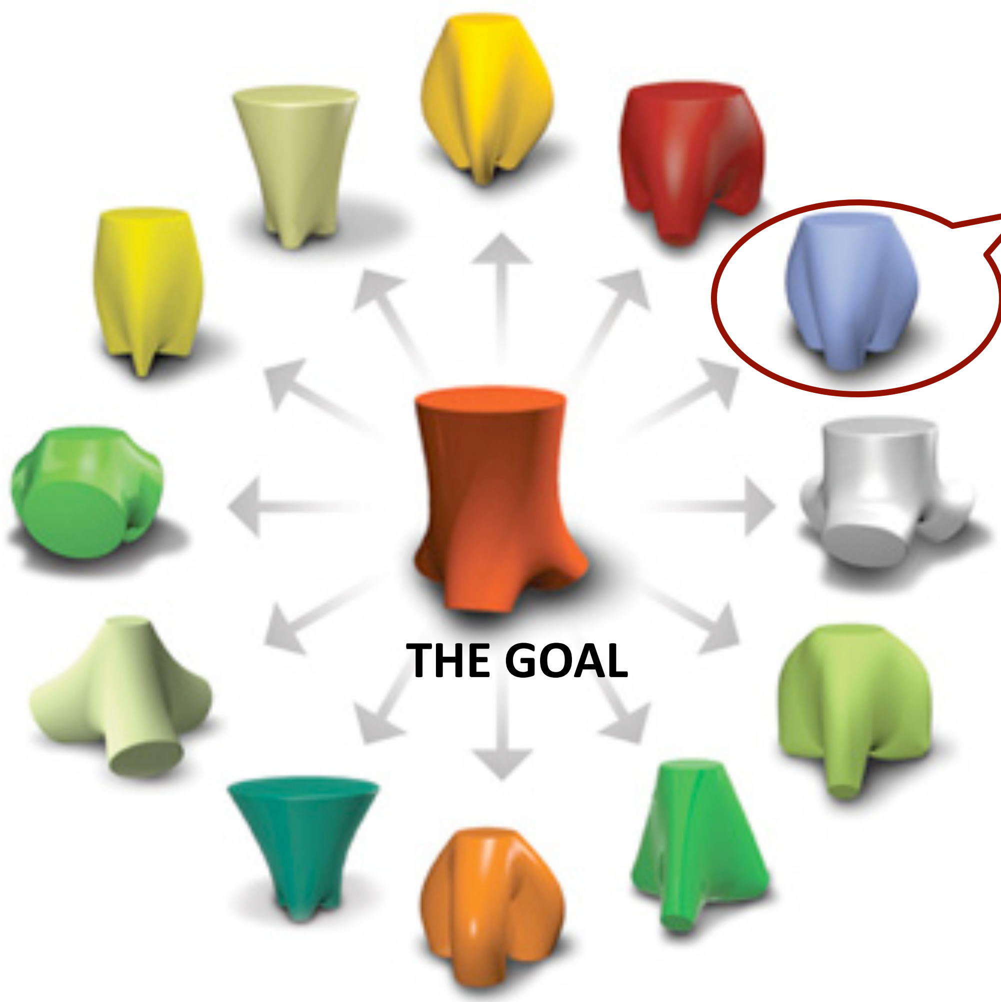
Efficiency in the context of engineering design: a starting point

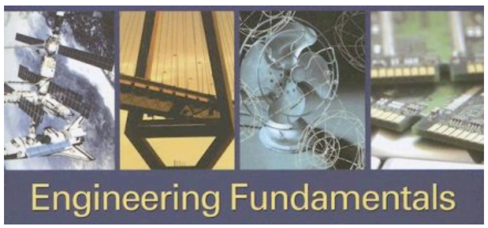


Design Process Knowledge

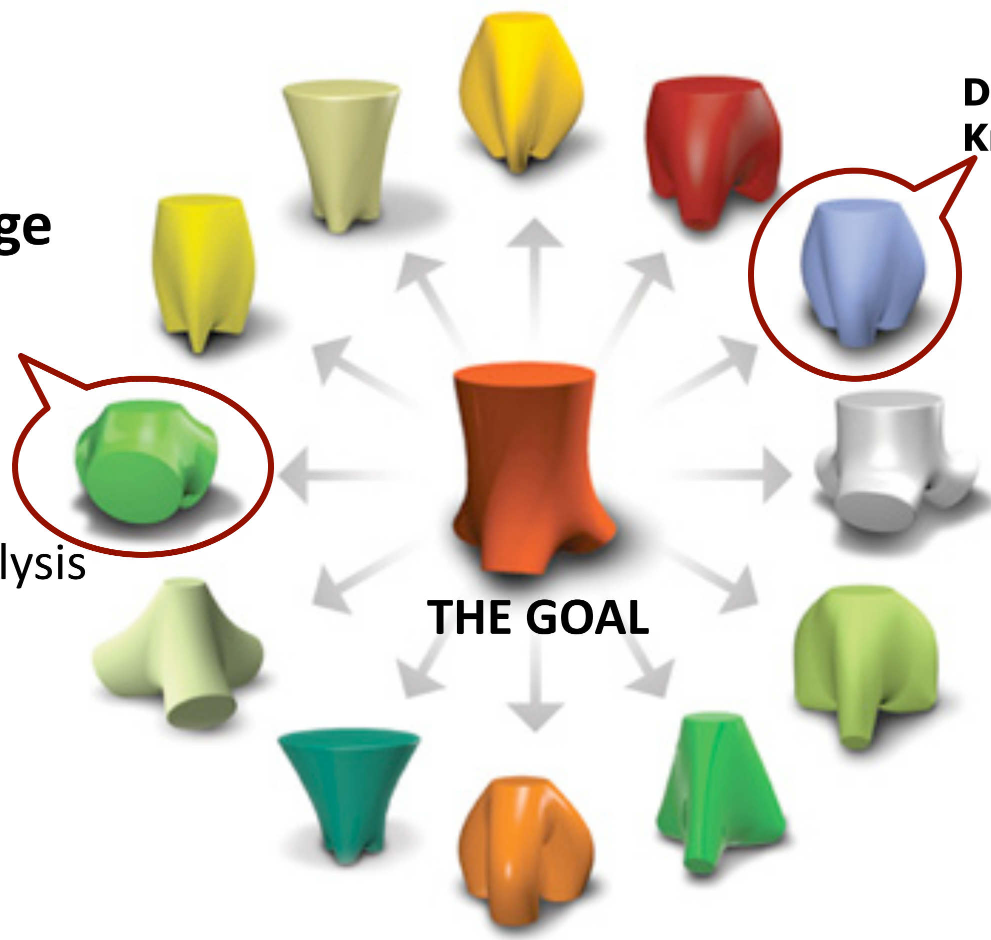
- Identify need
- Generate ideas
- Build mock-up/prototype
- Perform user testing
- etc…

Efficiency in the context of engineering design: adding more detail

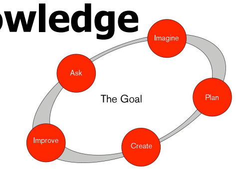
Disciplinary Knowledge



- Perform engineering analysis
- Make approximations
- Simulate/model
- Experiment and test
- etc…



Design Process Knowledge



How can students be more innovative with their disciplinary knowledge when developing design solutions?

Observations that motivate study

- From many years of experience teaching design we find students…
  - Develop an appropriate fluency in design process knowledge
  - Enjoy the early phases of the design process such as user observation and idea generation but resist the more technically sophisticated aspects of design
  - Have difficulty recognizing when disciplinary knowledge applies
  - Struggle with *translating physical world into models* appropriate for engineering analysis

Computational Adaptive Expertise (CADEX): Working Definition

- How one flexibly uses computational/analytic knowledge in novel situations. CADEX includes…
  - Making appropriate approximations
  - Using strategies for translating the physical world into models appropriate for engineering analysis
  - Setting up models and experiments with appropriate boundaries, dimensions, etc.
  - Interpreting results of calculations and making reasonable conclusions

What do students perceive as disciplinary knowledge?

What are the technical details that design projects should address?

% of items mentioned that fall into each category N=41

Business	Design Process	Users and Environment	CADEX	Other
12%	**12%**	**19%**	**39%**	**19%**
Cost analysis	Clear statement of the problem	Details about the environment the device will be used	Alternatives analysis	Contamination issues
Market analysis	Constraints	User testing results	Apply eng analysis	Issues associated w/ medication
	Anticipated risks, pitfalls, failures	Users and stakeholders	Define specs	Size and dimensions of object
		Training materials	Experimental/ empirical data	Durability
		Safety	Energy supply/power analysis	Estimated life of device
		Assembly instructions	Modeling of phenomena	Restrictions of codes
			Quantify requirements	Material selection
			Review current technology	

Findings

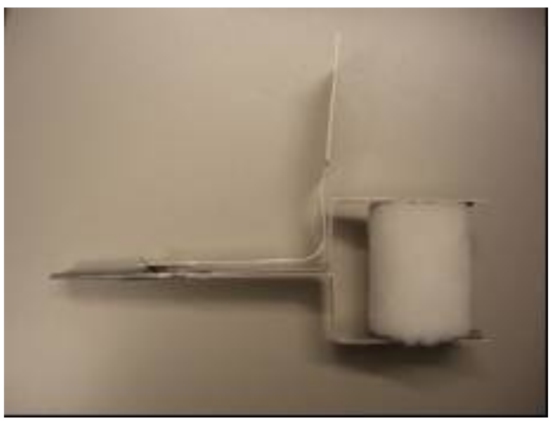
- Students do notice the role that CADEX plays in developing design solutions
- However, students conceive of “technical” as much broader
  - Indicates the complexity of knowledge required in design

How do students use disciplinary knowledge in design?

What **evidence** do students use to support design decisions?

Identifying Design Decisions

- Decisions made from available design alternatives that have been evaluated against a set of design criteria[1]
- Used language cues ("we selected", "was chosen", ...)

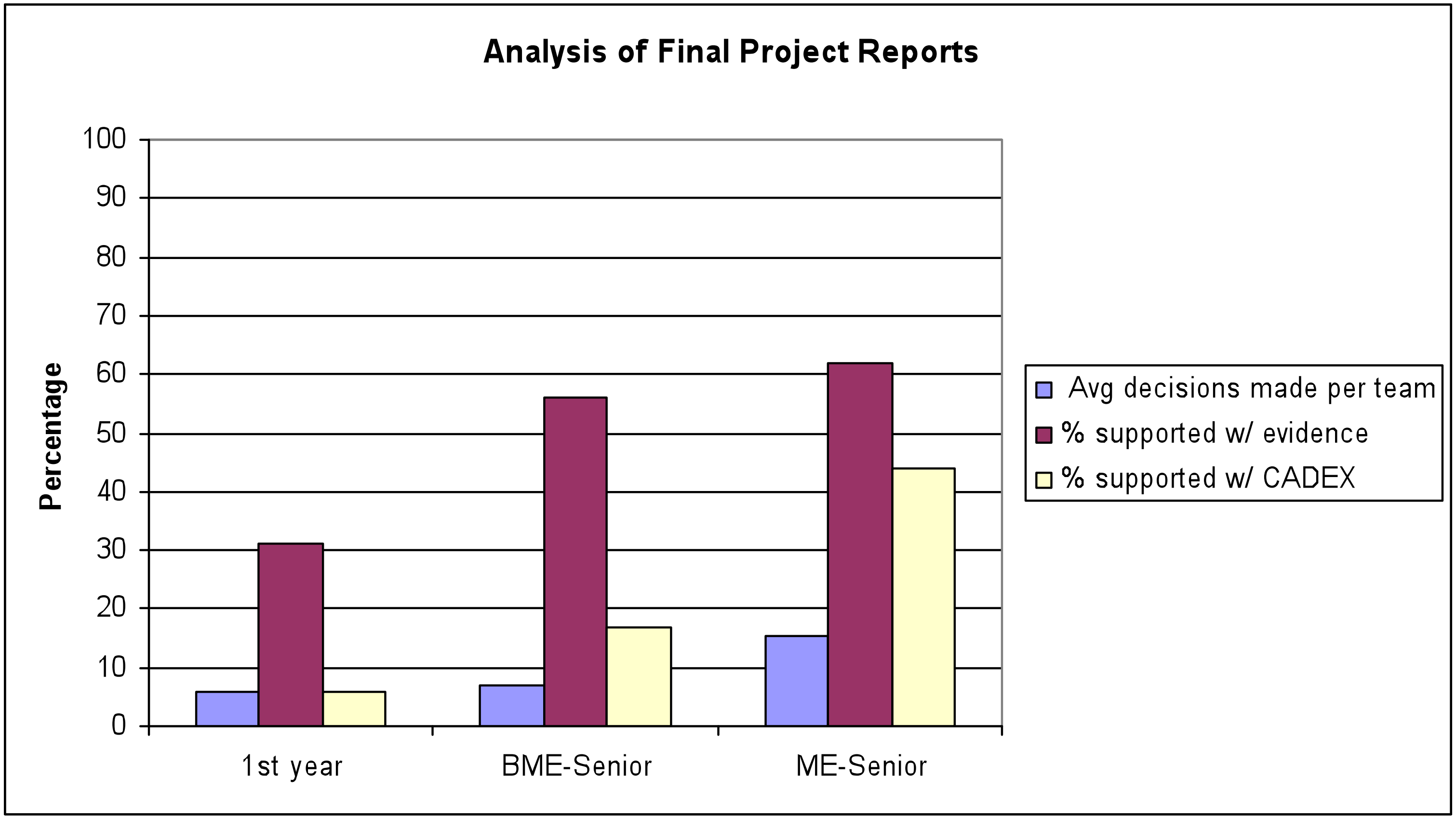


We decided to forgo the Y-release mechanism in Design A for the current quick release mechanism on Design B. The Y-release would have consisted of a complex system of springs, cables, and pulleys….

*(**Paint Roller Trim Tool**, ME Senior Design WQ2008)*

1. Beheshti, R., "Design Decisions and Uncertainty." *Design Studies*, 1993. **14**(1): p. 85-95.

What **evidence** do students use to support design decisions?



Report N
1st yr = 10
BME = 9
ME = 5

Some findings

- Average number of decisions per team is small
- Nature of evidence project-dependent
- Distinction between evidence and “convincing evidence”
  - chose the shape because of its “aesthetic value”
  - chose a frame material because it is “lightweight”
  - “selected material for its large tensile strength” but values not reported anywhere

Next phase of study: unpack "disciplinary knowledge" to focus on CADEX

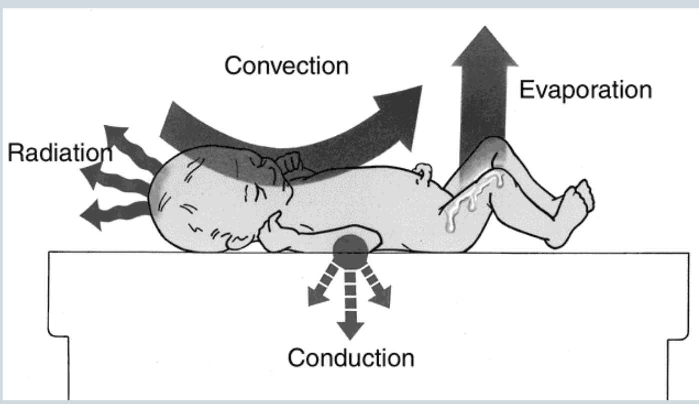
Focus on mathematical modeling

- What is the nature of students' ability to generate mathematical models in the process of design and innovation?
  - Emphasis on "quantitative literacy" i.e. not only the ability to develop models but to effectively use them in the decision making process

Data collection: BME capstone design, Fall 2009 and Fall 2010

Client: World Health Organization

Develop a system to supply appropriate medical care to low birth weight infants while operating under the unique challenges found in developing countries



CADEX-related issues
- Thermoregulation
- Ventilation
- Noise control
- Infection resistance
- Power source

Starting point: How might we characterize mathematical modeling?

Gainsburg Framework:

- Identify the real-world phenomenon
- Simplify or idealize the phenomenon
- Express the idealized phenomenon mathematically (i.e., "mathematize")
- Perform the mathematical manipulations (i.e., "solve" the model)
- Interpret the mathematical solution in real-world terms
- Test the interpretation against reality

Gainsburg, J., 2006, "The Mathematical Modeling of Structural Engineers." *Mathematical Thinking and Learning*, **8**(1): p. 3-36.

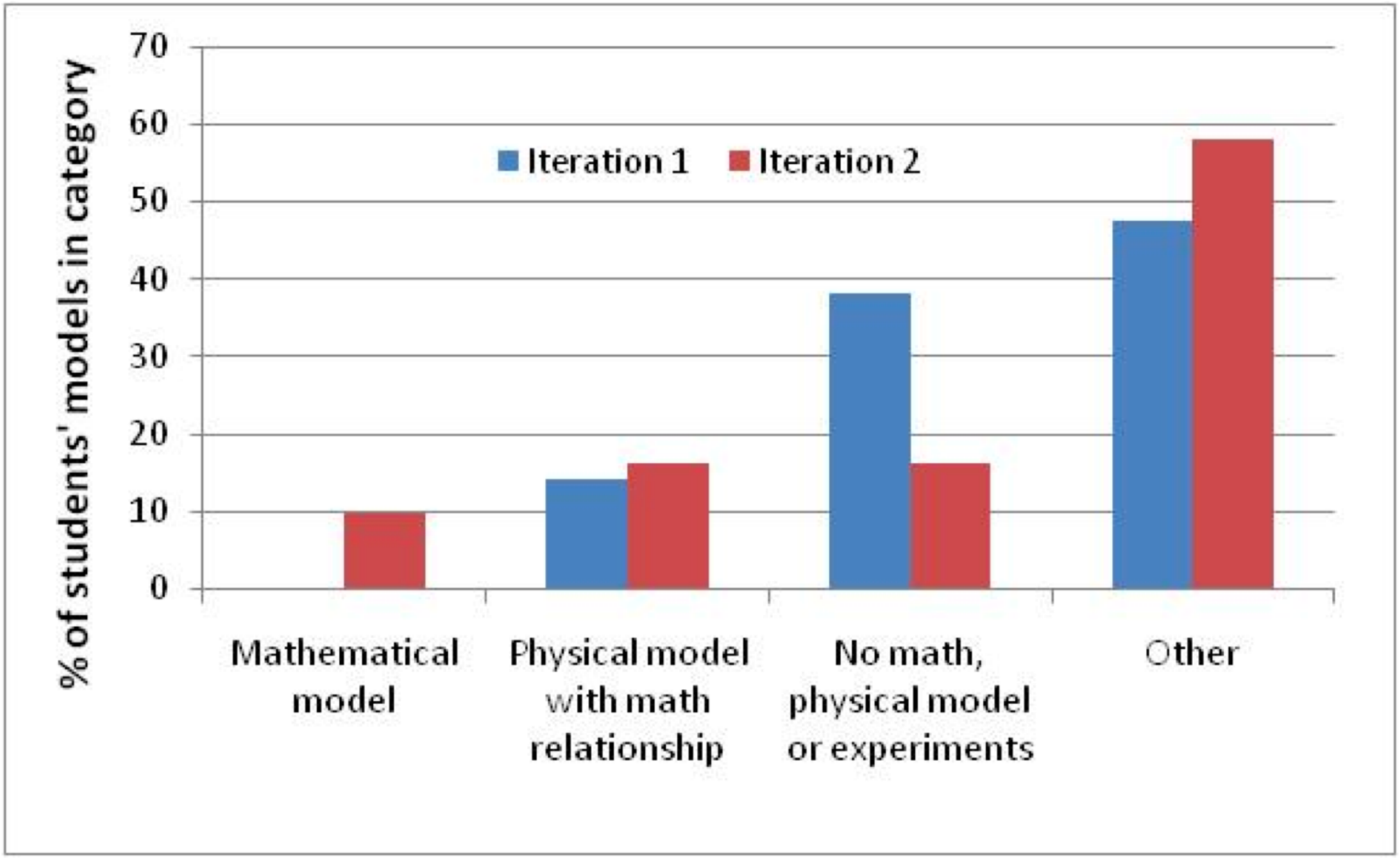
Used design scenario with a four stage implementation strategy

- Design a phototherapy device to treat jaundice that is compatible with Kangaroo Mother Care (KMC) for premature infants in the developing world
  - Iteration 1: “what do you think should be modeled, and how do you expect the model to eventually be helpful in the design.”
  - Iteration 2: sketch the system, list relevant parameters and variables, give reasons for why those parameters are important to the creation of the model, note any relationships between parameters, etc.

Iterations 3 and 4

- Iteration 3: find the equations and list the assumptions that would be useful to create the model, manipulate the equations.
- Iteration 4: students provided a model to critique

Mathematical modeling behavior…some preliminary findings



Current phase: unpack "modeling"

Everyday use…

- display version of something, i.e. fashion models
- a miniaturization of something, i.e. model boat

Engineering uses…for the purpose of description and prediction

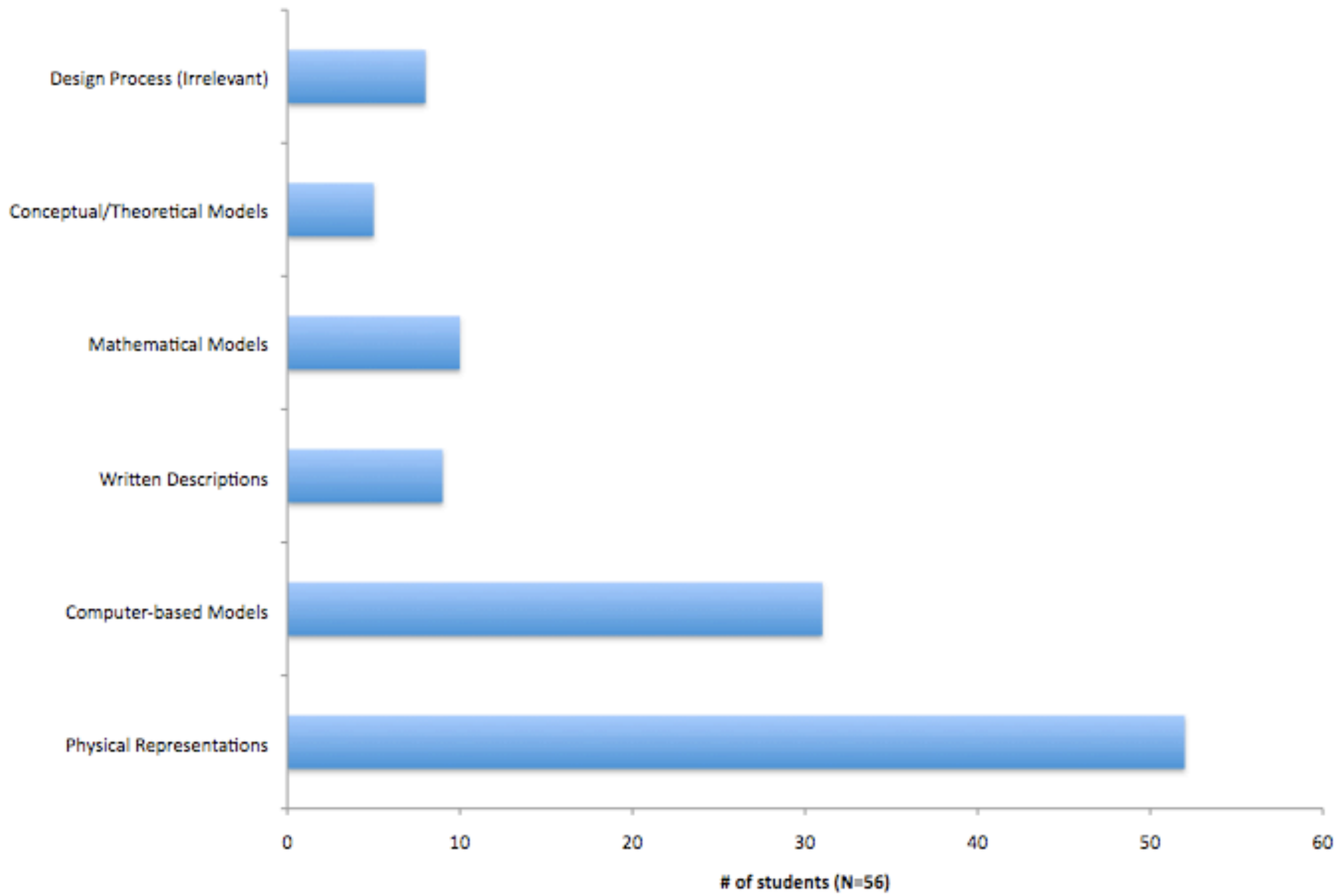
- Physical models
- Theoretical models
- Logical models
- Mathematical models
- Computational models

(Maki & Thompson, 2006)

What are engineering students' conceptions of modeling?

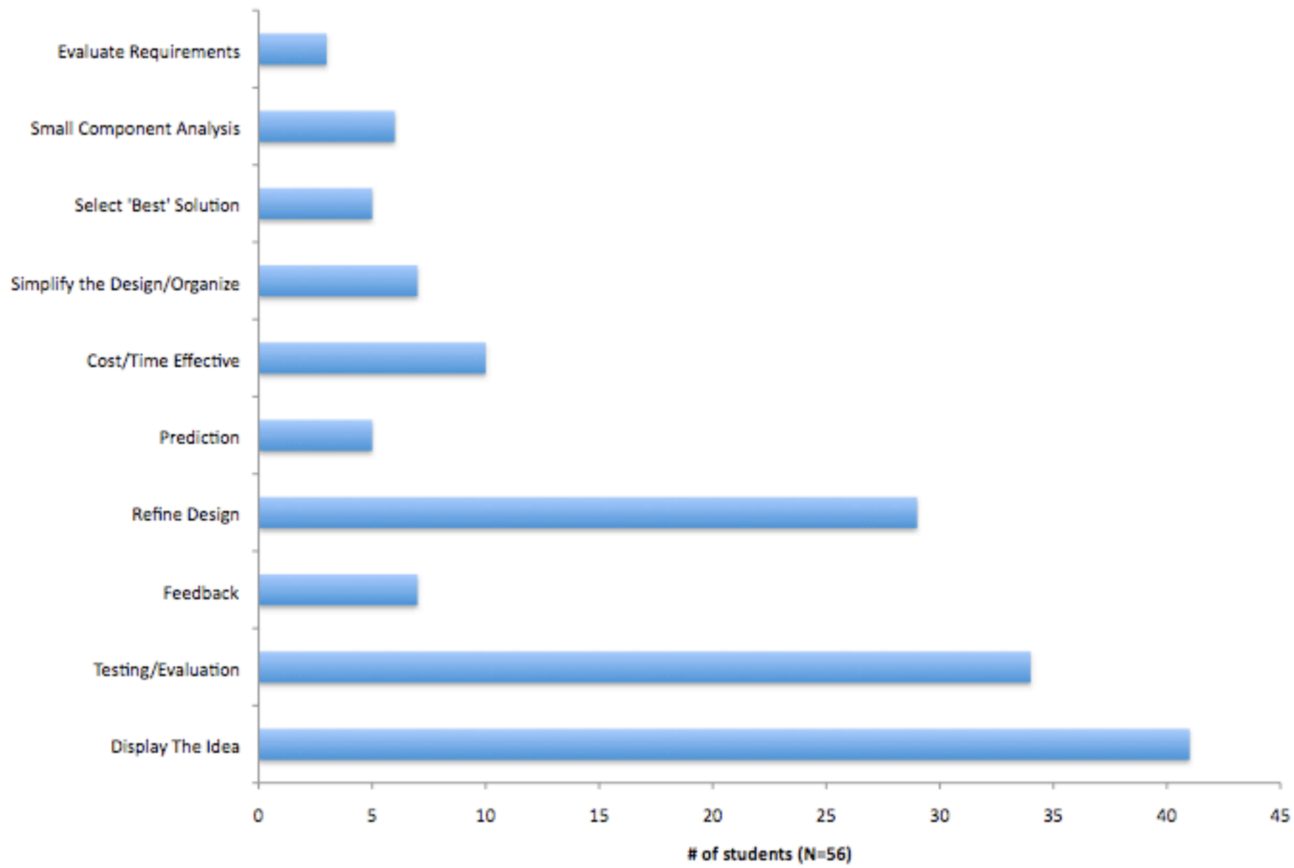
1. *Describe different ways to model a design idea or solution.*
2. *In what ways can models be useful/helpful in the design process?*
3. *List instances (in your courses or through personal experiences) where you used modeling.*

Describe different ways to model a design idea or solution



Physical Representation Breakdown: mock-ups/prototypes (45), sketches/drawings (28), charts/graphs/diagrams (10)

In what ways can models be useful/helpful in the design process?



Display an Idea breakdown: visualize (16), show progress (13), present/share ideas (12)
Testing/Evaluation breakdown: feasibility (9), functionality (15), what works? (5), what doesn't work (25)

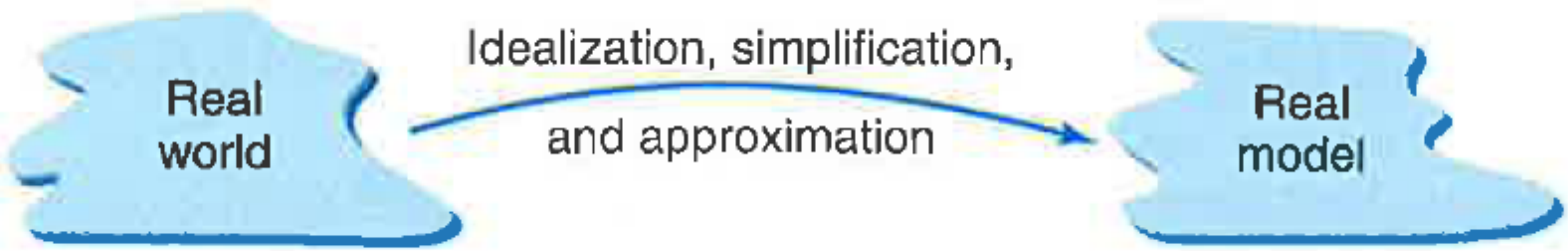
List instances (in your courses or through personal experiences) where you used modeling.

Focus:

- Physical models (20)
- Computer models (13)
- Mathematical models (3)

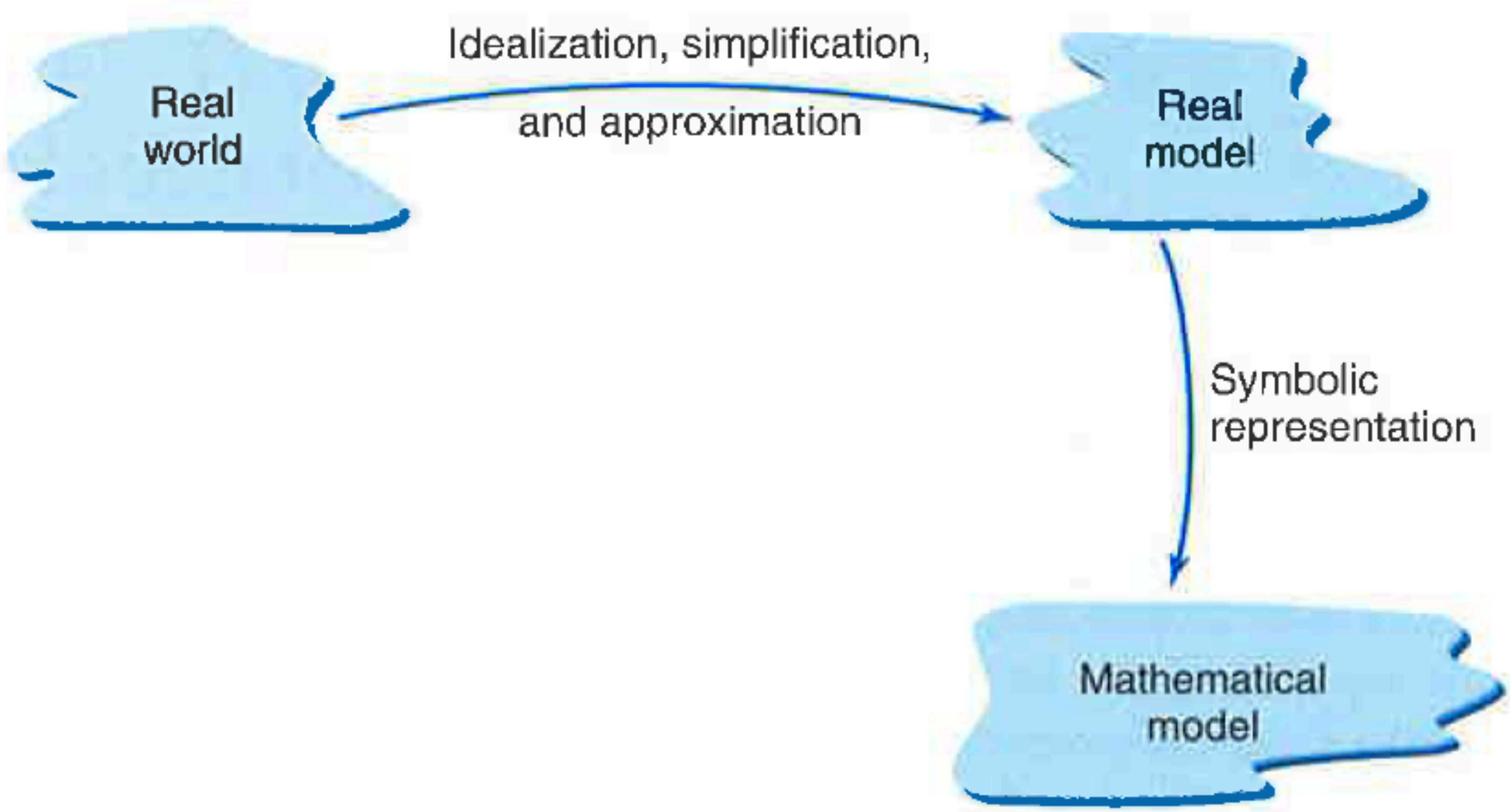
- 45 of 56 students mentioned the introductory engineering design course
- 10 students mentioned BME 305/306/307
- 3 mathematical model instances came from student experience gained from internships or undergraduate research
- 8 students listed personal experiences
  - Ex. general life decisions, setting up my dorm room, solving day-to-day problems, building my bed, model house, learning a piece of music, teaching martial art technique, home tinkering projects

Mathematical modeling process: make tacit steps explicit

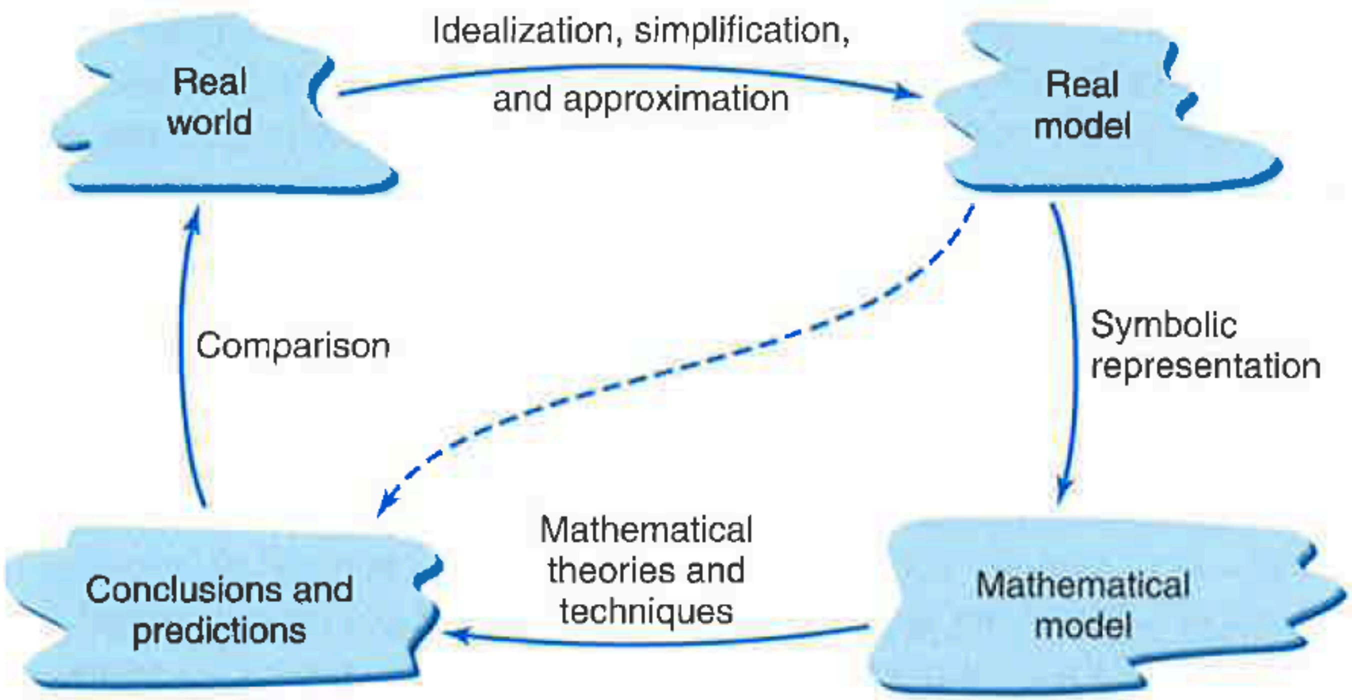


(Maki & Thompson, 2006)

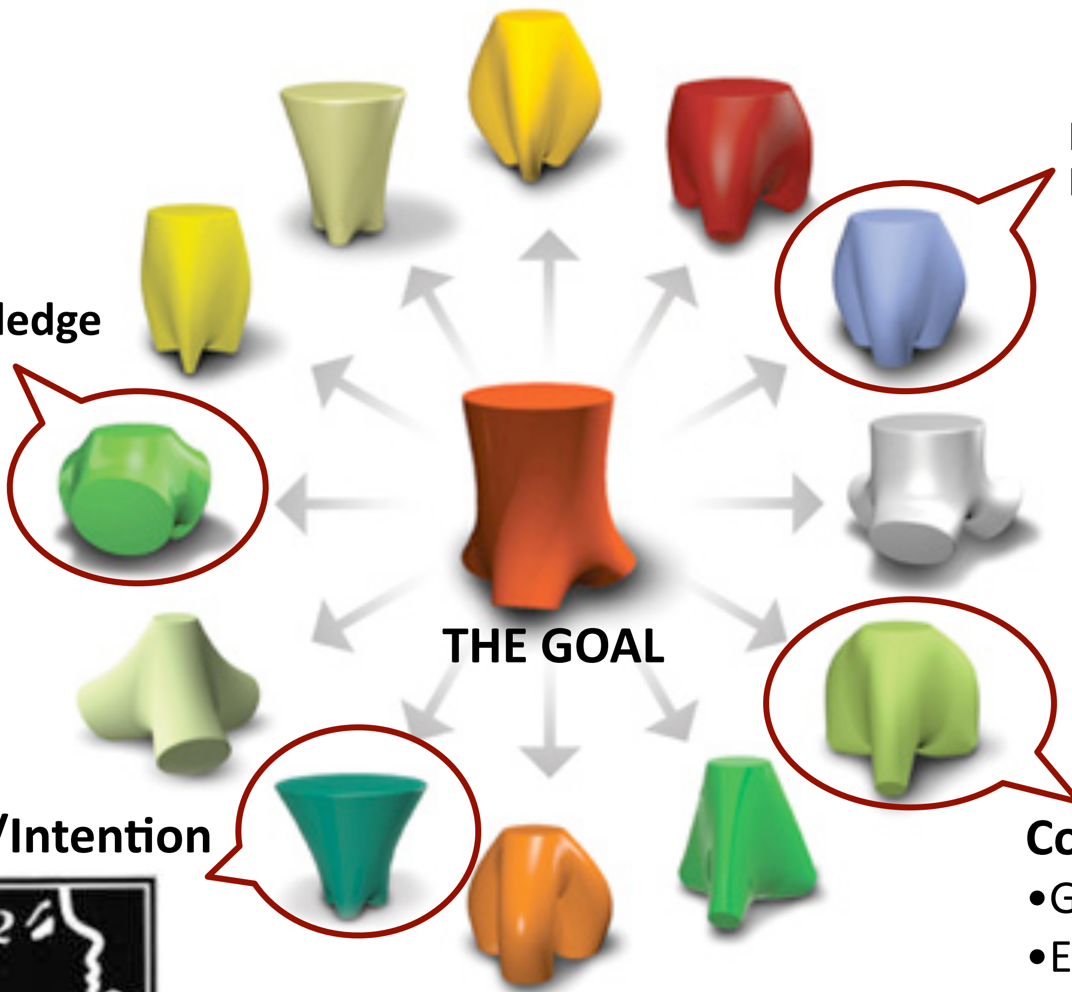
Mathematical modeling process: make tacit steps explicit



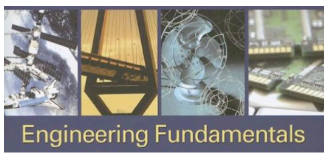
Mathematical modeling process: make tacit steps explicit



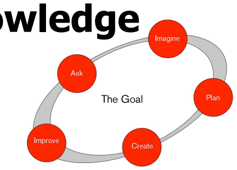
Efficiency in the context of engineering design: what are the elements, and what are the interactions?



Disciplinary Knowledge



Design Process Knowledge



Self Regulation/Intention

- Set goals
- Optimize
- Compensate

Context

- Global
- Economic
- Societal
- Environmental

Acknowledgments

- National Science Foundation Grants 0648316, 0935176, 0920047
- CADEX colleagues: Adam Carberry, Jennifer Cole, Matt Glucksberg, Rob Linsenmeier, Uri Wilensky