May 15, 2017 (am)

COURSE OVERVIEW

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ME 8730: Course

- **Course Description:**
  - *Advanced Methods for Engineering Design Research*. Topics of the course include: case study, user study, and protocol study research methods for studying collaborative design; team dynamics and tools to manage interpersonal issues; communication tools and methods for design; project planning; and team motivation strategies. Preq: ME 8700.
- **Objectives:**
  - To provide students with a foundation of conducting formal research in engineering design.
  - To produce knowledgeable project managers through practice.
  - To develop technical writing skills.

ME 8730: Assignments

Description	Weighting
Class Participation	5%
Reading Summaries (15, 5, 0)	Contract
Case Study Design Report	15%
Protocol Analysis Participation Reflection	10%
Protocol Analysis Design Report	15%
User Study Report	25%
Case Study *How To Manual*	10%
Protocol Analysis *How To Manual*	10%
User Study *How To Manual*	10%
Total	100%

ME 8730: Papers

- Follow the *Design Society ICED* format guidelines.
  - http://iced17.org/wp-content/uploads/2016/07/ICED17-Paper-Template.docx
- Due date for all papers and summaries: June 5
  - electronic, PDF, single email with attachments named:
    - **LAST NAME-Assignment Code.PDF**
- The papers will be evaluated at same level of conference review:
  - Presentation (organization, clarity of writing)
  - Content (frame of reference, breadth of discussion, depth of discussion)
  - Analysis (critique, conclusions)
- Assignments are used for assessment. Feedback on the assignments can be provided through office visits.

ALL: Research Manual

- Students will create a research manual based on the readings, discussion, and experiences for each of the three types of methods studied (case study, protocol analysis, and user study).
- These manuals are intended to be used as guidelines for their own future research and should provide explicit instructions on how to conduct the research.
- Students will submit these manuals periodically for peer and professor review.

ME 8730: Reading Discussion

- Papers will be distributed for reading and discussion in class throughout the semester. Students are expected to be prepared.
- Summaries should be submitted (one page; hard copy)
- **To earn an A**: 15 summaries are required
- **To earn a B**: 5 summaries are required
- **To earn a C**: No summaries are required

Readings

- Read General Design Research Papers
  - How to do Research (MIT AI Lab)
  - Developing and Testing Hypotheses (Antonsson, 1987)
  - Treatise on Engineering Design Research (Horvath, 2004)
  - The Need for Design Research (Durham)
  - My Method is Better (Reich)
  - Editorial (Papalambros)

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OVERVIEW OF DESIGN RESEARCH

Design Research

- Questions that we will try to answer:
  - What is design research?
  - Why do we care about design research?
  - What are the tools for design research?
  - What can we learn from design research?
  - When does design research start?
  - When does design research end?
  - How do we do design research?

Design Research

- Want to understand design
  - So we can make new tools
  - So we can predict design success
  - So we can monitor progress
  - So we can teach design
- Aspects of design to understand
  - Human thought processes
  - Creativity
  - Decision making
  - Collaboration
  - Communication
  - Representation
  - Reasoning
  - …

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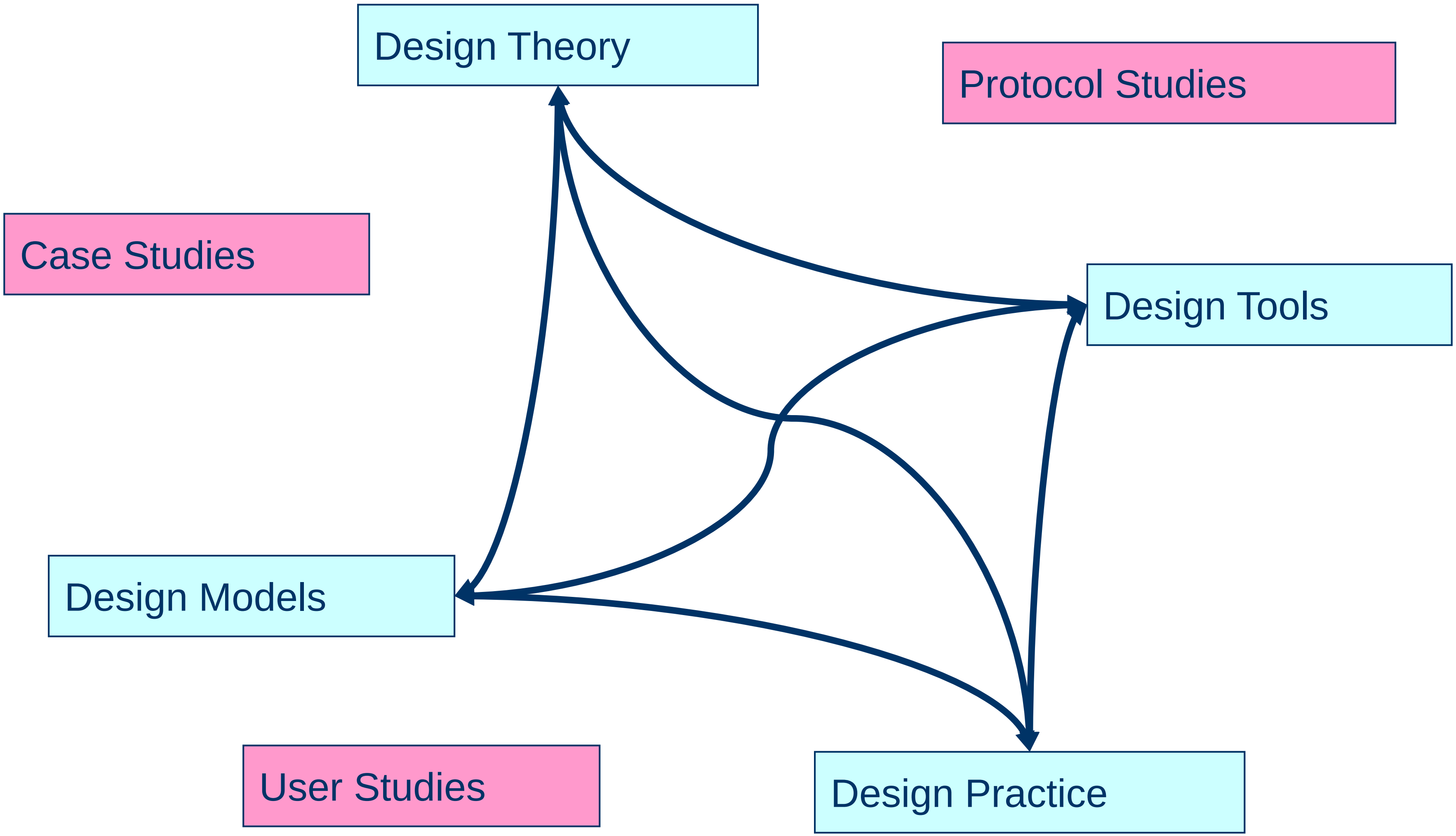
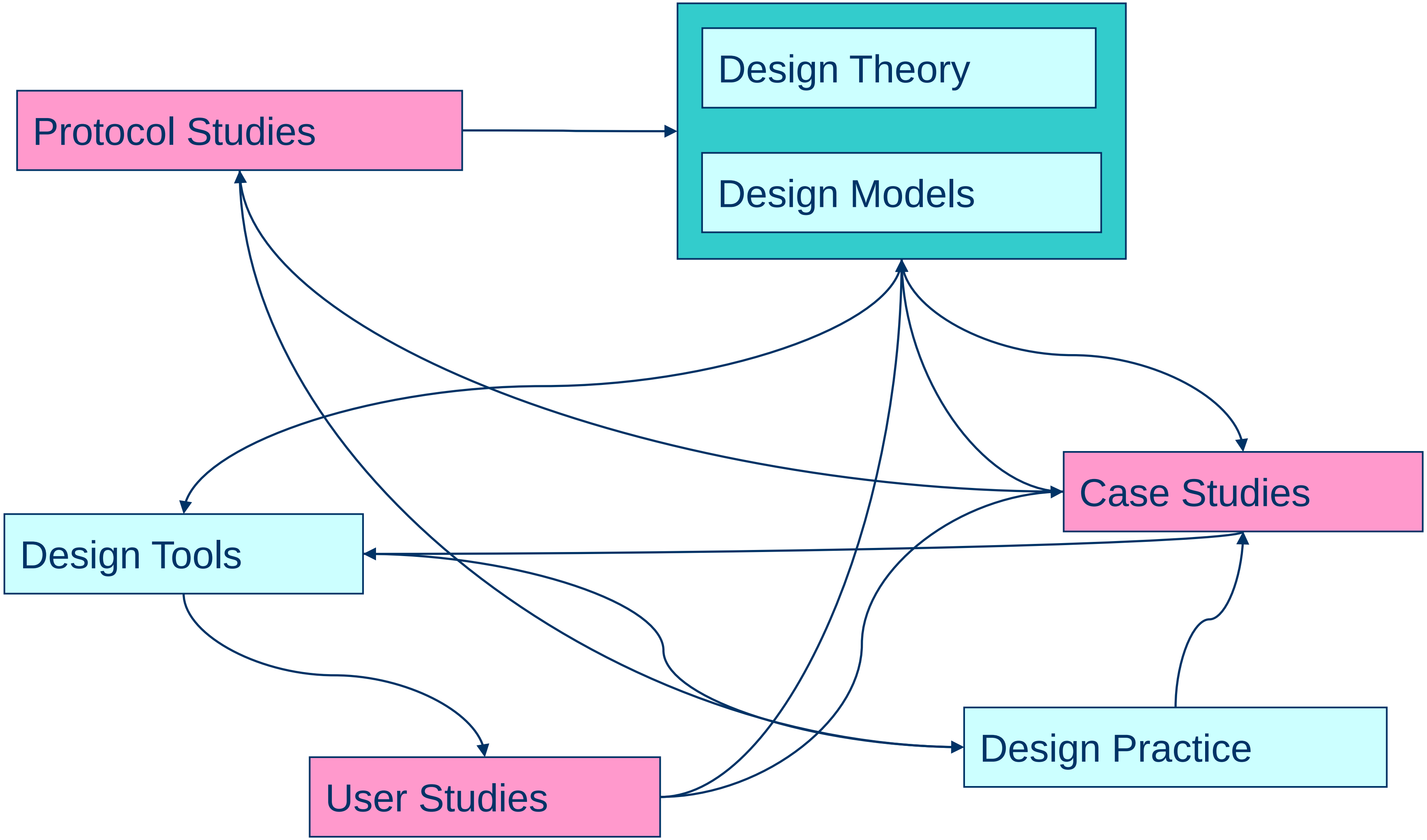
The Big Picture



Relationships



Design Research

- Research Methods developed
  - Informal (early work)
  - Formal (most emphasis)
- Research Methods used to
  - Calibrate values of design method variables (6-3-5 vs. 8-3-7)
  - Suggest contributing factors (group decision making – share information beforehand)
  - Develop models to explain design (Gen-Plore)

Informal Methods

- Introspection – self study; designer exams what he is doing by asking questions
  - Why is it that I need to have a clear understanding of the problem?
  - Why do I sometimes go back to previous solutions instead of generating a new one?
  - …
- Intuition – offers general observations (no questions)
  - Suh observed that good designs decouple function and requirements
    - Gave us “Axiomatic Design” (a theory???)
  - Alschuller observed that there are common mappable problem/solutions
    - Gave us “TRIZ”
  - Alexander observed that problem-solution-context can decompose
    - Gave us “Design Patterns”
- Major Premise:
  - “good designers” (experience and skills)
  - Study the right way to learn and then teach this way to students

Formal Methods

- Controlled Experiments
  - Protocol Analysis
  - User Experiments
  - Cognitive Experiments
- Case Studies
  - Industry/Academic
  - Historical/Live
- Use studies to
  - Find areas to research
  - Verify new methods
  - Compare different approaches

Research and Design

- When trying to understand
  - Benchmark and Reverse Engineer
  - Case Study
- When trying to check
  - Scaled Prototyping
  - Protocol Analysis
- When trying to evaluate in field
  - Full scale prototyping
  - Case Study
- When trying to set variable values
  - Simulations
  - Experimental Studies

Review of research methods

Research method	Application	Advantages	Limitations
Written survey	Obtain quantitative information from a large sample.	Systematic data collection and analysis	Low response rate. Results are subjective.
Documents analysis	When respondents are not accessible and archives are the only record of the phenomenon under study.	Provides critical analysis of documents.	Documents do not capture entire phenomenon.
Interview	Obtain qualitative information from respondents who are personally accessible.	In-depth first hand information. Allows follow-up questions and clarification.	Tiresome data analysis.
Experiential analysis	Propose theories based on researchers own experiences in a particular field.	Observer being the respondent saves time and effort for data collection.	Validity is questionable.
Ethnographic study	Study cultural and emotional phenomenon by immersing self into the scenario under study.	Precise and in-depth analysis of a scenario.	Long duration. High cost.
Protocol study	Study respondents in a controlled laboratory setup.	Uncovers thought process by think-aloud approach.	Respondents are not studied in their natural setting, many induce biases.
Case study	Investigates a contemporary phenomenon in its real-life context.	In-depth results. Use of multiple research methods.	Takes long duration for planning, testing and implementation.
Controlled Studies	Determine influencing factors (and levels). Test theories in controlled environments	Replication logic (well accepted) Statistics and repeatable	Extrapolation of the findings from laboratory environment

Readings

- Blessing: Application of Methods from Social Sciences
- Dorst: Design Research
- Eckert: The Lure of the Measurable
- Strauss: Grounded Theory
- Mistree: Validating Design Methods and Research
- Reich: Layered Models of Research Methodologies

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MODELING AND SIMULATION

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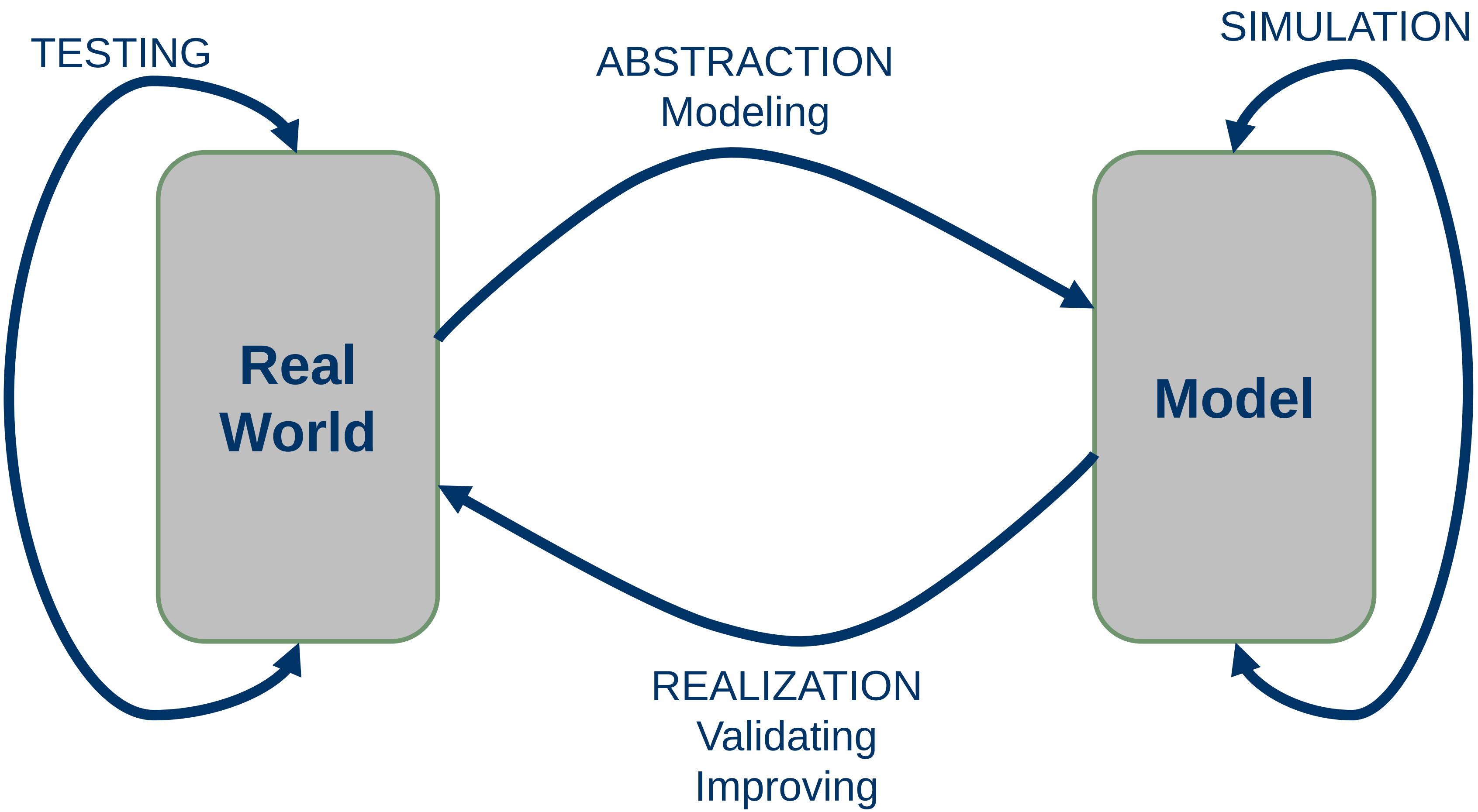
Learning Objective

- Students will know:
  - **Why** one might study different points of view (reality vs. model)?
  - **How** can researchers validate their work?
  - **What** are the different types of research?
  - **What** are the research tools available?
- Students will be able to:
  - **Classify** their own research
  - **Identify** the dependency of their research on previous types of work
  - **Determine** how others' research types will build on their work
  - **Appreciate** different modes of research (limitations and benefits)

Reality?


TESTING
ABSTRACTION
Modeling
SIMULATION
Real World
Model
REALIZATION
Validating
Improving

Research Triangle

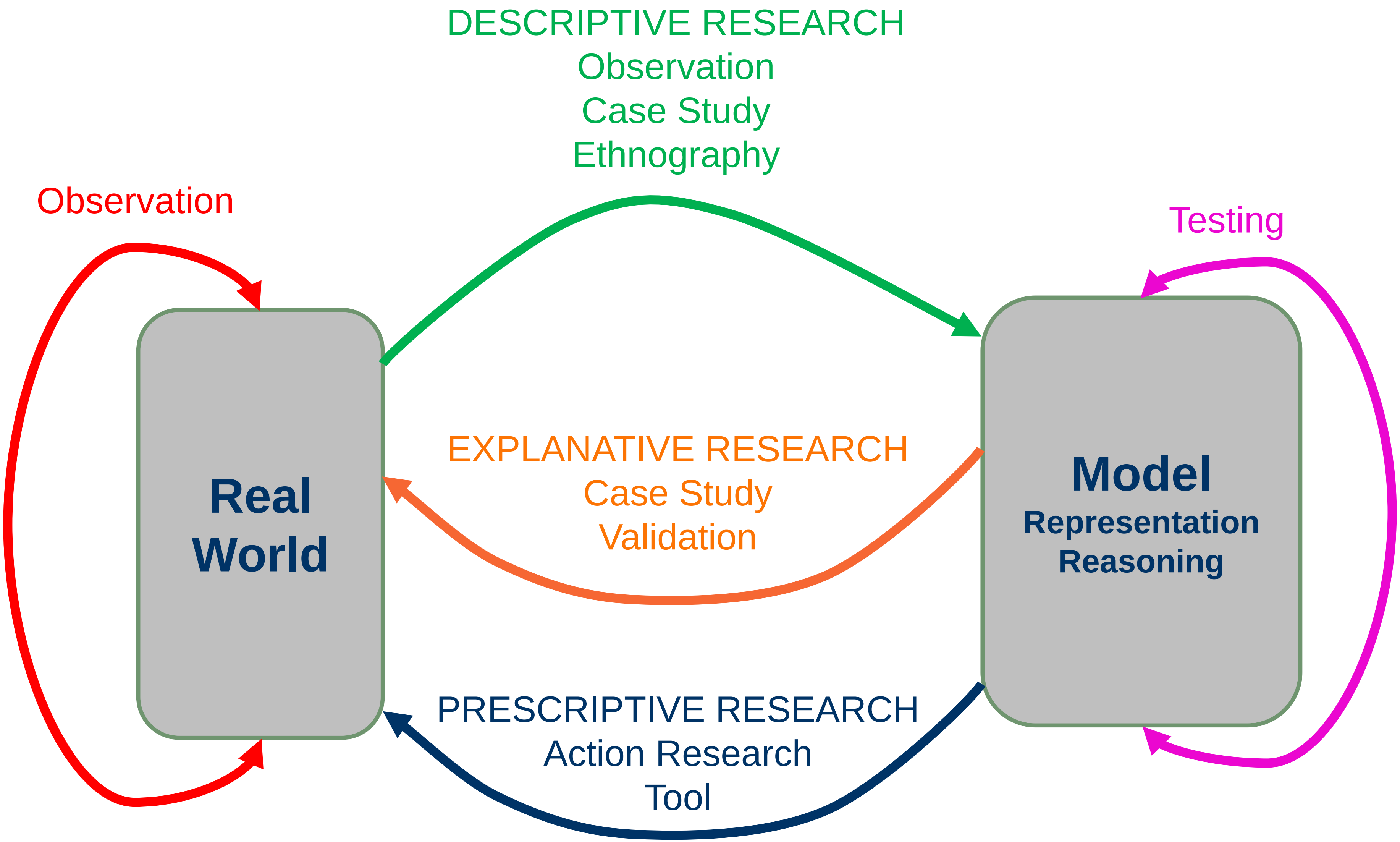
Reality

- Direct Observation – Un-Tampered
  - Case Study
- Direct Observation – Tampered
  - Action Research
- Indirect Observation – Objective
  - Historical, document analysis
- Indirect Observation – Subjective
  - Delphi, survey, questionnaires
- Reconstruction
  - Scaling of reality (prototype testing - physical)

Types of Research

- Prescriptive
  - This is how things **SHOULD** be done
  - Offer tools, methods, aids to improve or conduct
- Descriptive
  - This is how things **ACTUALLY** are
  - Used to create models, identify variables of interest
- Explanative
  - This is **WHY** things are

Types of Research



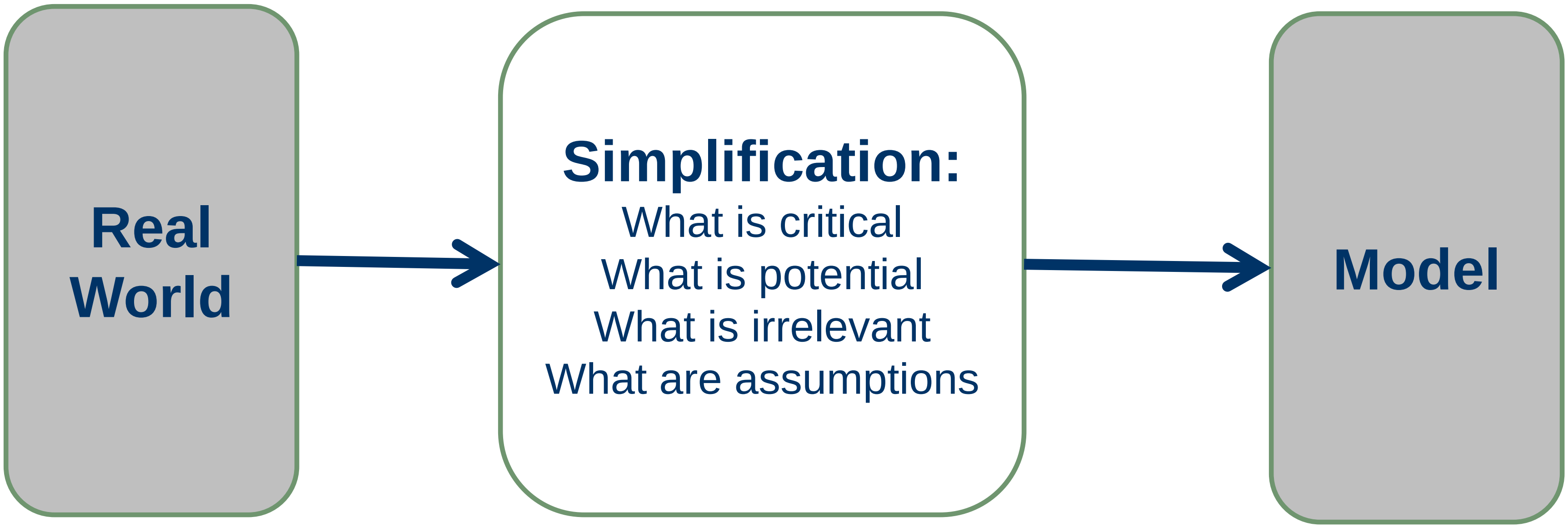
Where Can We Research?

- Modeling
  - Understanding Real World situations
  - Definition of a Representation
  - Choice of Critical Variables
  - Simplification
- Simulation/Inferencing
  - Determination of variable sensitivity
  - Behavior modeling for variables that are not controllable in reality
  - Optimization or value determination
- Realization/Implementation
  - Tool development from the simulation to practice
  - Concretization
- Testing/Validating
  - Measurement of behaviors in reality
  - Compare predicted to actual

Unique Qualities of Design Research

- What are the properties of Design Research that make it challenging?
  - Involves people
  - Involves organizations
  - Environmental/situational value sensitivities
  - Complex Adaptive Systems (unpredictable emergent behavior)
- What is done
  - Case Study (Empirical Research)
    - Understand existing situations
    - Develop models to explain situations
    - Compare proposed models to new situations
  - Simulation Study (Axiomatic Research)
    - Explore impact of variable changes
    - Optimize configuration

Modeling



The model may be virtual or physical

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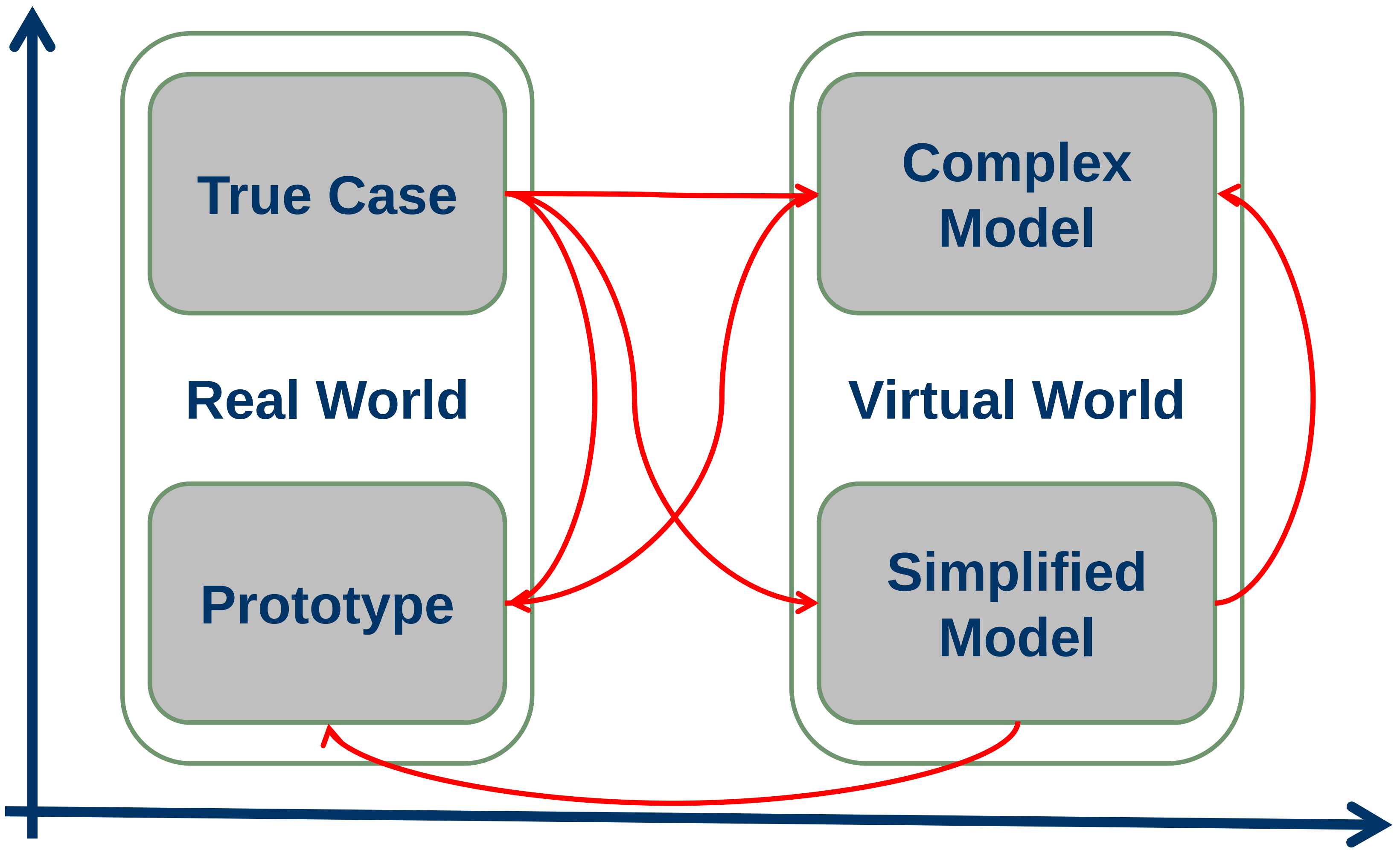
Choice of Modeling



Example: Line Balancing

- BMW (Reality)
  - Manufactures/assembles vehicles
  - Vehicle option packages vary in orders per month
  - Assembly stations can install different options
  - Ideally would like to balance the assembly line monthly (or weekly)
- TVG (Model)
  - Create information model of assembly processes
  - Determine/estimate assembly times
- Line Balancing (Model)
  - Use TVG information and optimization tools to create rebalanced sequences
- Implementation (Reality)
  - Use Line Balancing tool to improve time balances based on orders
  - Measure the efficiency of associate use

Readings

- LeDain: Assessing Design Research Quality
  - Papakonstantinou: Simulations
  - Ahmed: Influence of Design Evaluations
- Guba: Criteria for Assessing the Trustworthiness
- Lewis: Can a House Without a Foundation Support Design

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ASSESSING QUALITY RESEARCH

Motivation: Justify and convince

- Engineering Design is a complex social process
- New research methods explored in Engineering Design such as case study, experimentation, survey..
- Necessity to convince the relevance of research outside of ED community
- Same terminology but different meaning
  - For example case study as application case or source of empirical data

➔ **Research question**

What criteria can one use to characterize and qualify their design research?

Methodology

- Overview of methods used in ED research
- What are the metrics
- Illustration with two papers
  - Same research topic : failure evaluation in early stages of Engineering Design
  - Two different research approaches
    - Empirical research (*Marini et al*. 2011) – ICED11 (Design Society)
    - Simulation studies (Papakonstantinou *et al.* 2012) – IDETC/CIE (ASME)

Design Research

Type	Scope of Study	Stage of DRM		
		DS I	PS	DS II
EM	Product Development Process	Case Study		
EX	Design Task	Protocol Study	Experimental Study	Protocol Study
NT	Design Tool		Experimental Study Simulation	Protocol Study
IS	Product Develop Process with Tool			Case Study

Blessing and Chakrabarti 2009
Cantamessa 2003

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Quantitative vs Qualitative Research

Quantitative research	Qualitative research
Perception of Reality	
Reality exists as truth	Reality is dependent upon the individual
Research Purpose	
Explain, predict, verify phenomena occur in word where "Knowledge is context free" (Karlsson 2009) Theory Testing : Test existing theory, or causal relations, predict future outcomes, explore impact of variable changes, optimize configuration	Understand how and why events occur in real world setting (Yin 2003) Theory Building or extension: Identify key factors or new factors, describe their linkage and why these linkage exist

Design Research

Type	Scope of Study	Stage of DRM			Classification	
		DS I	PS	DS II	Qualitative	Quantitative
EM	Product Development Process	Case Study			++	+
EX	Design Task	Protocol Study	Experimental Study	Protocol Study	+	++
NT	Design Tool		Experimental Study Simulation	Protocol Study	+	++
IS	Product Develop Process with Tool			Case Study	++	

Metrics : Review of literature

Trustworthiness dimensions	**Quantitative Research** *Explain, predict, verify phenomena*	**Qualitative Research** *Understand phenomena in real world setting*
Truth value	***How to establish confidence in truth of the findings ?***	
	Internal validity *(Yin 2003)*	Credibility *(Lincoln and Guba 1985)*
Applicability	***How to generalize the findings to other contexts or settings ?***	
	External validity / Generalization *(Yin 2003)* *(McCutcheon and Meredith 1993)* Falsification (Popper 1959)	Transferability *(Lincoln and Guba 1985)* Analytical generalization *(Yin 2003)*
Consistency	***How to determine whether the findings would be consistently repeated with the same subject or in the same context?***	
	Reliability (Yin 2003)	Dependability (Bradley 1993) Recoverable (Checkland and Holwell 1998)
Neutrality	***How to establish that findings are function solely of the informants and conditions of the research and not of the biases, motivations, interests and so on of the researcher ?***	
	Objectivity (Patton 2002) *Construct validity (Yin 2003)*	*Confirmability (Lincoln and Guba 1985, Bradley 1993)*

Adapted from (Guba 1981) and (Lincoln and Guba 1985)

Proposition of criteria typology

Verification	• Truth Value • Consistency • Neutrality
Validation	• Applicability

Trustworthiness dimensions

- Criteria
  - Verification → Research process
    - Are you doing the research right ?
  - Validation → Research findings
    - Are you doing the right research?

Illustration with two papers

- Illustrative comparison on how the authors addressed the quality criteria proposed in literature in their research?
  - We are not comparing the value of the respective findings or the quality of the research itself
- Simulation paper (Papakonstantinou et al. 2012)
  - Goal : Propose a FFIP (Functional Failure Identification Propagation) framework taking into account a semi automatic reliability analysis of design configurations
- Empirical paper (Marini et al. 2011)
  - Goal: Understand “How design flaws motivate the rejection of alternatives and how they influence design feedback?”

Illustration with two papers

Simulation Study (Papakonstantinou et al. 2012)

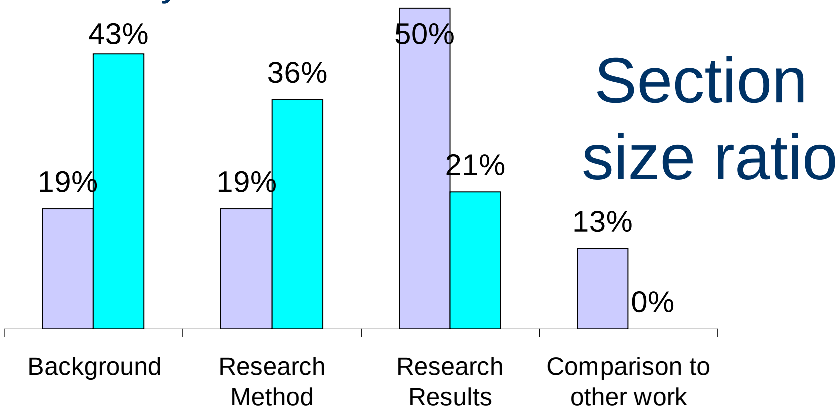
Goal: Explain and predict failures related to the reliability of design alternatives

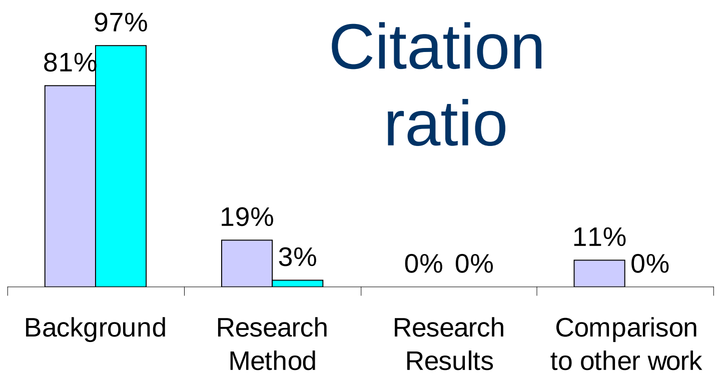
Perception of the reality: Reality exists as a truth

Empirical Study (Marini et al. 2011)

Goal: Understand how the technical risks are managed during the early design phases in real word setting

Perception of the reality: Reality is dependant upon the individual





Background ☑ Similarity	To explain the motivation of the research and to identify the gap with previous works
Research method ☑ Difference	Retrospective and longitudinal case study in Medical industry Use of a case of boiling water nuclear reactor system to test their tool
Discussion ☑ Difference	Comparison of the results with similar studies in literature conducted in other industries Emphasis the demonstration of their simulation tool without benchmark with other works

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Results and discussion

Verification criteria

Trustworthiness dimensions	**Simulation Study (Papakonstantinou et al. 2012)**	*Explicitly addressed*	**Empirical Study (Marini et al. 2011)**	*Explicitly addressed*
Truth Value	Internal Validity	☹	Credibility	☹
Consistency	Reliability	☹	Dependability Recoverable	☺
Neutrality	Objectivity Construct Validity	☺ ☹	Confirmability	☺

considered as implicit

sensitive to Verification

Validation criteria

Applicability	External Validity Falsification	☺ ☺	Transferability Analytical Generalization	☺ ☺

Conclusion

- Qualitative and quantitative research
  - Same trustworthiness dimensions but different criteria
- Necessity of both quality criteria : Verification & Validation
  - Validation depends on the verification
- Take away for teaching to students in ED
  - Beyond applied standards methods, getting a continuous questioning on verification and validation criteria concerning their research
  - Develop reflexivity about their research project
- Take away for communicating outside the ED community
  - Beyond the validation of research results, clearly explain the verification process whatever the adopted research method

"*If there were only one truth, you couldn't paint a hundred canvases on the same theme*" Pablo Picasso, 1966

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COGNITIVE EXPERIMENTS

Controlled User Experiments

- Design Experiments vs. Cognitive Experiments
  - Cognitive Experiments focus on specific cognitive activity
    - Interpretation of imagery
    - Single point decision making
  - Design Experiments focus on more complex activity
    - Use a method for a problem
    - Determine design issue (misinterpretation) based upon factor (representation)
- Both are controlled
- Both use statistical analysis
  - Can “loosen” p value to around 0.15 or 0.20 vs. 0.05 for significance

Survey of Psychology?

- Many schools of thought
  - Freudian Psychology to Behaviorism
  - Physiological Psychology
  - Gestalt Psychology to Cognitive Psychology
- Modern approach: take the best from all (eclectic)
- Gestalt Psychology
  - Studies perception, learning, and thinking processes using pattern models
  - Origins of Cognitive Psychology
  - German for Shape/Form
  - Def: a structure, configuration, or pattern of physical, biological, or psychological phenomena so integrated as to constitute a functional unit with properties not derivable by summation of its parts

Psychology

- Freudian
  - Three components of personality
    - ID: primitive; animal like; unconscious; insistent
    - EGO: constraints put by reality; acceptable behavior
    - SUPEREGO: moral judgment; conscience; internalizing of parental/social values
  - Conjectures
    - Our behavior is shaped by our childhood
    - Others conjectures have been disproved – but still influential
  - Primarily a theorist – psycho-analysis as an explanation

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Psychology

- Behaviorist Psychology
  - Watson (~1913) and Skinner (~1940)
  - Argues against introspection; uses objective measures via behavior (animal) experiments
  - Complex human behavior reduced to simpler elements (conditioned reflexes – see Pavlov); behavior patterns are chains of reflexes
- Watson
  - "consciousness should be banished from the vocabulary of psychology"
  - "there is no such thing as imagery"
  - "all behavior should be seen as stimulus-response associations"
- Results
  - Organisms (including humans) respond to sub-sets of stimuli from the environment by a finite probability
  - Animals behave like automata (give stimulus and response follows – within a probability)

Psychology

- Behaviorist
  - Skinner stressed REINFORCEMENT in behavior
  - Patterns resulting from various schedules of reinforcement (rats/pigeons)
  - Are humans also influenced in the same way?
- Behavior Modification
  - Modern theorists propose “script” vs. “schemata” (stimulus-response)

Cognitive Psychology

- Conscious AND Unconscious
- Studies macroscopic tasks such as
  - Problem-Solving
  - Memorization
- Conjecture
  - Human behavior is directed by goals and purpose
- Have been able to predict number of trials required to learn by creating associations
- Discoveries
  - Brain can hold fewer kinds of stimulus than what can be sensed
  - Ability to discriminate is facilitated if elements in stimulus are redundant

Physiological Psychology

- Medical Research to Explain Behavior
- Brain:
  - Mind is a machine
  - Construction, chemistry, electrical
- Neurons
  - Sensory: impulses transmitted to network
  - Motor: control muscles
  - Inter-Neurons: convey signals
- Observations
  - Chemicals used to inhibit or facilitate transmission between cells
  - Electrical signals transmitted through ions
  - Network processes information
  - Slow (1-250 mph vs. 186,000 mph for electric charge)
  - Expect 10^{11} neurons in network (brain)
  - Each connected to 1000 others
  - Brain is capable of 2^{1014} states

Physiological Psychology

- Limits
  - Short term memory
  - Speed of processing
  - Processes in parallel
- Development
  - No new neurons created (old view) – NEW VIEW: can keep growing
  - Number of connections depends on development
- Brain Regions
  - Different regions control different functions

Cognitive Psychology

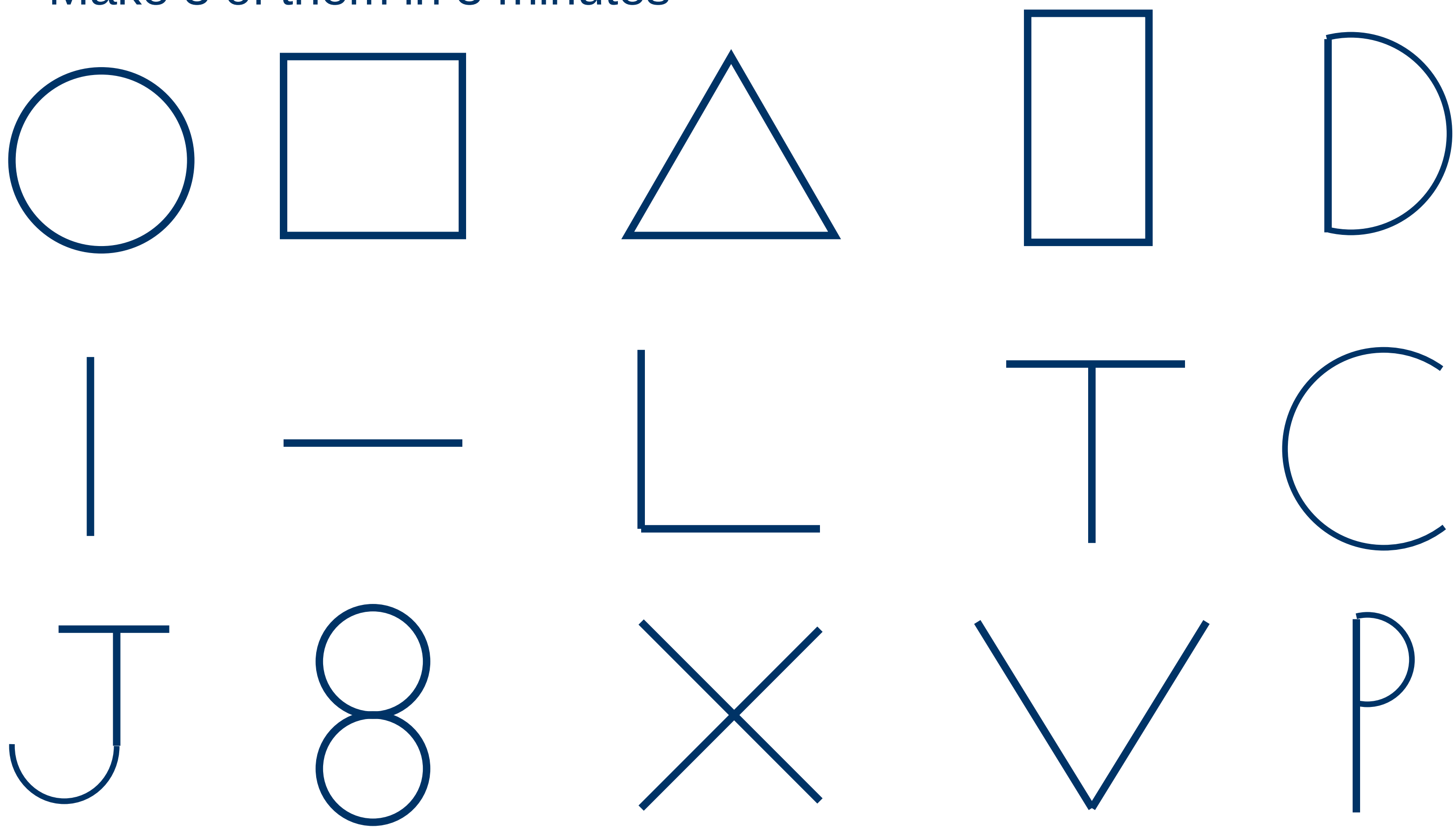
- Analogical models of the brain
  - Feedback system
    - Monitors responses and adjusts
  - Information processor
    - Information (measured probabilistically) rare events have higher information than expected
    - Looks at limits of processing (7 units)
  - Signal detector
    - Decisions are based upon subject criterion rather than stimulus-response
  - Digital computer
    - Models can be simulated
    - Artificial Intelligence (Frames; Semantic Networks; Neural Networks)

Cognitive Psychology

- Experimentalists
  - Slow and steady pace
  - Experiments on memorization of stories
  - Experiments on solution of tricky problems in reasoning
- Cognitive Science
  - Flash of insights that need further investigation (theorists)
  - Largely speculative
  - Possibly introspective

Cognitive Experiments

- Generate creative forms from this set of figures
  - Can scale, rotate, and combine (limited to three per figure)
  - Make 3 of them in 3 minutes



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Cognitive Psychology

- Creative Cognition: Experiments
  - Results (creativity judged subjectively)
  - 8 trials per person; 2 minutes to create figure (and name/describe it)
  - Total of 872 trials (109 people)
  - Total of 281 different figures generated
- Did similar experiment with 3D objects (specified or random) and with predefined functions (specified or random)
  - Found: random/random higher (twice) chance for creative solutions

Type of Pattern	Predicted	Not Predicted	Total	Percent predicted
Recognizable	40	203	243	40%
Creative	5	33	38	15%

Readings

- Campbell: An Experimental Study on the Effects of Computational Design Tool
- Jin: Study of Mental Iteration in Different Design Situations
- Wixon: Qualitative Research Methods in Design and Development
- Shah: Collaborative Sketching (C-Sketch)
- Yang: An Analysis of Sketching Skills
- Linsey: An Experimental Study of Group Idea Generation Techniques
- Mocko: The Effects of Language and Pruning on Function Structure Interpretability

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EXPERIMENTAL STUDIES

Readings

- Read General Design Research Papers
  - C-Sketch Paper (Shah, et al.)
  - Prototyping Paper (Yang)
  - Analogical Reasoning Paper (Linsey)
  - Communication in Design Reviews (Ostergaard)
  - Morphological Charts (Smith)
  - Shared Information (Wetmore)

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Controlled Design Studies

- Replication logic based investigation
  - Used to **TEST** hypotheses
  - Used to **CALIBRATE** method variables
  - Used to **COMPARE** methods
  - Used to **MEASURE** effectiveness
- Quantitative investigation
  - Define the variables, control the variables, measure the responses
- Applications in Industry
  - User investigation (how do people interact/use system)
    - Requirements setting – how much
  - Design investigation (how should we do things better)
    - Five people doing DFA analysis – how consistent/objective

Readings

- Wetmore: Experimental Study of Influence of Group Familiarity and Information Sharing

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EXPERIMENTAL STUDY (EXAMPLE)

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Influence of Group Cohesion and Information Sharing on Effectiveness of Design Review DAC-57509

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Initiation

- Must have **CLEAR** objective
  - This determines the problem, the protocol, the data collection, and the data analysis
- Research Question
  - Formulated as the motivation – what do you want to learn?
- Hypothesis
  - Informed, testable guess
  - Use (Null) – easier to disprove negatives than to prove positives
  - Examples
    - Null: Iteration does not have any influence on the amount of information generated from each seed.
    - Null: Functionality added to the models is predictable with no added value with respect to creativity metrics of novelty and variety.

Design Review

- Design Reviews are used extensively in industry
  - Required without specific guideline
- Little information available
  - How to conduct, form teams, communicate, …
- **What are they?**
  - Method in which to select and evaluate a given design or solution.
- **Why do we care?**
  - Unidentified risks lead to expensive changes later
  - 70% of total cost is determined in stage consumes only 5%
  - Mistake proofing leads to enormous potential savings
- Examples
  - Checklists, FMEA, ARID, etc.
  - Collaborative Activities without any guidelines

Information Sharing

- Design Reviews are (typically) collaborative activities
- Group Decision making is important cognitive activity (Winquist and Larson, 1998)
- Information Sharing is key to collaboration and group decision making
  - Unique information stimulates sharing and improves quality of decision making (Kelley and Karau, 1999)
  - Awareness of unshared information has positive impact (Mennecke and Valacich, 1998)
- Is Information Sharing an influencing factor for design review effectiveness?

Group Dynamics

- Negative Influences
  - Group Cohesion (Griffin, 1997)
  - Group Politics (Vecchio, 2003)
- Group Cohesion
  - lack of conflict, strong personal relationships
  - See 1986 Challenger Disaster
  - Results in GroupThink
    - an illusion of invulnerability
    - rationalization of poor decisions
    - belief in a group morality
    - negative stereotyping of outsiders
    - pressure on dissenters
    - pressure to conform
    - illusion of unanimity
    - mind guarding.

Research Question

- Does ***Group Cohesion*** influence design review effectiveness?
- Does ***Information Sharing*** influence design review effectiveness?

Variables

- Independent variables
  - **Experimental variables controlled by the researcher**
  - **Used to compare and assess the method or activity**
- Dependent variables
  - Secondary variables that cannot be directly controlled
- Control variables
  - Variables that are held constant throughout the experiment
  - Variables not of particular interest in testing the hypotheses
    - Problem
    - User expertise

Research Method - Variables

- Two factor ANOVA, 3-levels per factor (3X3 ANOVA)
- Group cohesion
  - Low: members from different design teams
  - Mid:
    - Mid-1: 2 members from same team, 2 not from same team
    - Mid-2: 2 members from same team, 2 members from same team
  - High: all members from same design team
- Awareness of unshared information
  - Low: each member gets all information
  - Mid:
    - Mid-1: Two pairs of group members receive the same pair of documents
    - Mid-2: Each document is common with three persons of the group
  - High: Each group member receives a single functional groups' output

Problem

- How difficult?
  - Measure complexity
- What domain?
  - Within domain of the subject pool
- How long?
  - Pilot studies
- What interest level?
  - Without interest, people will not fully engage
- What familiarity with problem?
  - Too familiar – replicating existing
  - Too distant – not typical
- How represented?
  - Text, sketch, oral, …

Research Method – Problem

- Self-propelled lawn mower mechanism
- Multiple documents generated
  - 30 pages
- Scope scaled
- Problem
  - 43 errors (calibrated)
  - "torque 2 ft-lbs" -> "torque 2 Nm"

	Development	Manufacturing	Purchasing	Document Control
Bill of Materials (BOM)				X
Component Drawings				X
PDS	X			
Process Flow		X		
Assembly Drawings		X		X
Component Costs			X	
Release Report	X			
Foreign Content			X	

Code	Location	Error
BNE	B-D	quantity of 2 for deck
BNE	B-D	5 thrust bearings are shown
BNE	B-D	6002LM0008 quantity should be 2 not 5
BNI	B	weight would be ok if thrust bearings and bushings were correct in count
BNE	B-S	non-deck weight is too high (would be ok if # of thrust bearings and bushings were correct)
RGI	D	6002LM0001 missing hole locations for drive plate through hole and thrust bearing holes
RTE	D	6002LF0012-2 ftlbs should be in NM

People/Environment

- Dealing with people, must consider
  - Expertise/Training
  - Gender/Race/Culture
  - Socio-economic
  - Self-efficacy
  - Personalities
- Environmental issues, must consider
  - Time of day (before meals/after meals; early morning; …)
  - Location of experiment (familiar, unfamiliar,…
  - External noises, smells, sights (overly distracting, too insulated,…)

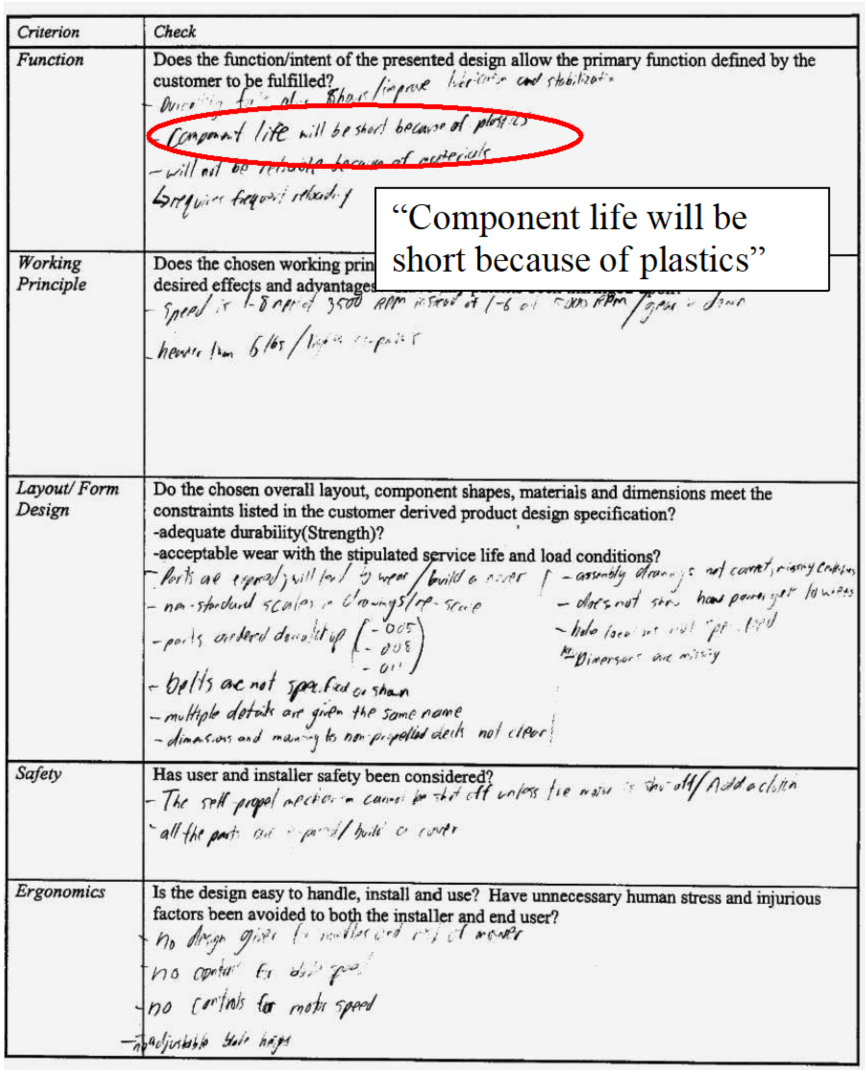
Research Method – Participants

- Undergraduate (sophomore) mechanical engineering students (5 sections ~30 students in each)
- Normalization of design review experience
  - Common lecture
  - Common practice (review of a children's block toy)
- Why this population?
  - Available (students in multiple sections)
  - Relevant (improve teaching)
  - Tool Impact (behavior is scalable)

Data Collection

- Protocol for Analysis
  - Needed before the experiment
  - Objective (would everyone yield same interpretation?)
  - Quantitative (what is MEASURED?)
  - How will you collect?
  - How will you analyze?
  - How will you keep?
- Participant Generated Information
  - Is the generation an interference with the hypothesis?
  - Incremental changes and evolutions – need pauses for
    - Collection, Copying, Redistribution
    - Use “surveys” to keep focused
- Exit Information and Observations
  - Surveys can collect impressions (not experimental)
  - Make/record observations throughout the experiment (separate documentation)

Research Method – Measures



Criterion	Check
Function	Does the function/intent of the presented design allow the primary function defined by the customer to be fulfilled?
Working Principle	Does the chosen working prin... desired effects and advantages...
Layout/ Form Design	Do the chosen overall layout, component shapes, materials and dimensions meet the constraints listed in the customer derived product design specification? -adequate durability(Strength)? -acceptable wear with the stipulated service life and load conditions?
Safety	Has user and installer safety been considered?
Ergonomics	Is the design easy to handle, install and use? Have unnecessary human stress and injurious factors been avoided to both the installer and end user?

- Classify errors
  - representation type
  - implicit/explicit nature
  - functional group
- Count Found Errors

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Variables

- Independent variables
  - **Experimental variables controlled by the researcher**
  - **Used to compare and assess the method or activity**
- Dependent variables
  - Secondary variables that cannot be directly controlled
- Control variables
  - Variables that are held constant throughout the experiment
  - Variables not of particular interest in testing the hypotheses
    - Problem
    - User expertise

Research Method – Controls

Variable	Method of Control
Design Problem	• Same problem to all teams • Prohibit discussion of the problem after class
Duration	• Limited to 35 minutes
Team Size	• Uniform size (4 students)
Communication Resources	• Same language (English) • No significant handicaps • All modes allowed
Technical Resources	• All required literature included in packet
Methodology	• Common tool (checklist)
Experience	• Common training
Administration	• Self governing (no “leaders” assigned)

Replications

- Constructing Replications
  - Limited subject pool
  - **Need a minimum of 3, preferred 10, ideal 30**
  - Collaborative – reduces replications
  - Cross sections – need to test for commonality
  - Statistical Significance (p-value)
    - <0.05 – significant
    - <0.15 – suggestive
    - >0.20 – not significant
  - Maximize planning/stay flexible
  - Avoid Learning (re-order?)
    - Increase replications by giving same subject pool multiple variations

Research Method – Data Collection

NOTE:

experiment planned for 3 replications, absenteeism resulted in unbalanced replication

Unbalanced ANOVA conducted

	Cohesion	awareness	
Experiment #	Factor 1	Factor 2	replications
1	low	low	4
2	low	mid	4
3	low	high	4
4	mid	low	3
5	mid	mid	4
6	mid	high	4
7	high	low	3
8	high	mid	4
9	high	high	4
		total	34

	Cohesion	Awareness	
Experiment #	Factor 1	Factor 2	replications
1a, 1b	low	low	2
2a, 2b, 2c, 2d	low	mid	4
3a, 3b, 3c, 3d	low	high	4
4a, 4b, 4c, 4d, 4e, 4f	mid	low	6
5a, 5b, 5c, 5d, 5e	mid	mid	5
6a, 6b, 6c, 6d	mid	high	4
7a, 7b	high	low	2
8a, 8b, 8c	high	mid	3
9a, 9b, 9c, 9d	high	high	4
		total	34

Planned vs. Actual: Must be flexible

Analysis

- Individual
  - One person can independently measure all factors (fully objective)
  - Quantity of solutions
  - Number of strokes
  - Number of requirements
  - …
- Panel
  - Group of judges needed to normalize subjectivity to an objective result
  - Inter-rater reliability (are all judging the same)
    - Judge 1: A=Low, B=Low, C=High
    - Judge 2: A=Medium, B=Medium, C=High
    - Good agreement

Results

- Results of ANOVA indicate no interaction present between factors 1 and 2
- Low awareness is typical of better performance

Hypotheses Test	Symbolic	Design Doc.	% of Total Problems	Text
Interaction	0.867	0.755	0.874	0.472
Factor 1 (cohesion)	**0.050**	*0.121*	0.753	0.590
Factor 2 (awareness)	**0.022**	**0.020**	*0.233*	*0.189*
Legend: **DOES**, *Possibly*, does not				

Summary

- Group Cohesion
  - Not significant (for this study)
- Information Sharing
  - More information shared, better
- Interaction
  - Not significant
- Future
  - Replications with different subject pool
  - Replications with different design problem
  - Replications with different review tools

Readings

- Ericsson: How to Study Thinking in Everyday Life
- Daly: Design Heuristics in Engineering Concept Generation
- Atman: Mapping Between Design Activities and External Representations
- Gero: Understanding Conceptual Electronic Design Using Protocol Analysis

May 17, 2017 (am)

DESIGNING DESIGN PROBLEMS

What is a design problem?

- Is any engineering problem a design problem?

  - Given {conditions}, determine the specific enthalpy of the steam at the turbine's exit.
  - Given {conditions}, determine the value of angle θ at which the structure will begin to collapse.

  - Given {conditions}, determine the value of angle θ that would minimize the weight of the truss.
  - Given {conditions}, determine the best unit cell geometry of the meta-material that approximates its <property> closest to <a benchmark material>.

- Traditionally, find $\mathrm{x} \in X \rightarrow \{O, C\}$

How are these problems different?

- Design a solution to assist a person access a higher or lower floor without using legs.
- Design a solution that could fasten multiple sheets of paper so that they could be separated easily using fingers.
- Design a solution to provide affordable means of lighting at night to homes located in remote regions of developing economies that are without electricity.

> Are these problems equally complex? Equally varied? Equally novel? Equally difficult to solve? If not, then how do you classify design problems?

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Design problem classification

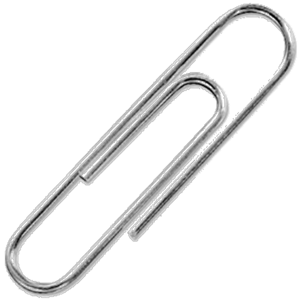
- In how many ways can you classify design problems?
  - By novelty/familiarity (original – adaptive – variant)
  - By size (number of unique variables and constraints)
  - By connectedness (topological complexity between entities)
  - By solvability (algorithmic complexity?)
  - By domain (product domains, process domains)
  - By value (impact / importance)
  - By direction (forward-reverse engineering)
  - By abstraction/problem space (chair – sitting device – solution that could provide relaxation and comfort in a seated position)

Problem Cx vs. Solution Cx

- Complexity = size, connectedness, solvability

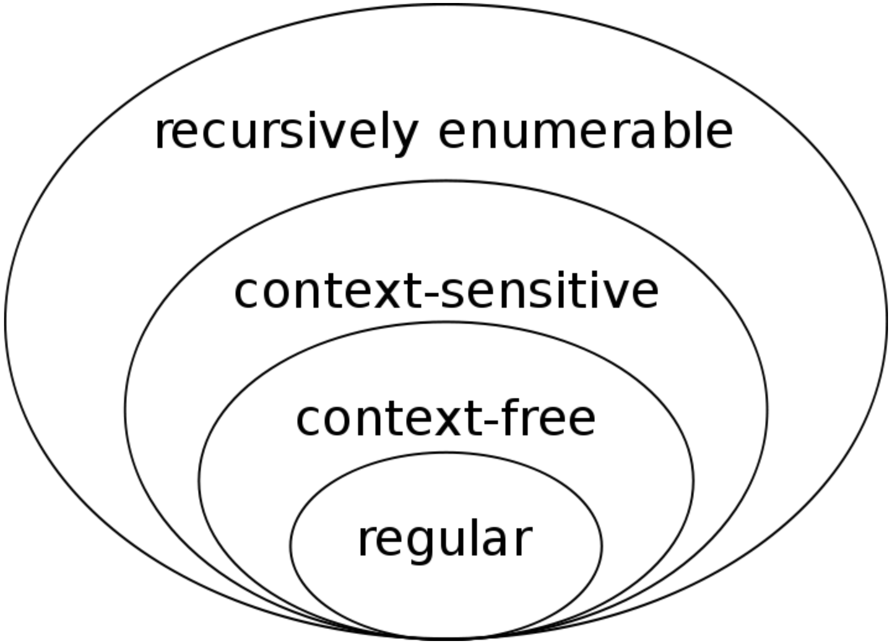
- Design a solution to assist a person access a higher or lower floor without using legs.
  - Problem complexity = ?
  - Solution complexity = ?

- Design a solution to fasten multiple sheets of paper so that they could be separated easily using fingers.
  - Problem complexity = ?
  - Solution complexity = ?



Solvability

- The cost of solving a problem
- Chomsky hierarchy of formal grammars
- Where is the ‘Chomsky’ hierarchy for design problems?



Activity 1 – design problem repository

- Form a pair with a neighbor.
- Review your design problems with partner.
- Plot each problem on the n-dimensional hyperspace
  - By novelty (original – adaptive – variant)
  - By size (number of unique entities: variables and constraints)
  - By connectedness (number of relations between entities)
  - By solvability (Easy – medium – hard)
  - By domain (types, e.g., consumer, defense, transport, etc.)
  - By value (High – medium – low)
  - By direction (forward design or reverse engineering)
  - By abstraction (high – medium – low)

Experimental assignments

- An assignment is a activity that the participant performs and the outcomes of which produce the data needed for your study
- Given resources {R}, perform task {T}, while satisfying constraints {C}.
- The design problem must be designed with the context of the assignment in mind. If the context changes, the design problem may have to adjusted.
- Is the assignment a 'treatment'?
- Is the participant a 'subject'?

Assignment examples

Resources (R)	Tasks (T)	Constraints (C)
Design problem, White board, markers, Eraser (or no eraser)	Construct model {M} for problem statement {P} M: req., function, struct., behavior, failure	Stay within the limits Finish in 20 minutes No erasing No overwriting No breaks
Interpretation problem, White board, markers, Erasers, other utensils	Identify function, structure, behavior, failure	Similar…
Recall problem, Artifact representation, Review time, media	Describe / draw the device that you reviewed	Similar…

When do you release information to the participant?
- Time limits, number of tasks, observing devices, grading, sharing, …

Which other factors could influence the data?
- Circadian rhythm, environment, tiredness, sickness, hunger, medication, …

Prerequisites for Designing a Problem

- Know your research objective.
  - Which phenomenon are you trying to study?
  - Will the design problem induce that phenomenon?
  - Which hypothesis you are testing?
  - Could the design problem produce a usable and significant data pool needed to test the hypothesis?
  - Would the data be conducive to analysis?

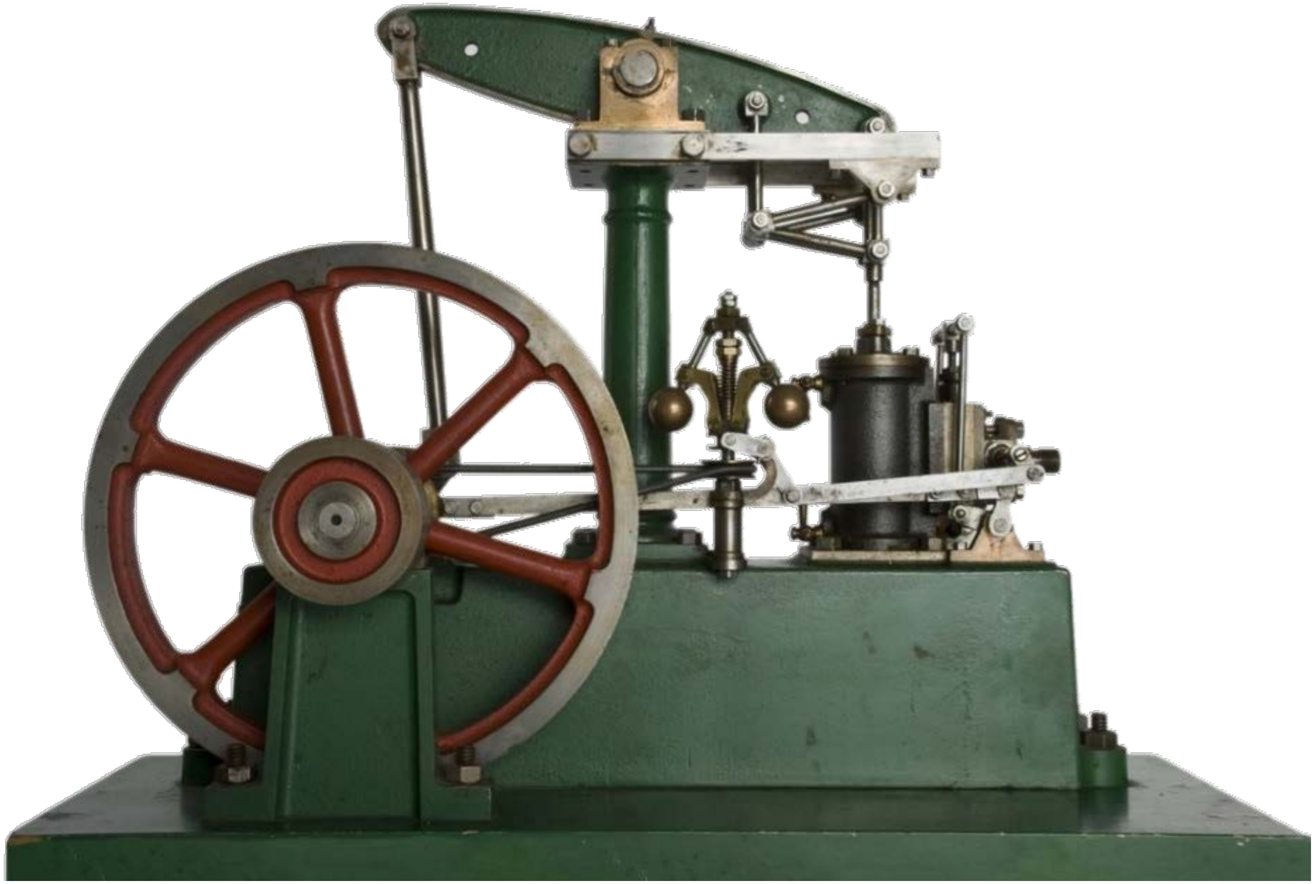
- Consider the context of the participant’s total experience
  - Has the participant’s total experience of executing the assignment been considered from her point of view?
  - What are the possible outcomes of the participant encountering the problem statement? What are the possible causes of the undesired outcomes? Have they all been considered and mitigated?

- Run pilot experiments on smaller data pools and iterate.

Basic qualities of design problems

- The problem should be solvable by the participants.
  - Should be able to make some progress
  - Should produce some data to analyze
- The problem should not be previously solved/familiar.
  - Unless previous exposure is part of the treatment
  - Previous exposure could bias the response.
- The problem should produce usable data.
  - This is not the same as artificially inducing the desired outcome.
  - The data should be not biased, not out of range, etc.
  - Example: You are trying to study the effect of caffeine on the speed of ideation, but all participants finish their design task before the caffeine is absorbed into their blood.
  - Example: You are trying to study how the quantity of ideas produced by designers vary with experience level, but the design problem is such that the even the most experienced subject produced only one idea.

Activity 2



Tasks

- What do you think is the device's name? Write your answer on the provided paper.
- Name as many parts/features of the device as you can recall.
- Identify the function of each part, from your best guess.
- Sketch the device from memory, as accurately and to as much detail as you can.

What could you study?

- Effect of functional cognition on interpretation
- Effect of experience and domain knowledge on recall ability
- Effect of chunking during engineering recall
- Growth of interpretation with academic grades
- Etc.

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EXPERIMENT PROPOSALS

Influence of Representation on Reverse Engineering Function Structure Outcome

May 18, 2017

Caleb Bennetts, Ashish Chaudhari, Marianna Coulentianos,
Hyeonik Song, Hallie Stidham, Adriana Valenci

ME 8730 NSF Summer Workshop on Research Methods for Collaborative Design, Clemson University

CEDAR
Clemson Engineering Design Applications and Research

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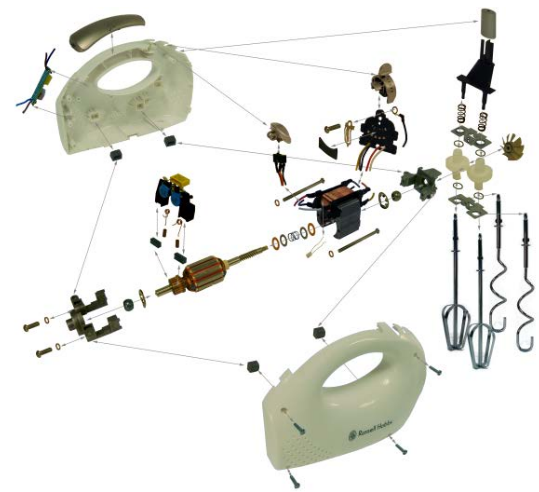
Research Objectives

- What is the influence of representation on reverse engineering function structure creation?
- Hypotheses
  - Exploded view of product will be sufficient for technically correct function structures.
  - Different representations (picture, physical product, disassembled) will result in different function structures.

2 x 3 Factorial Experiment

	Photograph	Product	Disassembled Product
Exploded View	Condition 1	Condition 2	Condition 3
No Exploded View	Condition 4	Condition 5	Condition 6



- 23 participants
- 6 conditions
- 4 participants for five conditions
- 3 participants for last condition
  - Subject to change depending on absences

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The Blue Team

BLANE, DARSHAN, DOUG, GIULIA, REZA

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Overview

- Research Goal:
  - To see how different modes of communication affect design teams.
- Research Question:
  - How do the different modes of communication influence design concept generation?
- Research Considerations:
  - Testing verbal communication is not feasible based on our time and resources, so we will only look at sketches and text.
  - Students are broken into 3 teams (random) and given the design problem.
  - Team 1 can only present concepts as sketches, Team 2 can only present concepts through text, and Team 3 can use all forms of communication.

The Experiment

- Teams should generate as many concepts as possible in response to the design prompt.
- Prompt:
  - Design a device to quickly shell peanuts for use in places like Haiti and West African countries. No electrical outlets available. Must shell large amounts quickly with minimum damage to the nut.
- Data Analysis:
  - Measure the number of concepts produced by each team and compare.
- References:
  - Linsey, Julie S., E. F. Clauss, T. Kurtoglu, J. T. Murphy, K. L. Wood, and A. B. Markman. "An experimental study of group idea generation techniques: understanding the roles of idea representation and viewing methods." Journal of Mechanical Design 133, no. 3 (2011): 031008.

Identifying How Supplement Excerpts Impacts Ability to Develop Design Requirements

Malena Agyemang
Jamie Asbach
Pouria Babvey
Elissa Morris
Murtuza Shergadwala
Megan Tomko

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Research Approach

- Research Objective
  - To identify how a different supplemental excerpts impacts the ability for students to develop design requirements when given a design problem.
- RQ1: Quantity - How many requirements do students generate given a certain excerpts to supplement a design problem?
  - RQ1.1: Between Subjects: How does this compare between student groups that are given excerpt A versus excerpt B for a given design problem?
  - RQ1.2: Within Subjects: How does this compare for an individual student who is given excerpt A for design problem 1 and given excerpt B for design problem 2?
- RQ2: Quality - How does the quality of the requirements that students generate differ (subject verb modality)?
- RQ3: Details - How do the details of the requirements that students generate differ?

Research Method

- Note: Excerpts are adjusted for the corresponding design problem

Condition X	Condition Y
Design Problem 1 Excerpt A1	Design Problem 1 Excerpt B1
Design Problem 2 Excerpt B2	Design Problem 2 Excerpt A2

Humor's Effect on the Brain

Garima Bhatia, Elizabeth Gendrau, Ronak Mohanty, Deep Patel, Shree Paudel

Research Question

- What is the correlation between comedy and creativity during engineering design concept ideation?
- Hypothesis:
  - Improv comedy training prior to a creative design ideation session has been proved to produce more creative and quirky ideas. Thus, a stimuli of humor prior to a design ideation session is believed to be able to produce similar results.

Experiment Summary

- Participants are randomly split into 2 groups
  - Group A acts a control group
    - No treatment is given prior to design question
  - Group B acts as an experimental group
    - Shown a comedy sketch prior to design question
- Design question:
  - Is a stimuli of humor to human brain capable of generating relatively creative design ideas as compared to a general design scenario.
- Outcome:
  - Number of concepts generated is used as a measure of creativity

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Impact of constraints on solutions generation

Xuejian Gong; Tyler Johnson; Arun BS; Amaninder Gill;
Amineh Zadbood ; Ting-Ju Chen; Long Jiang

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Research objectives:

- Understand the impact of the number of constraints on a design problem on the quantity of the solutions generated
- Design Problems: bulb replacement
  - Setting three problem levels
  - By varying the number of constraints
  - To observe their impact on solutions generation

Before Experiment
- Gathered Together
- Read Instruction
- Individually
- Pen & Pencil
- Conceptional Ideas

During Experiment
- Consistent Environment
- Quiet Room
- Reference Materials

After Experiment
- Demographic
  - Gender
  - # of ideation sessions
  - Age
  - When and where of their internship(s)
  - Briefly describe the internship
  - Internship's an impact on the solutions you generated

- Count the unique solutions
- Unique assessment
- Each set evaluated by three graders, average taken
- Average of each problem compared

Design problems

- Problem Variation:
- a) Design multiple artifacts that will accomplish the following task: replace a blown out light bulb for a ceiling that is 70 – 100 feet high.
- b) Design multiple artifacts that will accomplish the following task: replace a blown out light bulb for a ceiling that is 70 – 100 feet high. This ceiling is located inside of a building and the only way to bring an artifact inside is a double doorway. Facilities personnel shut down the power supply to the circuits when replacing the bulbs, so the artifact will not have access to power. OSHA regulations prohibit the facilities personnel working indoors to not be raised beyond the height of 25 feet from the ground.
- c) Design multiple artifacts that will accomplish the following task: replace a blown out light bulb for a ceiling that is 70 – 100 feet high. this ceiling is located inside of a building and the only way to bring an artifact inside is a double doorway. Facilities personnel shut down the power supply to the circuits when replacing the bulbs, so the artifact will not have access to power. The light bulb holder has a cover that needs to be removed before replacing the bulb and put back on after the operation is completed. The light bulb holders use different number and variation of fasteners that the artifact should be able to recognize and operate on. OSHA regulations prohibit the facilities personnel working indoors to be raised beyond the height of 25 feet from the ground.

Backup

STATISTICS (GENERAL)

Kappa Test

- For discrete data types
- For qualitative systems
  - Good vs. Bad
  - Go/No-go
  - Differentiating noises (hiss, clunk, clank, thump, pop)
  - For classifying solutions
  - Pass/Fail
- Treats all categories equally
- Does not assume equal distribution
- Requires independence
- Requires categories to be mutually exclusive

Steps for Kappa

- Select sample size to validate protocol
- Have each rater evaluate same unit twice
- Calculate the Kappa for each rater
- Calculate the inter-rater Kappa
- Interpret the results
  - >0.9 is excellent (accept the rating system)
  - <0.7 is not adequate (refine the rating system)
  - $P_{observed} = P_{chance}$ ➔ Kappa = 0
    - Response is random and rating system is totally random
- NOTE: small Kappa for a rater implies that they are not self-repeatable. Can skew the total results.

Select the Sample Size

- Two categories:
  - Minimum of 20 good items + Minimum of 20 bad items = Total of 40 items
  - Maximum of 50 good items + Maximum of 50 bad items = Total of 100 items
- If more than two categories and one is more expected
  - 50% of highly anticipated (“good”) items
  - Minimum of 10% for each other category
  - If not enough samples available for the low expectation categories, then combine these into “other” with greater than 10% sample
- If more than two categories and no clear expectation
  - Strive for balanced distribution
  - Use a minimum of 10% sample for a category

Kappa Calculation

$$Kappa = \frac{P_{observed} - P_{chance}}{1 - P_{chance}}$$

- $P_{observed}$: Proportion of units on which both Raters agree (proportion that both agree good and proportion that both agree bad)
- P_{chance}: Proportion of agreements expected by chance (proportion of A good * proportion of B good + proportion of A bad * proportion of B bad)
  - Poor agreement = Less than 0.20
  - Fair agreement = 0.20 to 0.40
  - Moderate agreement = 0.40 to 0.60
  - Good agreement = 0.60 to 0.80
  - Very good agreement = 0.80 to 1.00

Kappa Calculation

- Rater A (1 1 2 0 1 2 1 1 0)
- Rater B (1 2 1 0 1 1 0 0 1)

- P_observed = (1/9)+(2/9)=0.3333
- P_chance = (2/9)*(3/9)+(5/9)*(5/9)+(2/9)*(1/9) = (6+25+2)/81 = 33/81 = 11/27 = 0.40707

- Kappa =

  (0.3333-0.40707)/(1-0.40707) =

  -0.3333/0.3333 =

  -0.12347

Covariance Coefficient

- Pearson's (population or sample)
- A = (1 2 1 3) ➔ mean_A = 7/4 = 1.75
- B = (3 4 3 5) ➔ mean_B = 15/4 = 3.75
- $r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$
- (1-1.75)*(3-3.75)+(2-1.75)*(4-3.75)+(1-1.75)*(3-3.75)+(3-1.75)*(5-3.75) =
  -0.75*-0.75 + 0.25*0.25 + -0.75*-0.75+1.25*1.25 =
  0.5675 + 0.0625 + 0.5675 + 1.5675 = 2.765
- (0.75*0.75)+(0.25*0.25)+0.75*0.75+1.25*1.25=2.765
- r = 1

Covariance Coefficient

- Pearson’s (population or sample)
- A = (1 2 1 3) ➔ mean_A = 7/4 = 1.75
- B = (3 4 3 5) ➔ mean_B = 15/4 = 3.75
- $r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$
- (1-1.75)*(3-3.75)+(2-1.75)*(4-3.75)+(1-1.75)*(3-3.75)+(3-1.75)*(5-3.75) =
  -0.75*-0.75 + 0.25*0.25 + -0.75*-0.75+1.25*1.25 =
  0.5675 + 0.0625 + 0.5675 + 1.5675 = 2.765
- (0.75*0.75)+(0.25*0.25)+0.75*0.75+1.25*1.25=2.765
- r = 1

Readings

- Atman, 2005
- Chakrabarti, 2004
- Maher, 2003
- Gero, 1998
- Williams and Gero

May 18, 2017 (am)

IMPROVING OBJECTIVITY

Increasing Confidence

- Questions that we will answer
  - How can we improve the confidence in our research?
  - How can we say that our scales (evaluations) are repeatable?
  - How can we say that our observations are accurate?
  - How many local tests should we do for multiple judges?

Judges in Research

- Objective Measures vs. Subjective Measures
  - Objective: something that all people would agree and give the same answer
    - Blue, Red, Green
  - Subjective: something that allows for personal opinion and which will lead to different answers from different people
    - Attractive, Ugly
- Qualitative Measures vs. Quantitative Measures
  - Qualitative: non-numerical based rating system
    - Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree
  - Quantitative: numerical based rating system
    - >5 concepts, 5-3 concepts, <3 concepts
- Absolute Measures vs. Relative Measures
  - Absolute: no comparison is needed to measure the response
    - 5 m long, 10 N weight
  - Relative: comparison is needed to measure the response
    - Annika is taller than Julia

Why Judges

- Consider an experiment:
  - Study the effective of **number of functions vs. number of means** in generating concepts from a morphological chart
  - Want to explore the **Quantity** of the concepts
  - Want to explore the **Location** of the means used
  - Want to explore the **Variety** of the concepts
  - Want to explore the **Novelty** of the concepts
  - Want to explore the **Quality** of the concepts
- Which evaluation can we address without multiple evaluators?
- Which evaluation requires multiple evaluators?

Why Multiple Judges?

- One person can be biased (especially if the evaluator is the researcher – test your own hypothesis)
- Want to add confidence
- Want to remove subjectivity (show objectivity)
- Want to demonstrate repeatability

- Challenges with multiple judges
  - Different backgrounds
  - Different perspectives
  - Different interpretations
  - Different …

- Can address with a pre-experiment protocol definition…

Protocol Definition

- Protocol should
  - Be used to gather only data used in analysis
  - Be objective (independent of evaluator)
  - Be fully defined (can be shared with others)
  - Be validated

- Validation can be through:
  - Inter rater reliability
  - Inter rater repeatability
  - Intrinsically validated
  - Extrinsically validated
  - Intra rater reliability/repeatability

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Inter-rater Reliability

- Rather than use complete judges
  - Use a panel on subset of data
  - If agreement is found, then can analyze using protocol
  - ~10% of the data tested with 2-3 judges (adequate)
  - Saves resources (judges)
- Types of tests
  - Joint probability agreement (multiple raters)
    - Simplest of all
    - Works with discrete choices for two raters
  - Kappa statistics
  - Pearson product-moment correlation coefficient

Joint Probability Agreement

- Rater A (1 1 2 0 1 2 1 1 0)
- Rater B (1 2 1 0 1 1 0 0 1)

- Agreement (Y N N Y Y N N N N)
  - Number of agreements = 3
  - Number of disagreements = 6
  - Total samples = 9

  - Likelihood of Agreement = 3/9 = 0.333

- The ideal is what?

Backup

PROTOCOL STUDIES

Protocol Analysis

- How do designers do tasks
  - Direct Observation
    - Video
    - Collected documentation
    - Other recordings
  - Indirect Observation
    - “think aloud”
    - Interrogation
    - Reflection
- Live protocols
  - monologue (think aloud)
  - dialog (two or more designers)
  - interrogative (researcher asking the designer why they are doing something)
- Retrospective
  - monolog (depositional)
  - dialog (interview/survey)

Protocol Studies

- Applications
  - **Hypothesis generation (pattern recognition)**
  - Hypothesis testing
  - Test effectiveness of design methods
    - Determine optimal parameter values
- Goal
  - discover, develop, test encoding schemas
    - Thinking
    - Activity
    - Strategies
  - Transition schemas to novice designers
    - training
    - designed methods

Conducting Protocol Study

- Issues to be Addressed
  - Objective/Goal/Application – clearly defined
  - Design problem for the subject (scope)
  - Number and type of subject (1/many; novice/expert)
  - Time for exercise data collection
  - Environment (studio, foreign vs. familiar, …)
  - Data collection method (video, survey, sketches, …)
  - Type of interaction (think aloud, interrogative, …)
  - Analysis Methods (protocol)
- Major Limitations
  - 40:1 ratio for analysis (just analysis)
  - Not statistically significant (only one or two)
  - Medium control

Readings

- Chakrabarti: Identification and Application of Requirements
- Maher: Co-Evolution as a Computational and Cognitive Model
- Sen: A Pilot Protocol Study
- Ullman: A Model of the Mechanical Design Process
- Dorst: Creativity in the Design Process

Backup

PROTOCOL STUDY EXAMPLE

A Pilot Protocol Study on the Construction of Function Models in Novel Design

2012 Design Computing and Cognition Conference
College Station, TX

Chiradeep Sen, Oregon State University
Joshua D. Summers, Clemson University

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Research Questions

- Protocol Studies are interested in HOW and WHY
  - Study the PROCESS
  - Less interested in OUTCOMES
- Can explore/test existing models/theories
- Can explore/develop new models/theories
  - Not intended to PROVE theories

- Must have research questions
  - Transform these questions to patterns/hypotheses

Motivation

- How designers construct function models has not been experimentally studied.
- What can we learn from studying modeling actions / model interactions?
  - About the problem?
  - About the model / modeling tool?
  - About designers?

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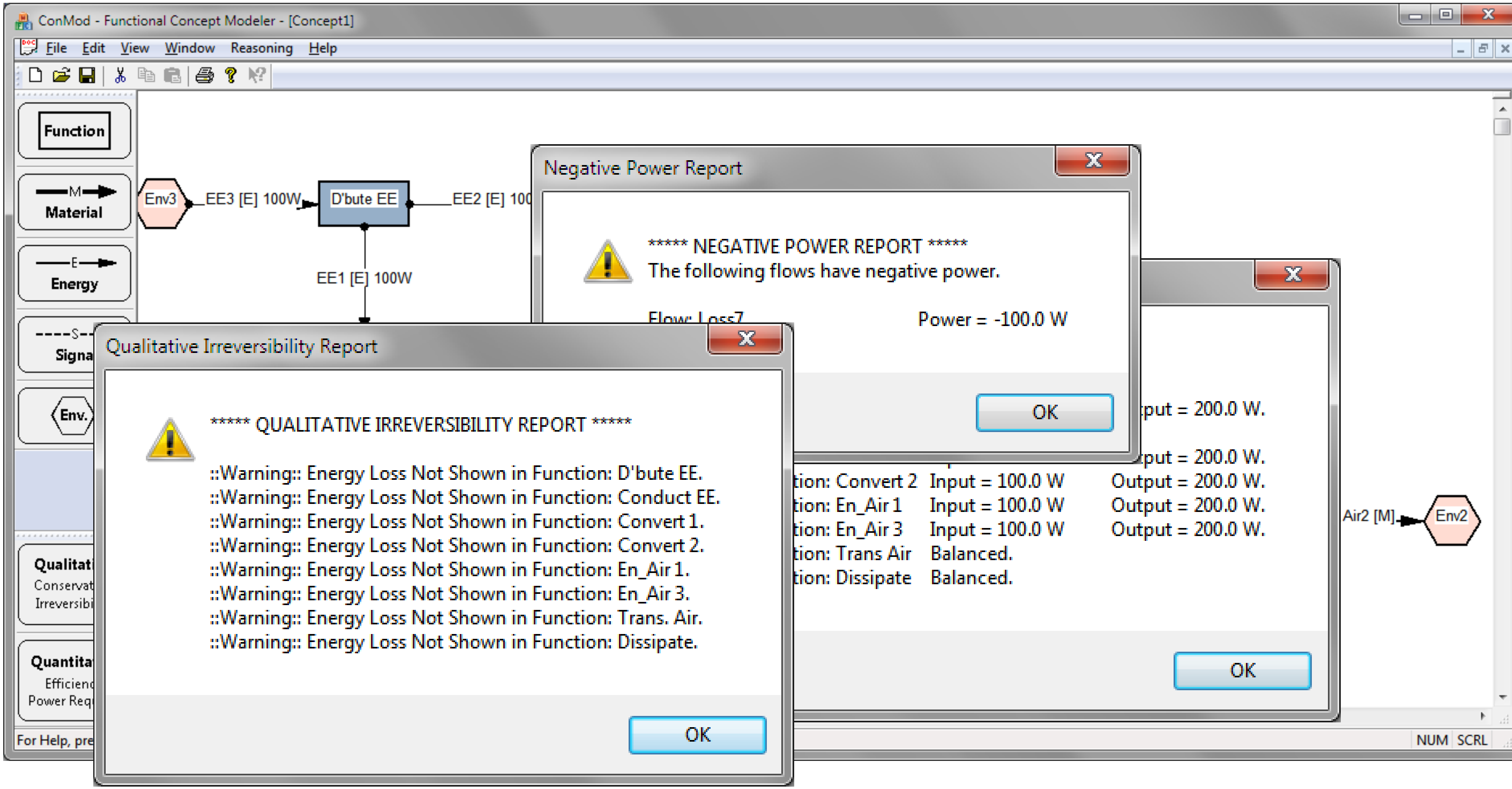
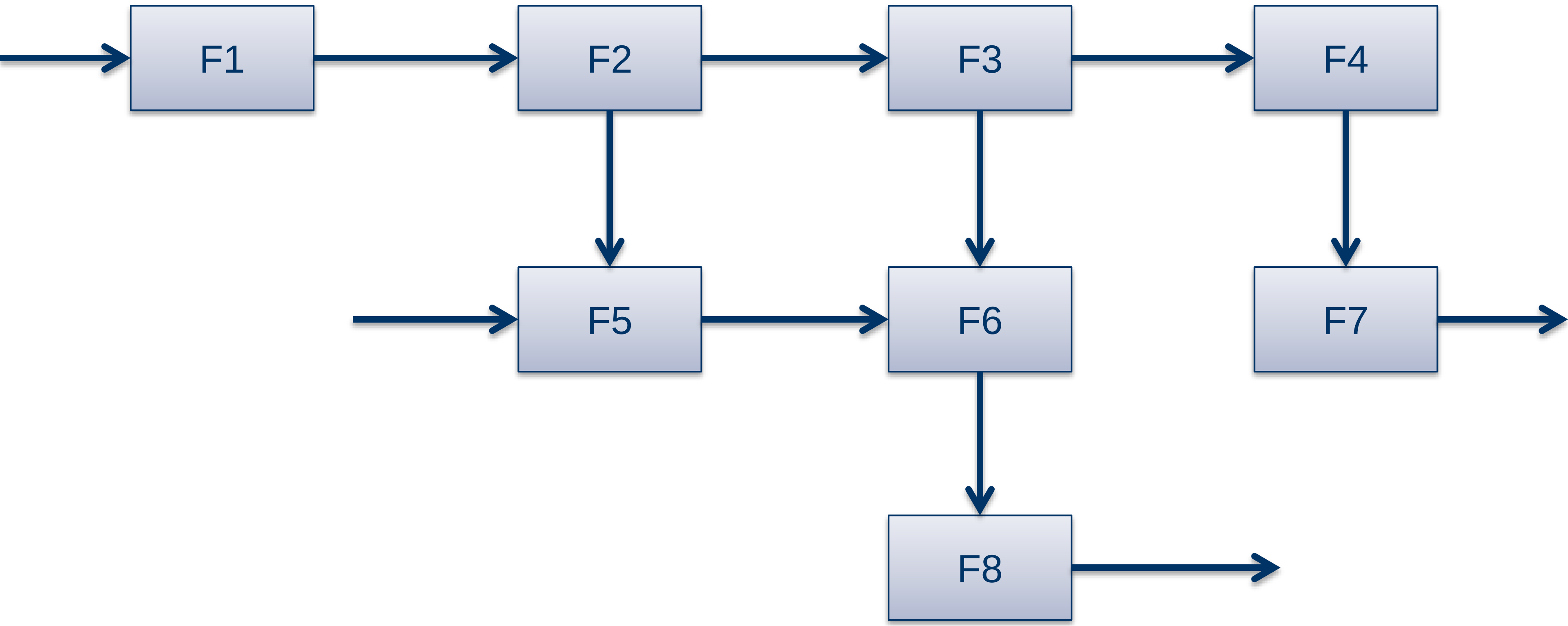
Background

- Concept modeling software GUI design



Model growth: Possible trends

- Forward propagation
- Backward propagation
- Nucleation



Population of Study

- Challenge to Protocol Studies
  - Small sample set (typically a few designers)
  - Is the set representative?
- How to select population?
  - Availability (students; professionals are possible – fewer needed than in controlled studies)
    - Need to collect and “test” demographics
- Dealing with people, must consider
  - Expertise/Training
  - Gender/Race/Culture
  - Socio-economic
  - Self-efficacy
  - Personalities
  - Rewards (need to be concerned about the population’s motivations)
- Institutional Review Board (IRB – Human subject experimentation = significant oversight)

Participants

- Two participants (PILOT)
  - P1 – design experience > 10 years
  - P2 – design experience ~ 2 years

- Preselection survey
  - Experience with function modeling (fwd, rev)
  - Experience and role in product design
  - Familiarity with various product types

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Design the Problem

- Most of time is spent on the problem
- Want it to be accessible to the participant
  - Culturally insensitive
  - Quick interpretation
  - Robust/fertile area for exploration
  - New (not previously seen by subjects)
  - Domain appropriate
  - Not leading (without bias to sought patterns)

Design problem

Design an automatic clothes-ironing machine for use in hotels. The purpose of the device is to press wrinkled clothes as obtained from clothes dryers and fold them suitably for the garment type. You are free to choose the degree of automation. At this stage of the project, there is no restriction on the types and quantity of resources consumed or emitted. However, an estimated 5 minutes per garment is desirable.

Variable Control

- Environmental issues, must consider
  - Time of day (before meals/after meals; early morning; …)
  - Location of experiment (familiar, unfamiliar,…
  - External noises, smells, sights (overly distracting, too insulated,…)

Data Collection Methods

- How do designers do tasks
  - Direct Observation
    - Video
    - Collected documentation
    - Other recordings
  - Indirect Observation
    - “think aloud”
    - Interrogation
    - Reflection
- Live protocols
  - monologue (think aloud)
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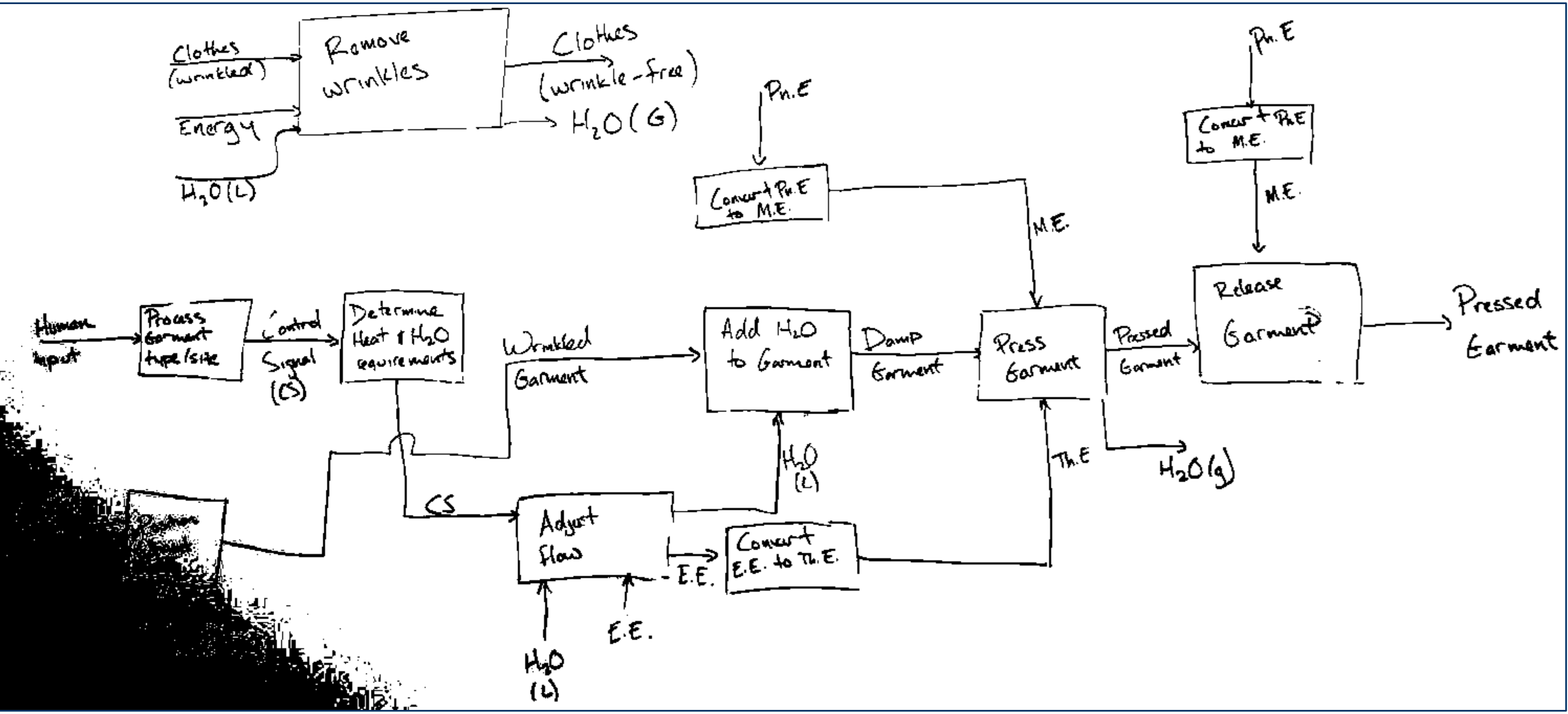
  - interrogative (researcher asking the designer why they are doing something)
- Retrospective
  - monolog (depositional)
  - dialog (interview/survey)

Sample data

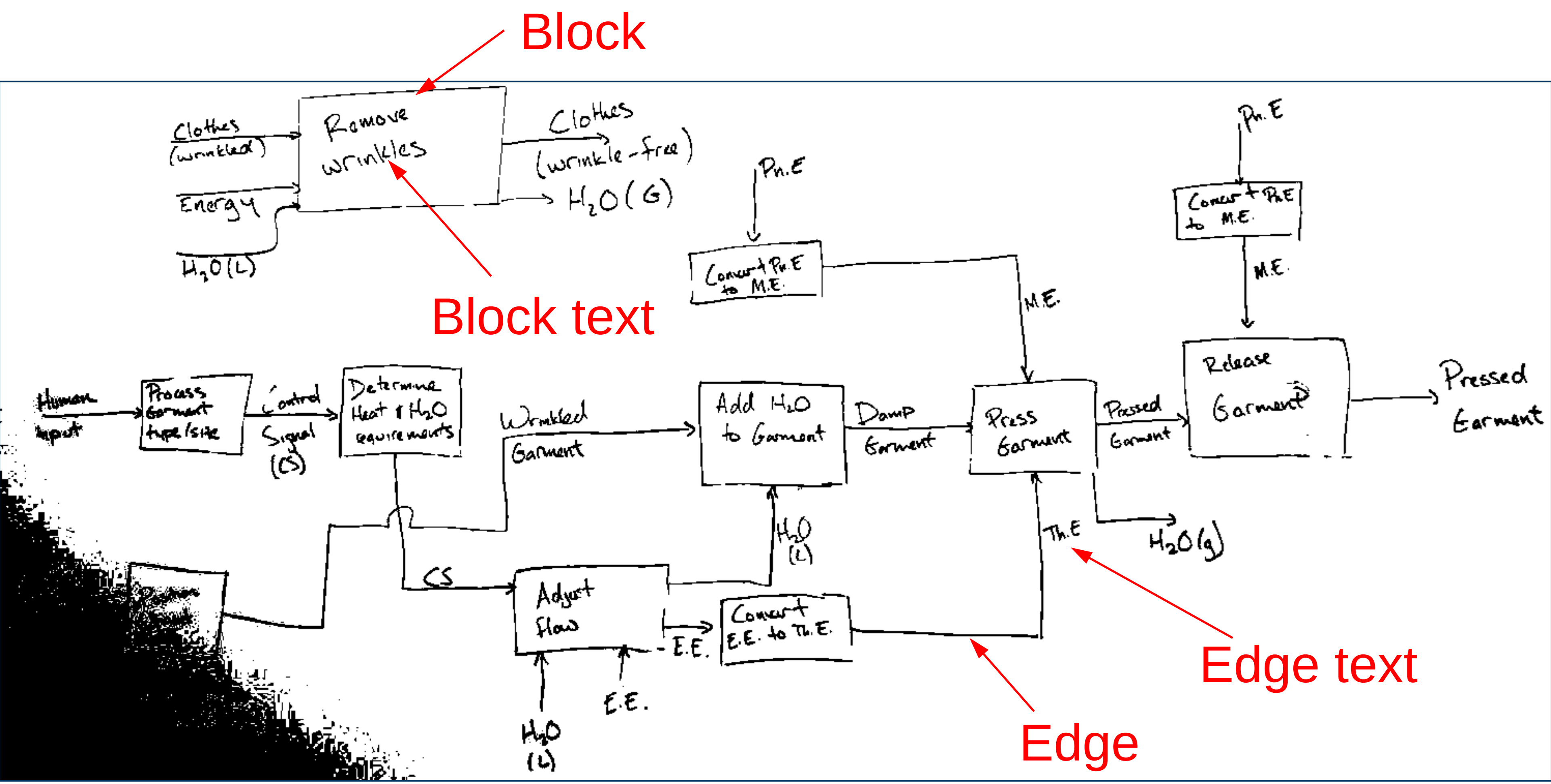
- Video, still photo



Protocol Development

- Coding is at the central of the protocol analysis research method
- Must develop codes that are:
  - Objective (different people would come code same slice similarly)
  - Repeatable (one person could code slice the same way each time)
  - Simple (coding can be time consuming)
  - Targeted (collect information on the subject of study only)
- Transcript to coding
  - Typically 40:1 ratio (if you collect 1 hour of data from 20 people, then you have 800 hours of coding = 20 manweeks of work!)
  - Must make the code explicit and available
  - Must make the protocol explicit and available

Coding: Element vocabulary



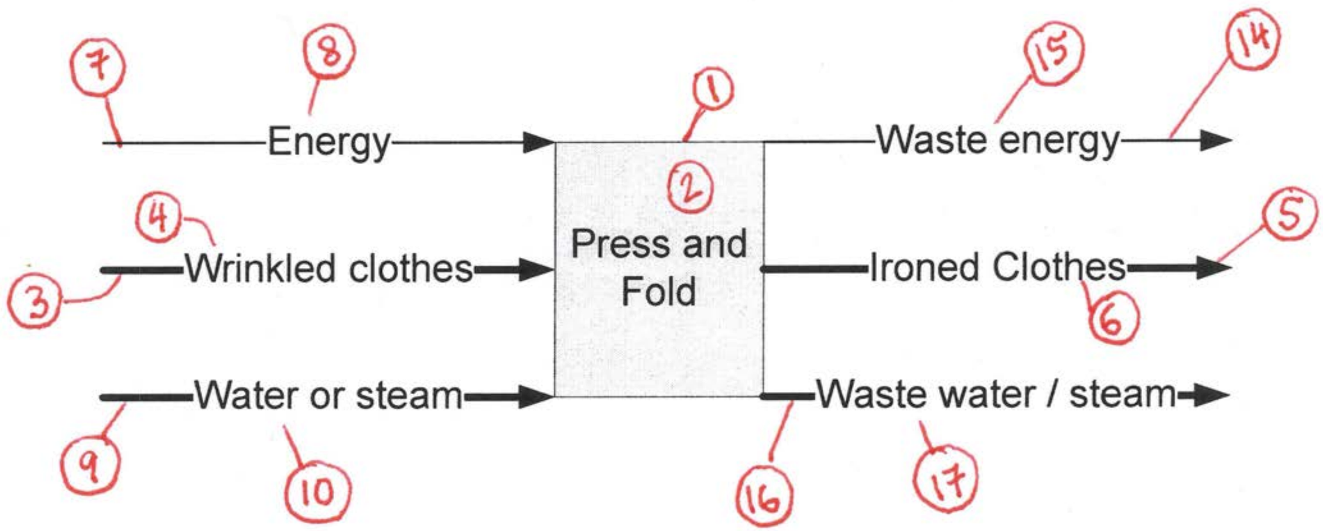
Coding: Element vocabulary

Element	Code	Definition
Block	B	A rectangle typically used to represent a mechanical function in the model. Incomplete definitions such as rounded edges or open corners included.
Block Text	BT	Text written within a block, indicating the name or description of the block (typically mechanical function)
Edge	E	An arrow, including its stem and its head, attached to a block or not, typically use to represent flows in the model
Edge Text	ET	Text written above, below, or beside an edge, indicating a name or description of the flow
Source	SC	A circle or other shape, indicating the source of a flow or flows that are not originating from a rectangle (function)
Sink	SK	A circle or other shape, indicating the terminus of a flow or flows that are not terminating to a rectangle (function)
Note	N	A textual or symbolic expression that is not an ET or a BT
Symbol	S	A graphical expression (such as an arrow, a highlighting on existing text (e.g., underlines, encircling, or a punctuation mark)
Symbol Text	ST	Text used to annotate a symbol, such as text written beside an arrow that is not an E
Diamond	D	Diamond-shaped boxes in the graph-based part of the model, typically used to represent a decision point
Diamond Text	DT	Text written inside a diamond
Edge Head	EH	The head of an edge, drawn at least one pregnant pause or more time lapse after drawing the stem

Coding: Activity vocabulary

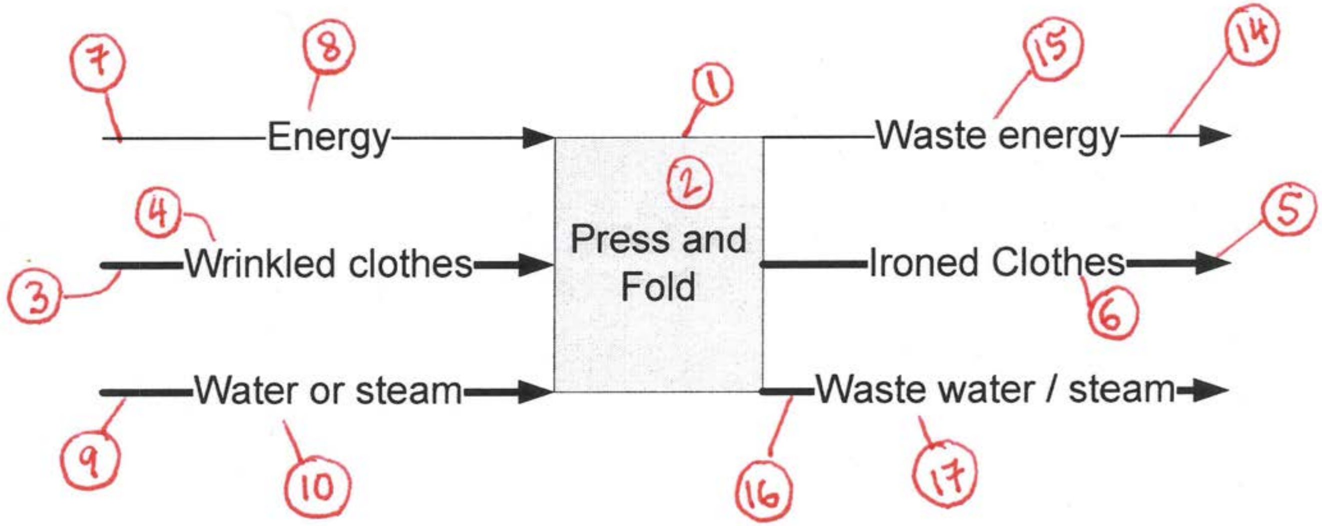
- Add element
- Delete element
- Edit element
- Read problem statement
- Pregnant pause

Step 1: Activity encoding



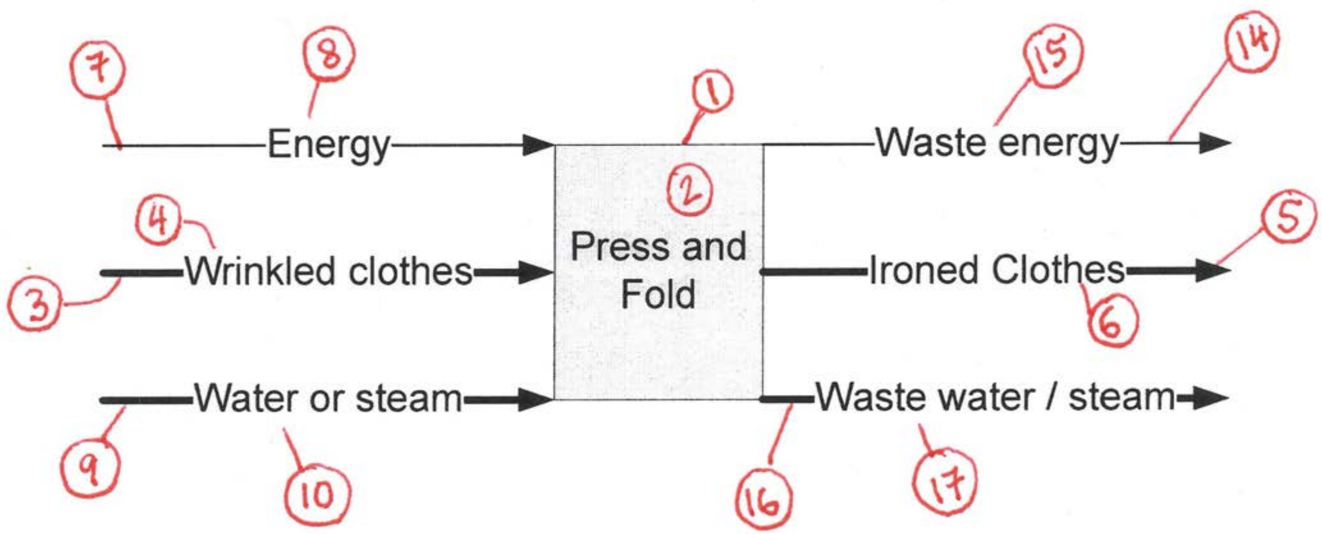
TmStmp	Act	Element IDs								
0:30	PS									
1:21	A	1	2	3	4	5	6			
1:48										
2:10	PS									
2:18										

Step 2: Element encoding



Elem ID	Elem Typ
1	B
2	BT
3	E
4	ET
5	E
6	ET
7	E

Step 3: Topology encoding



Elem ID	Elem Typ	Topology	
1	B	0	0
2	BT	1	
3	E	0	1
4	ET	3	
5	E	2	0
6	ET	5	
7	E	0	1

How to Test the Coding

- Need to be able to verify that the coding is objective and repeatable
  - Use inter-rater reliability (across raters)
  - Use intra-rater repeatability (within raters)
  - Use small slices of the data (~10% minimum)
  - Use 2-3 raters
- Types of tests
  - Joint probability agreement (multiple raters)
    - Simplest of all
    - Works with discrete choices for two raters
  - Kappa statistics
  - Pearson product-moment correlation coefficient

Joint Probability Agreement

- Rater A (1 1 2 0 1 2 1 1 0)
- Rater B (1 2 1 0 1 1 0 0 1)

- Agreement (Y N N Y Y N N N N)
  - Number of agreements = 3
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  - Likelihood of Agreement = 3/9 = 0.333

- The ideal is what?

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Pattern Analysis

- Define sought patterns *a priori*
  - Before testing, so that objectivity can be maintained
- Patterns
  - Adjacent patterns (sequenced elements/activities)
  - Distant patterns (interspersed with other elements)
  - Partial patterns (incomplete)
  - Counter patterns (opposite sought)
- Analysis
  - Break data (transcript) into units
  - Relate the units
    - Temporally, Cognitively, Ordered
  - Find encoding schemes
    - Patterns, Strategies

- The three steps are integrated

9:57	A	70	71	72	73							B	E	ET	BT		
10:03												74					
10:11	A	74										B					
10:14												75	76	77	78		
10:15	A	75	76	77	78							BT	E	ET	B		
10:22												79	80	81			
10:23	A	79	80	81								BT	E	B			
10:28												82	83	84	85	86	87
10:30	A	82	83	84	85	86	87					BT	ET	E	ET	SC	SC

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Observations

- Flow names immediately follow flows
- Function names rarely follow functions
  - They are added after the flows are added
  - Often edited multiple times

Flow name follows flow	Function name follows function
46 / 48	4 / 13

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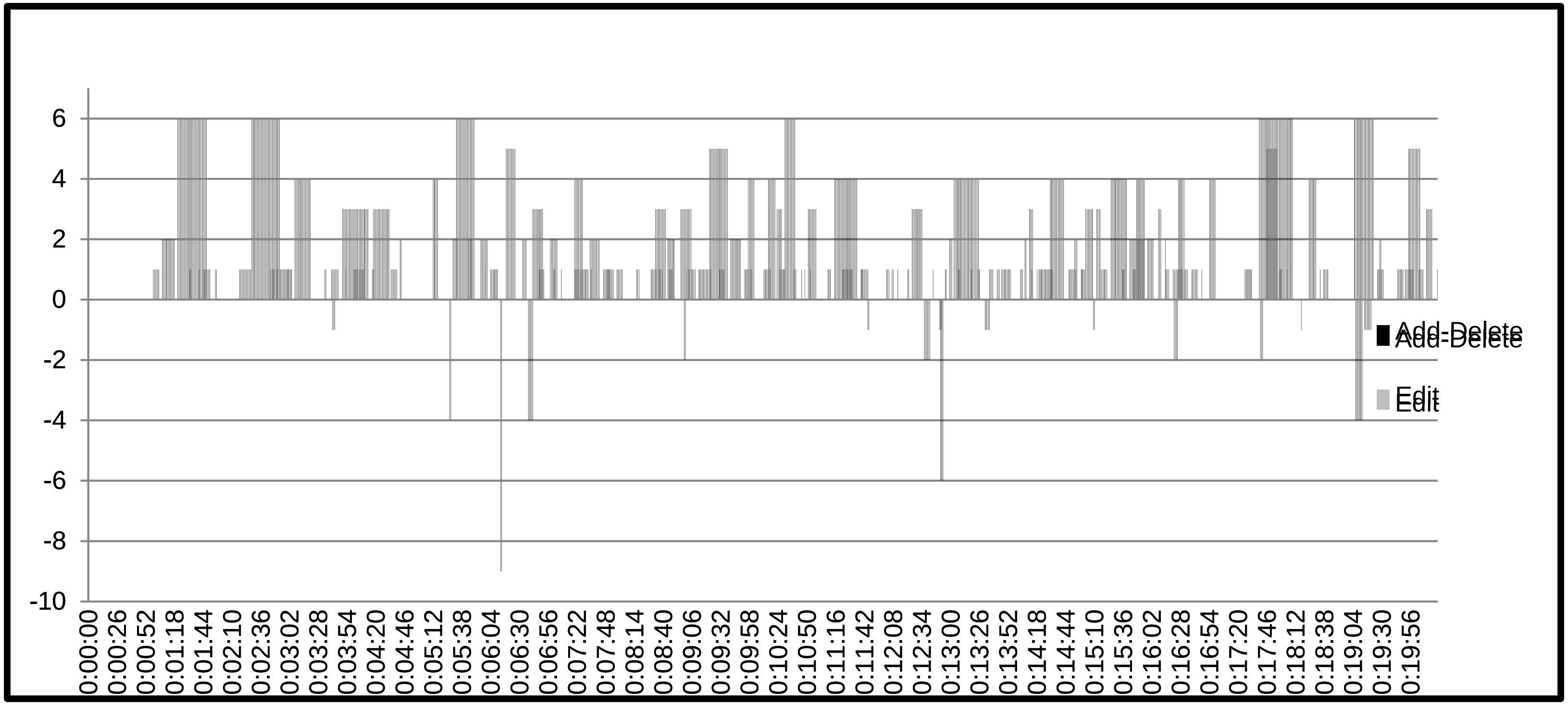
Model growth

- Experienced designer: nucleation
- Novice designer: forward

- Add function: forward, nucleation
- Add flow: forward, backward

	Forward	Backward	Nucleation
Function	7	1	6
Flow	16	11	2

Activity graphs



- Average column heights
  - Higher for experienced designer (6) than novice (2)
  - Relation to 7+/- 2 chunk size?

Results/Findings

- Findings are suggestive
  - Focused on behavior
  - Provide evidence to warrant additional detailed study
  - Support theory/model formation
  - Provide evidence (not proof)
- Good Research leads to New Research
- General Findings (Protocol Studies in Literature)
  - Evidence of design fixation
  - Expert = Greedy; Novice = Systematic
  - Preferred Language = Drawings
  - Conjectures -> Constraints -> Solutions
  - Oscillate between Problem Definition and Solution
  - Designers not good at generating alternatives
  - Problem Solving Strategies found

Cross and Dorst

- Specific Findings from Cross and Dorst
  - first real effort on trying to develop a standard approach(es) to engineering design research
- Problem Formulation
  - do not define problems rigorously in advance
  - study the problem/solution together
  - drawing is preferred (pictures “talk back” to the designers who “respond”)
  - solution is not directly derived from the problem
  - problem is understood from the solutions presented
- Solution Generation
  - poor job of generating adequate number of solutions
  - solve alternative problems
  - designers attempt to constrain space
  - process is self-correcting
  - avoid radical changes to initial solution (design fixation)

TEA Model

- Task, Episode, Accumulation Model
  - Ullman at Oregon State (also founder of ASME DTM)
- Design
  - State – Contains all information about evolving design
    - Proposal (How)
    - Constraints (What)
  - Operators – Primitive information processes
    - Generate (Select, Create)
    - Evaluate (Simulate, Calculate, Compare)
    - Decide (Accept, Reject, Suspend, Patch, Refine)
- Operators Change the State
- Episodes: Macros of operators
  - Assimilate, Document, Plan, Repair, Specify, Verify

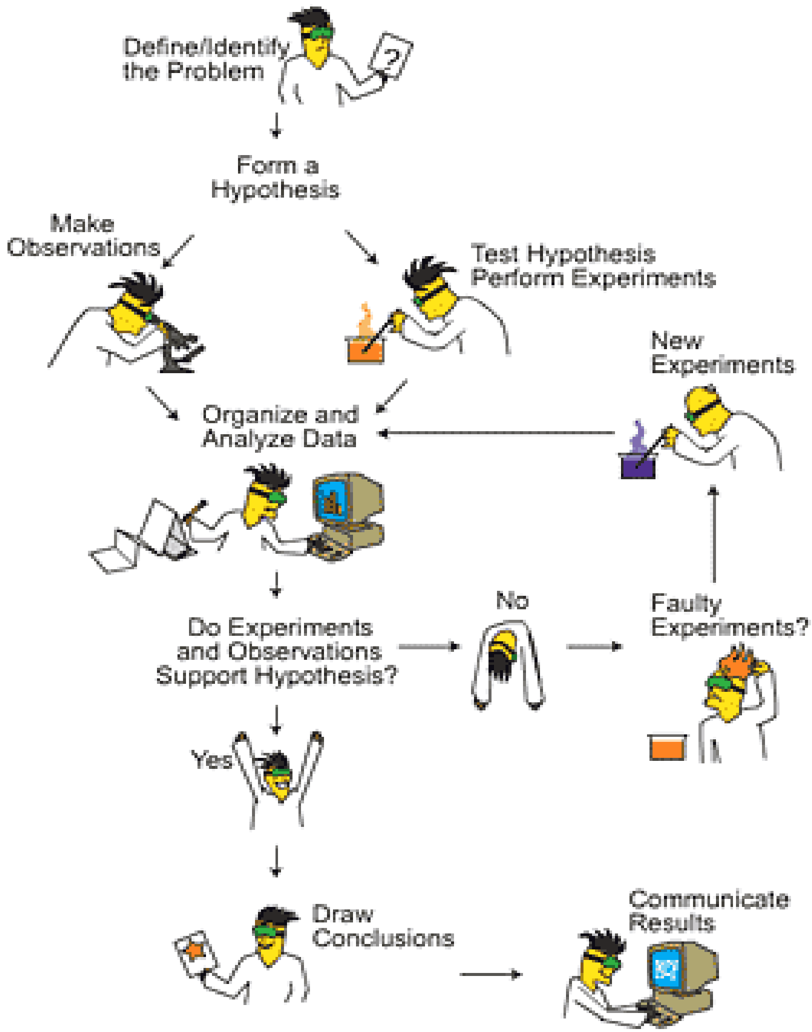
Readings

- Teegavarapu: Case Study Method for Design Research
- MacNealy: Toward Better Case Study Research

May 22, 2017 (am)

CASE STUDY

Research Methods



- Qualitative Methods
  - Interviews
  - Participatory research
  - Document analysis
  - Ethnographic study
  - Experiential analysis
  - Observatory study
  - Cultural inventory
  - Protocol study
- Quantitative Methods
  - Anthropometric study
  - Structural test
  - Standardized test
  - Written survey
  - Demographic study
  - Statistical analysis
  - Experimental study

Case Study

- Definition
  - *empirical research method used to investigate a contemporary phenomenon, focusing on the dynamics of the case, within its real life context*
- Uses
  - Exploratory
  - Descriptive
  - Explanatory
- Scenarios of use
  - Objective is to find answers to “why” and “how” questions
  - Not possible to control the behavioral events
  - used in situations where the contextual details have to analyzed, but the phenomenon is not distinct from context

Major Case Studies

- David Marples (1960's)
  - Studied the design process (one of the first)
  - "The Decisions in Engineering Design", IEE Transactions on Engineering Management, vol. 8, no. 2, pp. 55-71, 1961.
- ASEE (1970's)
  - Developed a series of "case studies" for teaching engineering
  - Similar to Law, Medicine, and Business
  - Never widely applied
- Shingo (1980's)
  - Toyota Production System
    - Lean Manufacturing, Value Engineering, Six Sigma
- Ward (1994, 1996)
  - Toyota Design Process

Objections

- Cannot generalize from a single case
  - Must be careful about selecting the critical case (or case set)
  - Developing theories with propositions
  - Use falsification logic (if theory fails for one, then it is not universal)
- Lacks rigor
  - Onus on the researcher to follow well defined protocols
- Take a long time
  - Length of time is typically determined by superfluous information
  - Must focus on the specific goals of study
- Biased
  - Use falsification logic
  - Use triangulation

Case study method

- Case study is an ideal method, when
  - The aim of research is to find answers to ‘why’ and ‘how’ types of questions
  - It is not possible to control the behavioral events
  - Contemporary events are studied
  - phenomenon is not distinct from context
  - the variables of analysis are more than the data points collected

Research method	Type of research question	Requires control of behavioral events?	Focuses on contemporary events?
Experiment	How, why?	Yes	Yes
Written survey	Who, what, where, how many, how much?	No	Yes
Documents analysis	Who, what, where, how many, how much?	No	Yes/No
Historical study	How, why?	No	No
Case study	How, why?	No	Yes

Case Study Method - Summary

- Used in design research because:
  - The sample sizes are statistically invalid.
  - Number of variables is greater than data points.
  - A design task cannot be appropriately replicated /simulated outside its real life context.
  - Intrusion by external factors, including a research method, would affect the design process.
  - Direct observation of variables is many times impossible .
  - There is no fixed measure of success in design.
  - Some of the decisions made by designers, many times based on their intuition, could not be explicitly justified.
  - A design task cannot be performed twice without the effect of learning bias.
  - Variables and influences are highly interconnected .

Readings

- Sobek-2004: Relating Design Activity to Quality of Outcome
- Sobek-2005: Adapting Real Options to New Product Development
- Stowe: Prototyping in Design of a Lunar Wheel

Backup

CASE STUDY EXAMPLE

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Prototyping in Design of a Lunar Wheel, Comparative Case Study of Industry, Government, and Academia

SAE Aero Queretaro

Queretaro, Mexico (2010)

David Stowe (Corvid Technologies)

Samantha Thoe (Clemson University)

Joshua D. Summers (Clemson University

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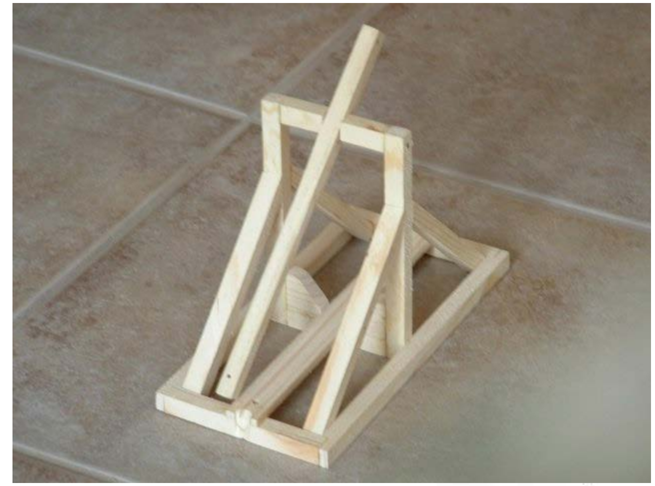
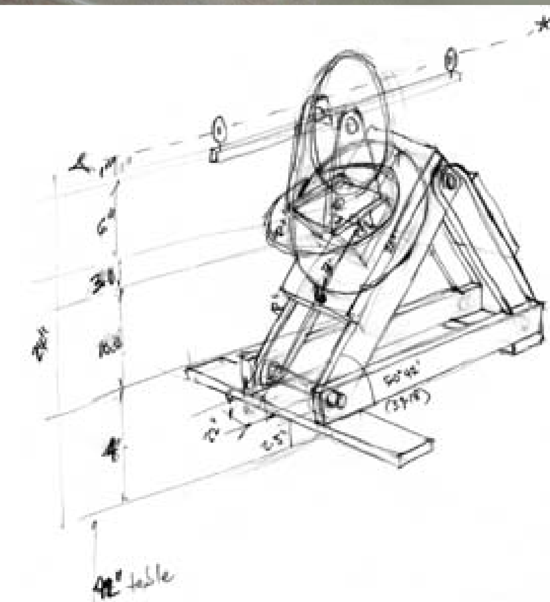
How do you do it?

- Determine the scope of the case study
  - Are you investigating the tool use?
  - Are you studying the communication between groups?
  - Are you trying to extract the rationale for why something was designed?
  - Are you looking at the process or the product?
- Determine what will be done with the study
  - Use it to improve process?
  - Use it to justify the existing tools?
  - Use it to identify future research?
- Determine the method of investigation
  - Documentation
  - Interviews (scripted, unscripted)
  - Surveys

Prototype Definition:

- Prototypes are **fit**, **form**, or **functional** design representations which enable designers to **communicate**, **test**, or **validate** design ideas
- Representations which do not require translation between designers





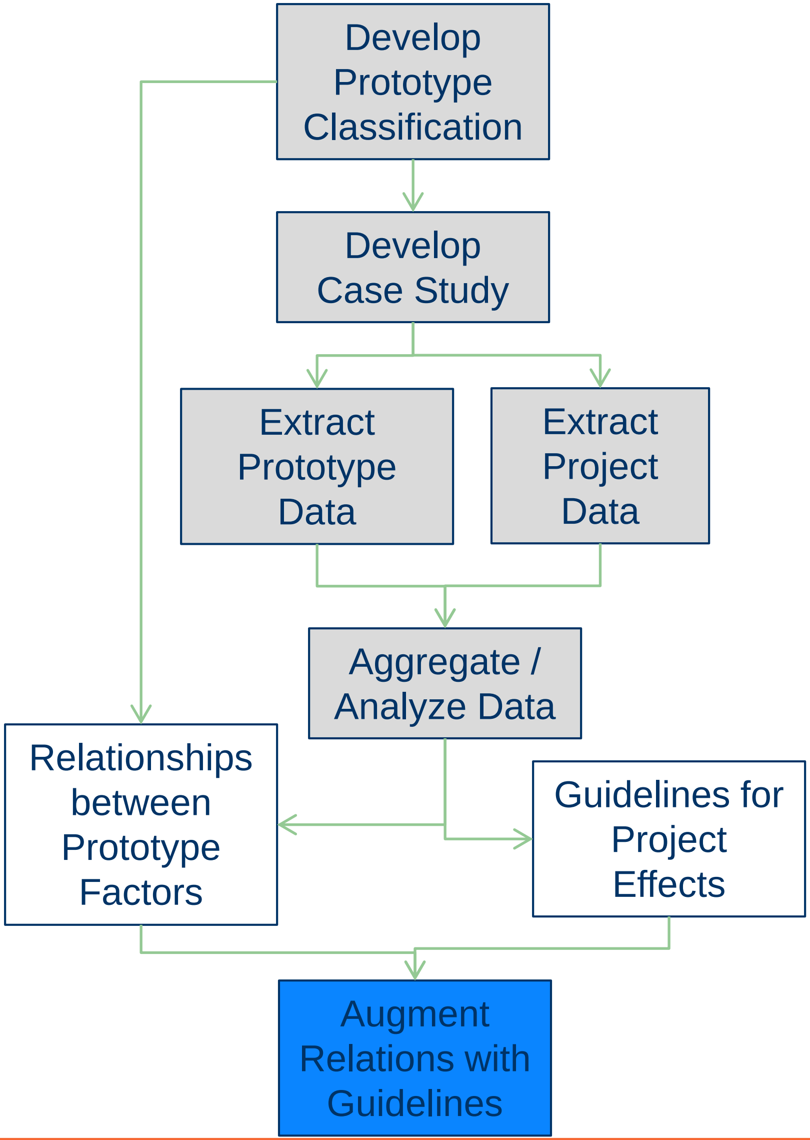
Problem Statement:

- Prototyping is almost universally employed as a component of the design process [1, 2, 3]
- Prototypes have inherent benefits [1, 3, 4, 5, 6]
  - are often misapplied in the design process which results in negative consequences [3, 4, 5, 7,8]
- The role of prototyping in design is well defined
  - its relationship with the design process is **not** due to the complex interaction [9, 10, 11, 12].

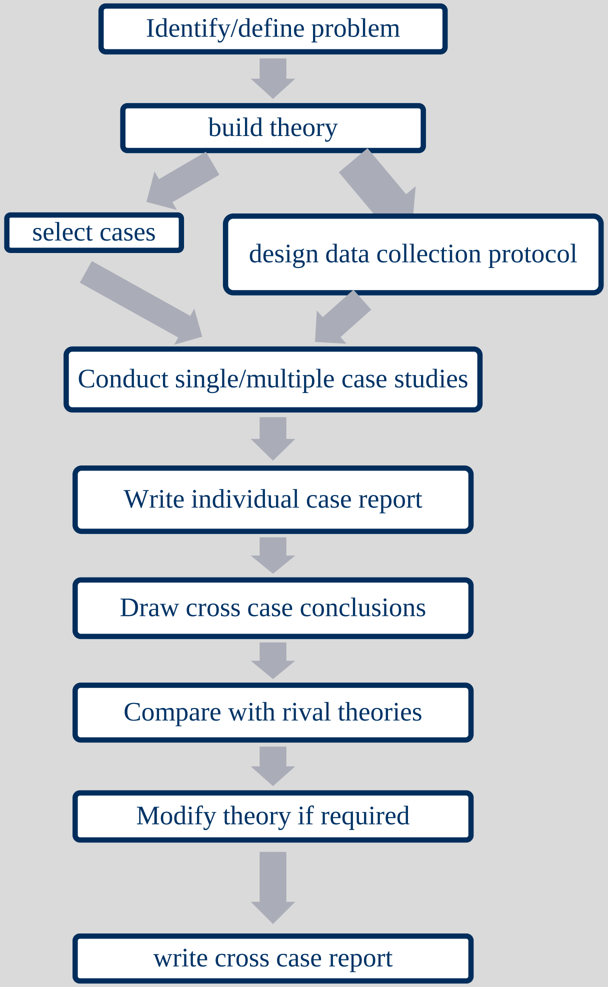
- Therefore how to effectively apply the prototyping process is not well understood

Research Method Overview

- Two distinct processes
  - Classification Development
  - **Case Study Development**
- Dependency between processes
  - Classification defines case study focus
  - Case study data is used to define relationships in classification system
- Ordered Process
  - Starts with developing the guiding prototype process in order to enable the remainder of the process



Case Study Method



- Define and Design
- Prepare, Collect, and Analyze
- Analyze and Conclude

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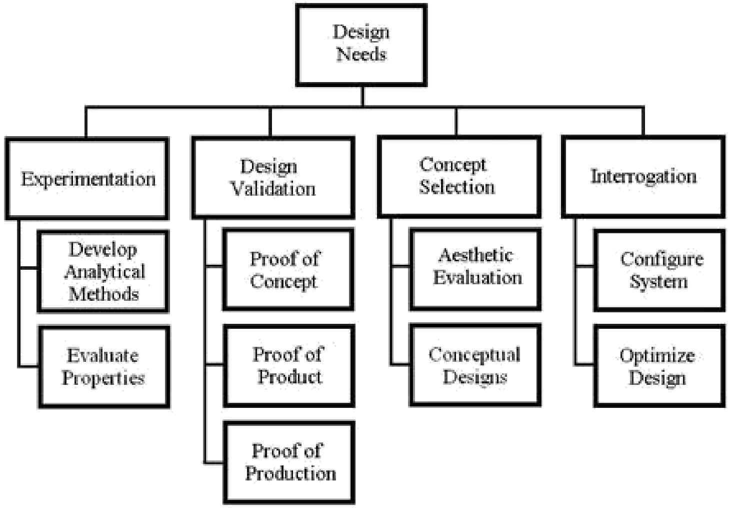
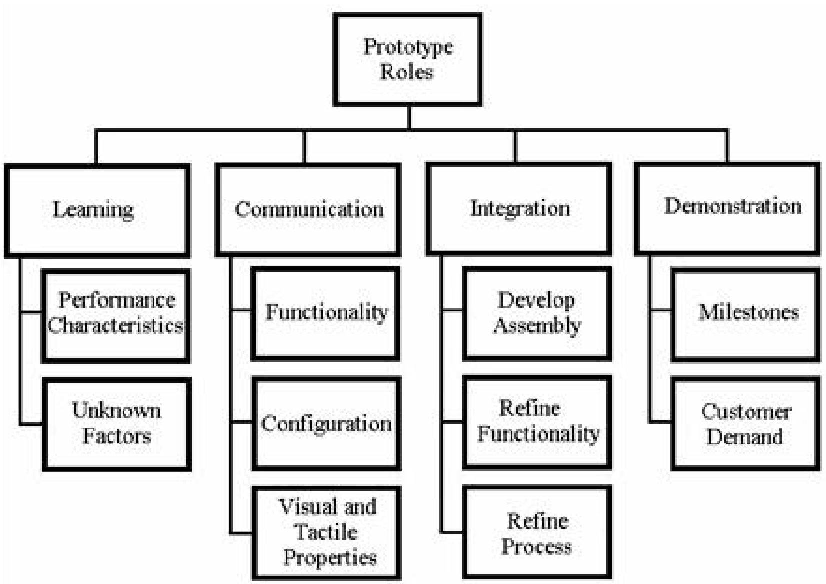
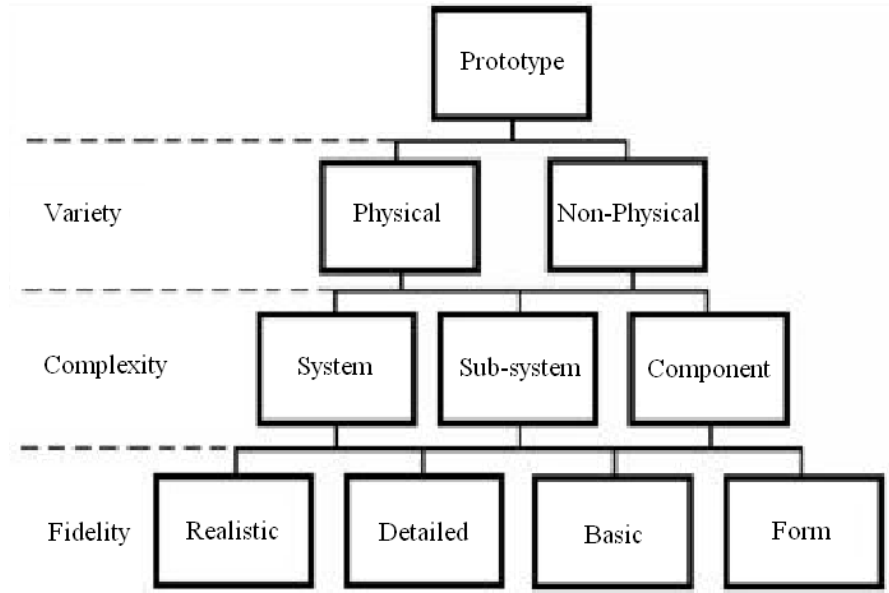
Prototype Taxonomy







Project Specific Factors	
Project Details	**Project Constraints**
Collaboration	Expertise
Project Goals	Budget
Technical Level	Team Size
Design Methods	Other
Situational	

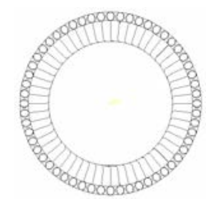
Case Studies

- Subjects
  - Artifact (construction, function)
    - Catalogs, Product families, Benchmarks
  - Failure of a Product
    - Lessons learned, regulations
  - Design Process
    - Current procedures, New procedures
  - Design Organization
    - Innovation, success factors
  - Tools and Techniques
    - Best practices
  - Production Systems
    - Coordination, communication
  - Ethics
    - Education, profession

Case Study Background



- NASA's mission to the Moon:
  - The lunar environment (40 K to 400 K)
  - Aggressive surface
  - Long time (10 years)
  - Long distance (10,000 km)
- Tweel for Lunar Applications
  - Physical testing in Clemson Soft-Soil, Off Vehicle Endurance System
  - Calibration against obstacle impact (ATV testing)
  - Numerical simulation of Tweel over obstacles



- Four year development project at Clemson University
  - Initiated as a Senior Design project (4 patents filed)
  - Follow on projects with Michelin, NASA, NIST (~$3.5M)
- Involved parties
  - Michelin (industry partner and inventor of the Tweel technology)
  - Jet Propulsion Laboratory (developer of the ATHLETE and consumer of Lunar Tweel)
  - Clemson University (prime developer for the Lunar Tweel)

Case Selection

- Must be *Critical*
  - Is this a common/representative case?
  - Is this a unique/unusual case?
- Must be “real world”
  - Does this case have interesting context?
- Is the case unbiased?
  - Are the researchers vested in the outcome?
  - Can the researchers influence the case progression?

Case Selection

- Provide information on collaboration, various prototyping practices, and different organizational practices:
  - Lunar Wheel Development project was chosen to because it fulfilled these needs
  - Sources for study: 5 interviews, 3 documents, and 1 ethnographic study
- Supplementary studies were chosen from literature to independently test the data extracted during the primary study:
  - 5 independent sources were chosen to use for comparison with the conclusions of the primary study (out of scope for this presentation)

Case Studies

- Data Collection
  - Models
  - Process – paper trail (documents)
  - Interviews/Surveys
  - Organizational Charts
- Want **objectivity**
  - Data (no interpretation)
  - Temporally stable
  - Traceable
  - Triangulated

General Views (Industry)

- Bart Thompson (Senior Engineer at Michelin)
  - Two seperate prototyping practices
  - One was tire design
    - Design lots of new tires, test them, then select just a few for production based on the testing results.
    - Rudimentary tools to help them design, but the problem is well understood and they pretty much brute forced it.
  - Tweel design was much more analytical and conceptual
    - They do not have the tooling to do it on-site at low cost, so they out sourced it to Clemson and the Swiss.
    - Michelin is streamlined to making tires, not necessarily adaptable enough to design and test something like the Lunar Tweel on their own.
    - “In making Tweels, we first do some virtual prototyping and do some FEA. The FEA includes in-house code as well as ABAQUS commercial software. We try to do as much optimization as we can in terms of software before we build physical prototypes. We gain a lot in physical prototyping…”

General Views (Government)

- Jaret Mathews (Lead Robotics Engineer)
  - Prototype to reduce risk (tend to work in very risk adverse fields such as propulsion, military vehicles, or satellites: need to get it right)
  - Use prototyping to explicitly test their technical readiness level.
  - They prototyped for the sake of prototyping because it helped them obtain more funding.
  - “The goal is for the research side of the house to spearhead the concepts. To develop proof-of-concept systems, test them, and try to advance our technology readiness level (TRL) up to a point where they can be integrated into the flight systems. There the goal is to retire as much risk as possible before you make the decision to fly into space.”

General Views (Academia)

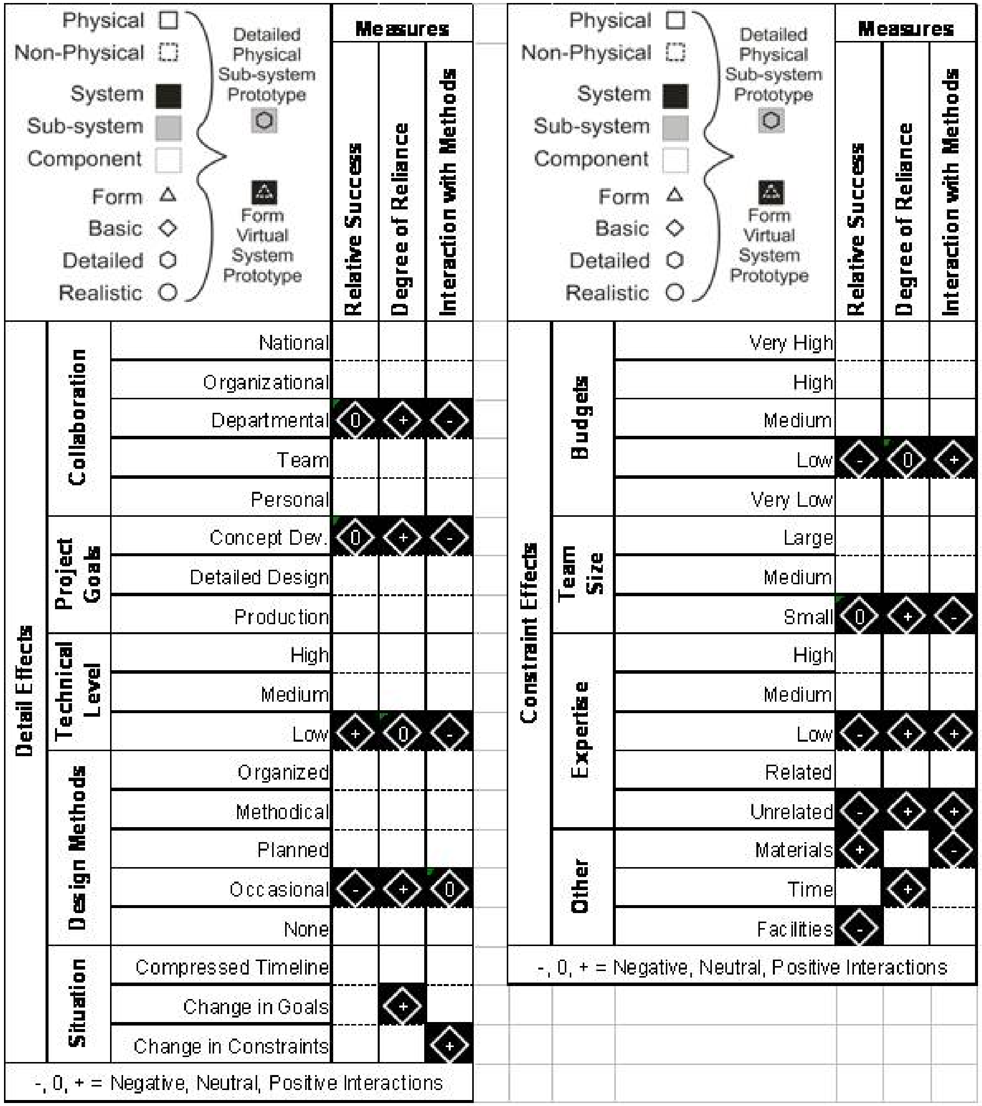
- Joshua D. Summers (Faculty)
  - prototyping links what students learn in coursework to the actual application of those principals
  - “what you have on paper isn’t necessarily what you’re capable of building… The challenge of building something and then having to validate that it works or has some level of performance introduces an interesting level of understanding for the students”
- Beshoy Morkos (Undergraduate/Graduate Student)
  - Prototyping in time constraints leaves many details to be sought out later.
  - “We were more concerned developing different concepts and finding new domains you could reach into in order to create a wheel. It wasn’t so much to have a design set in stone, and say that this works and we’ve tested it in every possible manner.”

Case Study Tools

- People based data collection
  - Survey
  - Interviews
- Data based collection
  - Document analysis
    - Internal (information within document)
    - External (macro document properties – date, size, author)
  - Product analysis
    - Prototype evolution
    - Failure analysis
    - Benchmarking

Case Study Data Collection

- Project Specific Factors
  - Tool to collect and organize project specific factor data
  - Tabulated data maintains chain of evidence
  - allows for analysis of aggregated data in the cross-case study
  - All data was interpreted directly from sources
  - Measures used:
    - Relative Success
    - Degree of Reliance
    - Interaction with Methods



Case Study Data Collection

- Prototype Specific Factors
  - tool to collect and organize prototype specific factor data
  - data extracted directly from study sources, with exception of success measure (used outside sources – such as project progression)

Description	Success	Prototype Option		Roles Played	Needs Fulfilled
Example 1	0	**Variety**	Physical	communication functionality	develop analytical methods
		Complexity	System	unknown factors	evaluate properties
		Fidelity	Detailed	performance characteristics	configure system
Example 2	+	**Variety**	Virtual	performance characteristics	develop analytical methods
		Complexity	Component		optimize design
		Fidelity	Basic		
Example 3	-	**Variety**	Physical	milestones	proof of product
		Complexity	Sub-system	customer demand	
		Fidelity	Realistic	refine functionality	
- is unsuccesful, 0 is no effect, + is successful					

Data Collection Example

- ***Interview:*** Academic, Lead, Faculty

- ***Transcript:***
- "“We had 1st generation lunar wheels built by the senior design students that we oversaw…Though there were some attempts at virtual prototyping: the bristle analytical models were moderately useful and the cylindrical models were almost moderately useful …it proved more productive for the students to build physical prototypes, especially during this early conceptual stage of design.”
  - ***Note:***
  - Mentions physical and virtual prototypes, expertise of designers, project goals and some measures of success for the virtual and physical prototypes.

- These can be extrapolated into data

Cross-Case Data Analysis Protocol

- Project Specific Data
  - Embodies cross-case synthesis
  - General patterns for project factors
  - Aggregate data allows for general prototype related project trends to be discovered (right)
  - Aggregate data can also be used to determine prominent successful prototyping options for various combinations of measures and effects. (bottom)

			Measures: Relative Success	Measures: Degree of Reliance	Measures: Interaction with Methods
Detail Effects	Collaboration	National	-0.8 (4)	-0.9 (5)	-0.1 (3)
		Organizational	+0.1 (2)	[illegible]	[illegible]
		Departmental	+0.5 (5)	[illegible] (3)	[illegible] (1)
		Team	+0.9 (2)	+0.9 (2)	-0.9 (2)
		[illegible]			
	Project Goals	Concept Dev.	[illegible] (7)	-0.7 (8)	+0.7 (6)
		Detailed Design	+0.1 (2)	+0.1 (3)	-0.1 (4)
		Production			
	Technical Level	High			
		Medium	+0.2 (2)	+0.2 (2)	-0.1 (4)
		Low	-0.5 (8)	+0.1 (9)	-0.7 (7)
	Design Methods	Organized			
		Methodical	-1.0 (1)	+0.2 (2)	-0.7 (1)
		Planned	+0.8 (3)	-0.6 (4)	-0.2 (3)
		Occasional	-0.4 (2)	+0.6 (5)	+0.4 (1)
		None			
	Situational	Compressed Timeline			
		Change in Goals	+0.3 (5)	-0.1 (3)	+0.8 (1)
		Change in Constraints	+0.6 (2)	-0.1 (3)	+0.4 (4)

No High Technical Level Projects

			Measures: Relative Success	Measures: Degree of Reliance	Measures: Interaction with Methods
Con[illegible]fects	Budgets	High			
		Medium	+0.5 (4)	-0.3 (5)	+0.1 (3)
		Low	-0.3 (8)	+0.1 (9)	-0.6 (13)
	Team Size	Large			
		Medium			
		Small	+0.5 (4)	-0.1 (5)	+0.8 (3)
	Expertise	[illegible]gh	+1.0 (2)	+1.0 (3)	+0.7 (4)
		[illegible]edium	+0.3 (3)	+0.8 (3)	-0.6 (3)
		Low	+0.4 (2)	-0.5 (6)	+0.6 (1)
		Related	-0.2 (5)	+0.8 (3)	+0.3 (1)
		Unrelated	-0.5 (2)	-0.7 (6)	-0.2 (1)
	Other	Materials			
		Time	-0.3 (3)	-0.7 (1)	+1.0 (2)
		Facilities	+1.0 (5)	+0.3 (3)	-0.2 (1)

Low Budgets Resulted in Reduced Success

Larger Team Sizes are Not Represented

Legend

	Measure 1
Effect 1	-0.7 (5)

-0.7 ← Avg. of Data
(5) ← # of Samples

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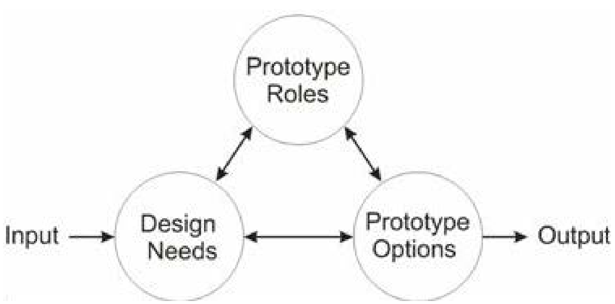
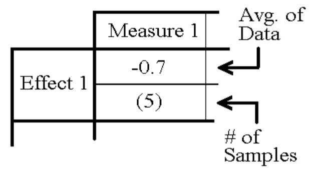
Cross-Case Data Analysis Protocol:

- Prototype Specific Data
  - Embodies cross-case synthesis
  - Reveals general patterns in the data
  - Compares prototype options against prototype roles or design needs
  - Can also be used to compare design needs and prototype roles





PROTOTYPE OPTIONS			PROTOTYPE ROLES: Learning		Comm.			Integration			Demo.			
			Performance	Unknown Factors	Functionality	Configuration	Visual/Tactile Properties	Develop Assembly	Refine Funcitonality	Refine Process	Milestones	Customer Demand	*Average Value*	*Number of Samples*
Physical	System	Form	-0.33 (3)	0.00 (4)	-0.33 (3)	0.66 (3)	0.75 (4)	0.50 (2)					0.21	(19)
Physical	System	Basic		-1.00 (3)	0.50 (2)	1.00 (1)			0.20 (5)		0.33 (3)	-0.66 (3)	-0.06	(17)
Physical	System	Detailed	0.60 (5)	0.40 (5)	-0.25 (4)	-0.50 (4)		-0.50 (2)		0.80 (5)	0.50 (4)	0.40 (5)	0.26	(34)
Physical	System	Realistic	1.00 (1)			0.00 (1)		0.00 (2)	-1.00 (2)	0.50 (2)		1.00 (1)	0.11	(9)
Physical	Sub-sys	Form												
Physical	Sub-sys	Basic												
Physical	Sub-sys	Detailed		0.50 (2)	1.00 (1)	1.00 (2)	-1.00 (1)	0.50 (2)	0.00 (2)	1.00 (2)		1.00 (1)	0.54	(13)
Physical	Sub-sys	Realistic												
Physical	Comp.	Form		0.00 (1)		1.00 (1)	1.00 (1)		-1.00 (1)	0.00 (1)		-1.00 (1)	0.00	(6)
Physical	Comp.	Basic			0.50 (2)		-1.00 (1)	1.00 (1)		0.00 (1)	-0.50 (2)	-0.50 (2)	-0.11	(9)
Physical	Comp.	Detailed												
Physical	Comp.	Realistic				-1.00 (1)		0.00 (2)		1.00 (1)			0.00	(4)

Triangulation

- Research
  - Use different tools to study same thing
  - Verifies findings
  - Reveals different issues
- Questions
  - Ask questions such that they re-enforce
  - “The instructor clearly communicated what I was expected to learn”
  - “The instructor clearly explained what was expected on assignments and tests”
  - “Overall, the instructor is an effective teacher”
  - “The instructor’s teaching methods helped me understand the course material”

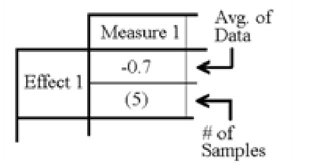
Data Collection Summary

- Interviews
  - Total Hours of Interviews: 5 hours (~1 hour per interviewee)
  - Total Hours to Transcribe Interviews: 25 hours (~5 hours per interview)
  - Total Time for Data Extraction: ~3 weeks (3-5 days per interview)
- Documents Analysis
  - Total Documents Analyzed: 3 (~80 pages)
  - Total Time for Data Extraction: ~1 week (1-3 days per document)
- Ethnographic study was integral to the other components and was accomplished simultaneously.

Aggregate Project Factor Data (Details):

- Trends Identified through Pattern Matching
  - High prototype interaction and reliance generally resulted in prototyping success. (LS)
  - High prototype reliance and low interaction resulted in reduced prototyping success.
  - A compressed timeline resulted in high success despite the limitation it introduced.
  - Higher order planning resulted in higher measures of success. (LS)
  - Conceptual designs are more successful than detailed designs given the common limitations encountered in the study.

- LS = Literature Study Confirmation of Trend



			Measures			
			Relative Success	Degree of Reliance	Interaction with Methods	OVERALL
Detail	Collaboration	National	0.50 (2)	0.50 (2)	0.00 (1)	0.40 (5)
		Organizational	0.13 (8)	0.88 (8)	0.00 (7)	0.35 (23)
		Departmental	1.00 (1)	0.00 (1)	1.00 (1)	0.66 (3)
		Team	0.71 (7)	0.33 (9)	0.43 (7)	0.48 (23)
		Personal	0.93 (14)	0.64 (14)	0.42 (12)	0.67 (40)
	Project Goals	Concept Dev.	0.81 (11)	0.91 (11)	0.77 (13)	0.83 (35)
		Detailed Design	0.10 (10)	0.54 (13)	-0.20 (10)	0.18 (33)
		Production		-1.00 (1)	1.00 (1)	0.00 (2)
	Technical Level	High	1.00 (2)	1.00 (4)	1.00 (4)	1.00 (10)
		Medium	0.00 (13)	0.64 (14)	0.23 (13)	0.30 (40)
		Low	1.00 (7)	-0.28 (7)	-0.43 (7)	0.10 (21)
	Design Methods	Organized		0.00 (2)	1.00 (2)	0.50 (4)
		Methodical	1.00 (3)	1.00 (3)	1.00 (3)	1.00 (9)
		Planned	1.00 (5)	0.00 (6)	1.00 (6)	0.64 (17)
		Occasional	0.11 (9)	0.17 (12)	0.73 (11)	0.34 (32)
		None	-0.33 (3)	0.67 (3)	-1.00 (2)	-0.13 (8)
	Situational	Compressed Timeline	1.00 (3)	1.00 (3)	-1.00 (3)	0.33 (9)
		Change in Goals	-0.60 (5)	0.40 (5)	-1.00 (3)	-0.31 (13)
		Change in Constraints	-0.67 (9)	0.30 (10)	0.00 (7)	-0.12 (26)

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Aggregate Project Data (Constraints):

- Trends Identified through Pattern Matching
  - Facilities limitations had the mostly negative impact on factors of success and reliance. (LS)
  - Low expertise had the most negative impact on prototype success.
  - Higher expertise and budgets are more successful. (LS)

Legend: Effect 1 / Measure 1 — -0.7 = Avg. of Data; (5) = # of Samples

Constraint			Relative Success	Degree of Reliance	Interaction with Methods
Constraint	Other	Materials	-0.50 (6)	-0.50 (4)	1.00 (3)
		Time	0.67 (3)	1.00 (3)	-1.00 (3)
		Facilities	-0.82 (11)	-0.60 (10)	0.67 (9)

Legend: Effect 1 / Measure 1 — -0.7 = Avg. of Data; (5) = # of Samples

Constraint			Relative Success	Degree of Reliance	Interaction with Methods	OVERALL
Constraint	Budgets	Very High				
		High		1.00 (2)	0.00 (2)	0.50 (4)
		Medium	0.75 (4)	0.75 (4)	0.50 (4)	0.66 (12)
		Low	-0.29 (7)	0.00 (8)	0.57 (7)	0.09 (22)
		Very Low	0.40 (10)	0.10 (10)	0.88 (8)	0.43 (28)
	Team Size	Large		0.00 (1)	1.00 (1)	0.50 (2)
		Medium	0.50 (2)	0.50 (2)	0.00 (2)	0.33 (6)
		Small	0.24 (17)	0.31 (19)	0.26 (19)	0.27 (55)
	Expertise	High	1.00 (3)	0.20 (5)	0.25 (4)	0.42 (12)
		Medium	0.90 (10)	0.27 (11)	0.50 (10)	0.55 (31)
		Low	-0.85 (13)	0.69 (13)	0.38 (13)	0.08 (39)
		Related	0.93 (14)	-0.12 (16)	0.20 (15)	0.31 (45)
		Unrelated	-0.36 (11)	0.64 (11)	0.50 (10)	0.25 (32)
	Other	Materials	-0.50 (6)	-0.50 (4)	1.00 (3)	-0.15 (13)
		Time	0.67 (3)	1.00 (3)	-1.00 (3)	0.22 (9)
		Facilities	-0.82 (11)	-0.60 (10)	0.67 (9)	-0.34 (27)

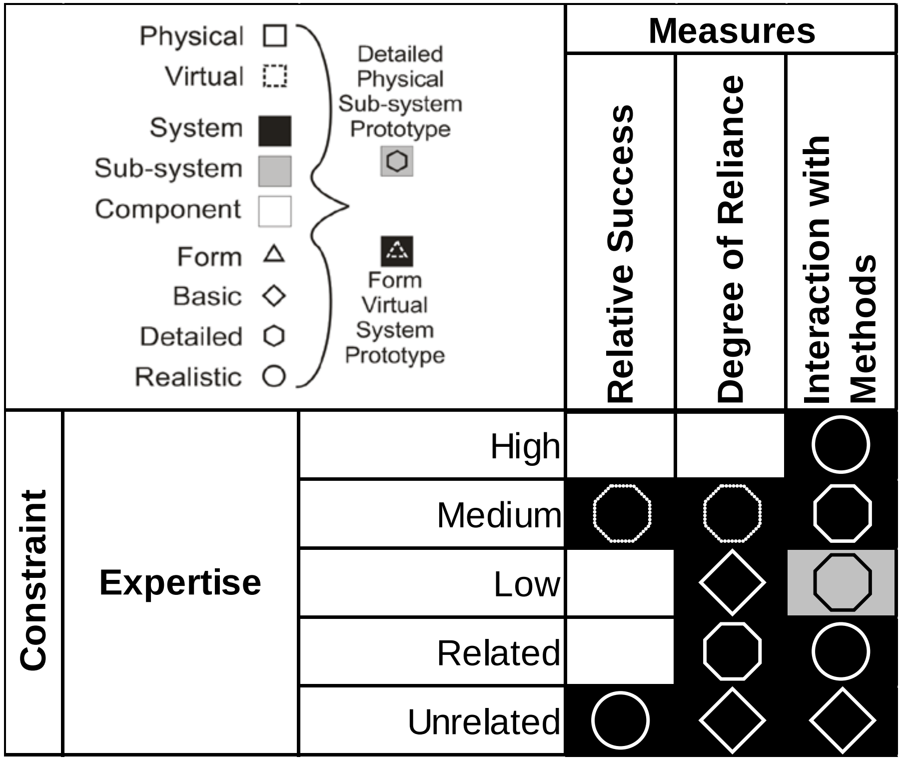
Trends Found in Source Notes

- Note trends were cross-referenced with the aggregate data to help identify additional trends, they were compared with specific quotes found within the sources, and they were furthermore validated by independent research into the respective fields they imply
  - Facilities are a major factor in prototyping success and reliance
  - Non-physical prototypes are more flexible than physical prototypes
  - Collaboration can ease an organization's shortcomings in facilities and expertise
  - Changes to design goals or constraints during a project result in reduced success
  - Low expertise result in high reliance on physical prototyping and reduced success
  - Small teams are ineffective at detailed design prototypes
  - Flexibility in the prototyping process can help mitigate project limitations
  - Component level prototypes are more useful for design engineers
    - Trend did not have triangulated confirmation from cross-referencing

Identifying one trend:

4. Lower expertise requires simplifying the system or decomposing it to compensate for limitations

- CAVEAT
  - Successful prototypes determined by analytical comparison of options
  - There is not a statistical basis for determinations, all current evidence is used including aggregate data trends, note themes, and general comparison of prototype success.
  - Must be careful at evaluating data due to study being heavily weighted towards physical and system prototypes.
  - This is addressed in future work



Guidelines

- Outcome: good analytical basis between notes, trends, and literature study for trends
  - Facilities must be considered
  - Account for available expertise and difficulty
  - Compensate for budget and team size
  - Establish an accurate plan at the beginning of a design endeavor
  - Reduce prototyping fidelity and complexity
  - Integrate prototyping more thoroughly with the design process
  - Reduce need for physical prototyping

Design Needs Conclusions

			Design Needs
			Option is most appropriate for...
Prototype Options	Variety	Physical	Evaluate Properties, Conceptual Designs, Design Optimization, Develop Analytical Methods
		Non-Physical	Configure System, Develop Analytical Methods
	Complexity	System	Aesthetic Evaluation, Evaluate Properties, Proof of Product, Conceptual Designs
		Sub-system	**INSUFFICIENT DATA**
		Component	**INSUFFICIENT DATA**
	Fidelity	Form	**INSUFFICIENT DATA**
		Basic	Develop Analytical Methods, Evaluate Properties, Proof of Concept
		Detailed	Aesthetic Evaluation, Conceptual Design, Design Optimization
		Realistic	Proof of Product, Configure System

Prototype Roles Conclusions

			Prototype Roles
			Option is most appropriate for…
Prototype Options	Variety	Physical	Unknown Factors, Functionality, Milestones
		Non-Physical	Configuration, Visual/Tactile Properties, Develop Assembly, Refine Functionality, Refine Process, Customer Demand
	Complexity	System	Performance, Unknown Factors, Visual/Tactile Properties, Refine Functionality, Milestones, Customer Demand
		Sub-system	**INSUFFICIENT DATA**
		Component	**INSUFFICIENT DATA**
	Fidelity	Form	Visual/Tactile Properties
		Basic	Performance, Functionality, Milestones, Unknown Factors, Refine Functionality
		Detailed	Develop Assembly, Refine Process, Unknown Factors, Visual/Tactile Properties
		Realistic	Configuration, Customer Demand, Unknown Factors, Refine Functionality, Visual/Tactile Properties

Readings

- Creswell: Survey Designs (Chapter 12)

Backup

SURVEYS

Surveys

- Guidelines
  - Start with easy questions.
  - Divide the survey (and the questionnaires) into sections to make it less intimidating.
  - Use appropriate graphics and a pleasant layout.
  - Ask questions that prompt useful responses. (PCs)
  - Provide space for comments throughout the questionnaire.
  - Use a familiar rating scale, such as (high-medium-low)
    - Do NOT change the rating method within the questionnaire.
  - Don't ask for personal details unless you really need it (explain why it is needed)
  - Use a carrot to encourage participant to take the survey (prize or final results)

Surveys

- Guidelines
  - Prioritize the information.
    - Structure your questions so that the participant is 'prompted' to discuss these subjects.
  - For hard facts, use Yes/No questions.
  - For open-ended questions, plan for interviews.
  - Test a draft questionnaire on a small group to judge the effectiveness of the questions.
  - Offer different options for returning the questionnaire (fax, email, mail).
  - Always follow up with a thank-you phone call or letter. This is especially important if the responder is a customer or client.

Surveys

- Avoid
  - Asking for secondhand information
  - Asking hypothetical questions
  - Asking about causation
  - Asking for solutions to complex issues
  - Ambiguous wording or wording that means different things to different respondents
  - Using terms for which the definition can vary. (If it is unavoidable, provide the respondent with a definition.)
  - Being ambiguous about the time period the respondent should consider
  - Asking complex questions (double-barreled)

Guidelines

- DO
  - Use simple wording
  - Be brief
  - Be specific
- DO NOT
  - Be vague
  - Be condescending or talk down to respondent
  - Use biased wording
  - Use abbreviations or scientific jargon
  - Use objectionable questions
  - Be redundant

Readings

- Eckert and Summers: Interviewing as a Method for Data Gathering (unpublished)

May 24, 2017 (am)

INTERVIEWING

Interviewing

- ASME Journal of Mechanical Design
  - 15 query hits
  - Agogino, Ahmed, Cagan, Clarkson, Papalambros, Ramani, Seepersad, Seering, Summers, Yang
- Research in Engineering Design
  - 68 query hits
  - ~1/3 with moderate level of description
  - 2 with good level of description
  - # that interviews were “core”
- Journal of Engineering Design
  - 138 query hits

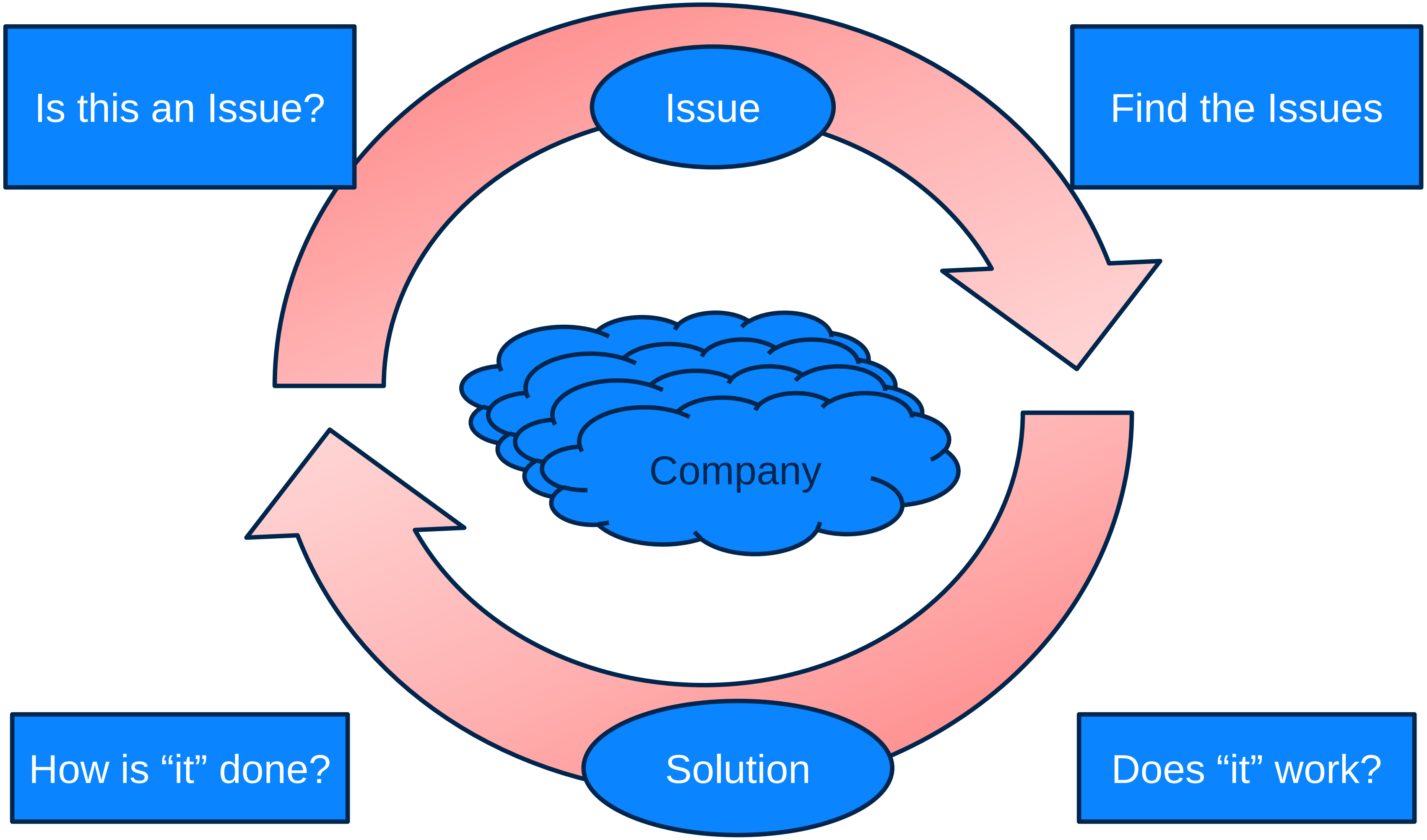
Interviewing (Real life)

- Media
- Police
- Therapy
- Lawyers
- Employers

Interviewing (Creswell Definition)

- Options for Interviewing
  - Face to face; in person
  - Telephone/video conference
  - Focus group
- Advantages of Interviewing
  - Useful when direct observation not possible
    - Confidential, temporally constrained, completed
  - Historical information can be collected
  - Researcher controls the questioning (bias?)
- Limitations of Interviewing
  - Indirect information filtered through the interviewee
  - Information collected in designated place rather than natural setting
  - Researcher's presence may bias responses
  - Interviewees are not all articulate or perceptive

Purpose of Interviewing



May 24, 2017 (am)

DEVELOPING THE INTERVIEW

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Lifecycle of Interview

- Defining the Context
  - Roles
  - Case
  - Planning
- Designing the Interview
  - Questions
  - Strategy
- Executing the Interview
  - Confidentiality
  - Recording
- After Interview
  - Transcriptions
  - Analysis
  - Closure

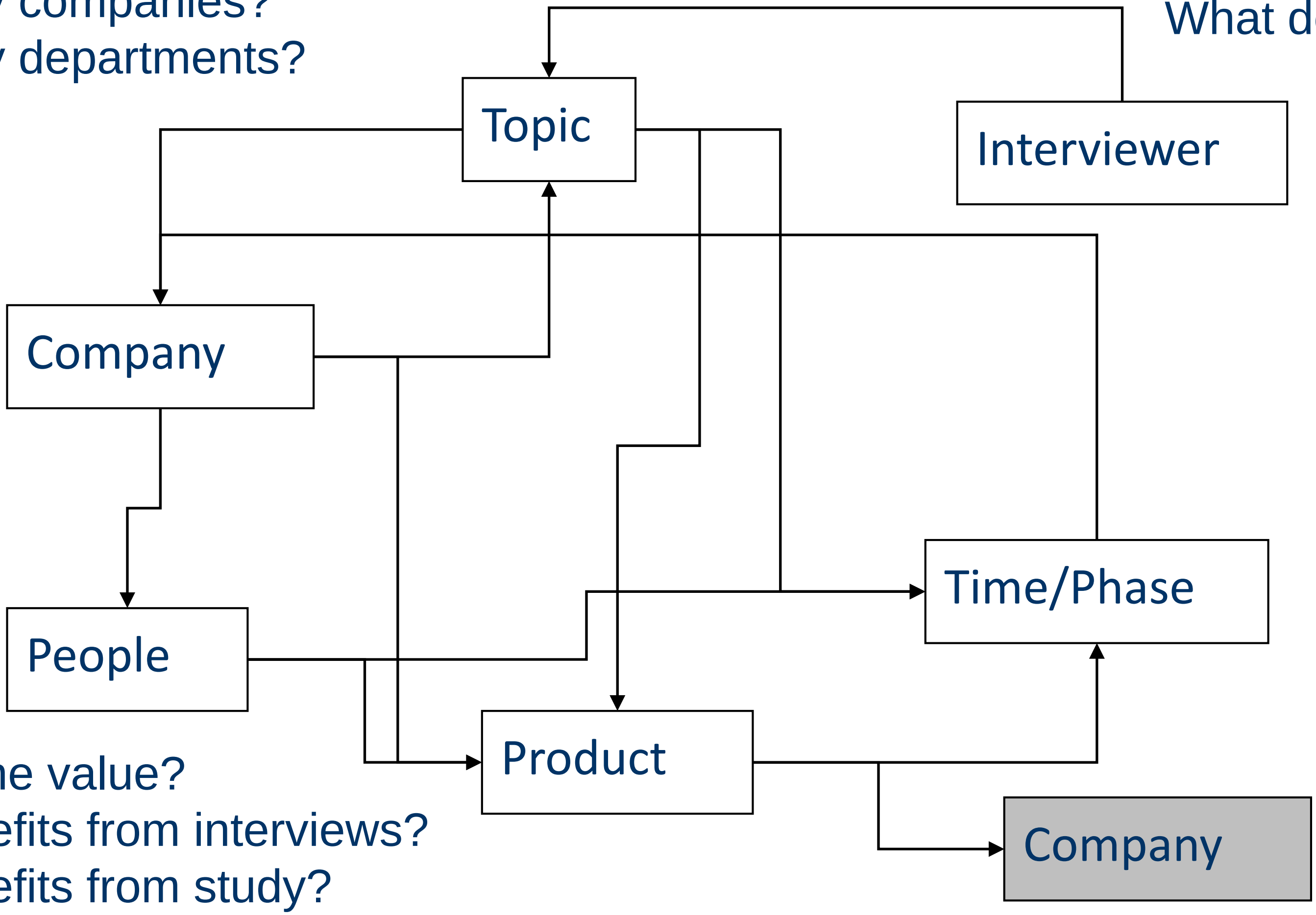
Defining the Context

- Considerations:
  - Time, Product/domain, The data
- Vertical vs. Horizontal Study
  - Breadth: Multiple organizations, domains, people
  - Depth: Single organization, domain, people
- The Case
  - Finding the Company
  - Finding the Interviewees
    - Only interview/analyze what you need
  - Defining the **Value** to all
- The Interviewer
  - Roles
  - Status
  - Team interviewers
  - Culture

Where do you start?

How many people?
How many interviews?
How many companies?
How many departments?
…

How do we analyze?
When do we analyze?
What do we analyze?
…



What is the value?
Who benefits from interviews?
Who benefits from study?
…

DESIGNING THE INTERVIEW

Designing the Interview

- Conversation
  - Questions,
  - Examples,
  - Comments
  - Humor…
- Interview as conversation
  - But not a chat!
  - It is not an interrogation!

Questions

- Types of question
  - Fact finding
  - level of understanding individuals have about facts
  - close precious questions
  - fishing questions
  - ice breaker
  - requests for explanation
  - confirmation questions
  - What is your opinion?
- Examples
  - Seeking comment on examples
  - Asking for examples to explain
- Triangulation
  - Built in to the questions (but not repeating)
  - Enforced through clarification
  - Other research tools, sources, …

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General Strategy

- General to Specific
  - Comfortable, background context is needed, avoid fixation/bias
- Targeted
  - Fact finding, corroboration, context is known (assumed)
- Directing the Flow
  - Prompting, know your question topic and want to lead them to talk

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People (individual/team)

- Interviewing team
  - Individual
  - A pair of interviewers
    - additional interpretation
    - Reflection
    - Validation
    - Shared energy
    - Ownership of questions
    - One topic vs. multiple
    - Patience
  - Student vs. Advisor dynamic…
- Interviewees
  - One at a time
  - Small groups
    - Openness
    - Personal dynamics
    - Corporate hierarchy
    - Talking over each other

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Preparing for interviewing

- Background research
  - Know the company – do not ask Michelin what they make
  - Know the product
  - Know the functional roles in the organization
- Preparing questions
  - Tailor the questions based on interviewee
  - Know your question set without looking at it
- Splitting questions across people if multiple interviewers
- Piloting the interviews
  - Role play with colleagues as “throw away” interviews
  - Play both sides
- Observe other people interviewing
  - Read transcripts or listen to tapes
  - Shadowing
- IRB – Make sure that you have secured your EXEMPT

Executing the Interview

- Gaining Access
  - Use your network to open doors
    - Past sponsors of projects
    - Former students
    - Supply-Design chain network of colleagues
    - Social contacts (church/mosque/synagogue, school, friends)
  - Cold call companies
  - Must anticipate the need for VALUE for company and for interviewee
  - Demonstrated success leads to more open doors
- Who picks the interviewees
  - Managers (top down) - bias
  - Interviewees (side-ways) - bias
  - Interviewer - naivety
- Who organizes the interviews
  - Managers (forced to attend)
  - Company expert/insider/contact/interviewee (peer pressure)
  - Interviewer – more work

Executing the Interview

- Planning interviews
  - Confidentiality – will this be an issue?
  - No more than three interviews in a day
    - Plan to write review/summary/impressions the same day
  - Avoid first thing in the morning and last thing in the day schedules
  - Schedule additional 30 minutes of slack time after the interview
  - Create a checklist for each interview
    - Verify materials, batteries, directions, printouts prepared day before
    - Schedule these meetings, send preparation material as needed, send reminder 48 hours before
    - Ensure that you have appropriate attire (same level as interviewee, appropriate footwear if site visits)

Executing the Interview

- During the interview
  - Stay positive, polite, courteous, supportive, encouraging, nice, friendly, respectful
  - Recording
    - Audio/video recording (tape recorders, computer, phones)
    - Note Taking
    - Proformas
    - Post-hoc notes
  - Physical Location
    - Neutral (conference room, coffee room)
    - Familiar (offices, labs, shops)
    - Noises and distractions

After the Interview

- Transcriptions
  - **Write summaries**
    - **Within 48 hours of interview**
  - Convert notes into readable form
  - Convert the recordings to archived transcripts
    - time consuming (~12:1 ratio), but valuable for future mining
    - Use MS Word (dragon, etc.) to create first pass on transcription
    - Consider key quotes only
  - Make these available when possible to others – share the data and let them draw conclusions
    - It increases the confidence in your work if you are willing to share with others
- Analysis
  - Define **HOW** you will convert the interview data into inferences and conclusions **BEFORE** you conduct any interview
    - This increases the objectivity of your work
  - Coding, Searching for Quotes, Familiarizing with Interviews

Cleaning Up

- Verification
  - Send transcript to interviewee for verification
  - Send summary to interviewee for verification
- Feedback/Reflection (finish the value loop)
  - Give collective presentation to all interviewees/stakeholders
  - Provide overview report to company/sponsors
  - Send the completed papers to all partners
  - Invite the interviewees to final thesis defense
- Thank you letters to the immediate supervisor
  - Written by the advisor/interviewer to the interviewee/supervisor

Best Practice/Worst Practice

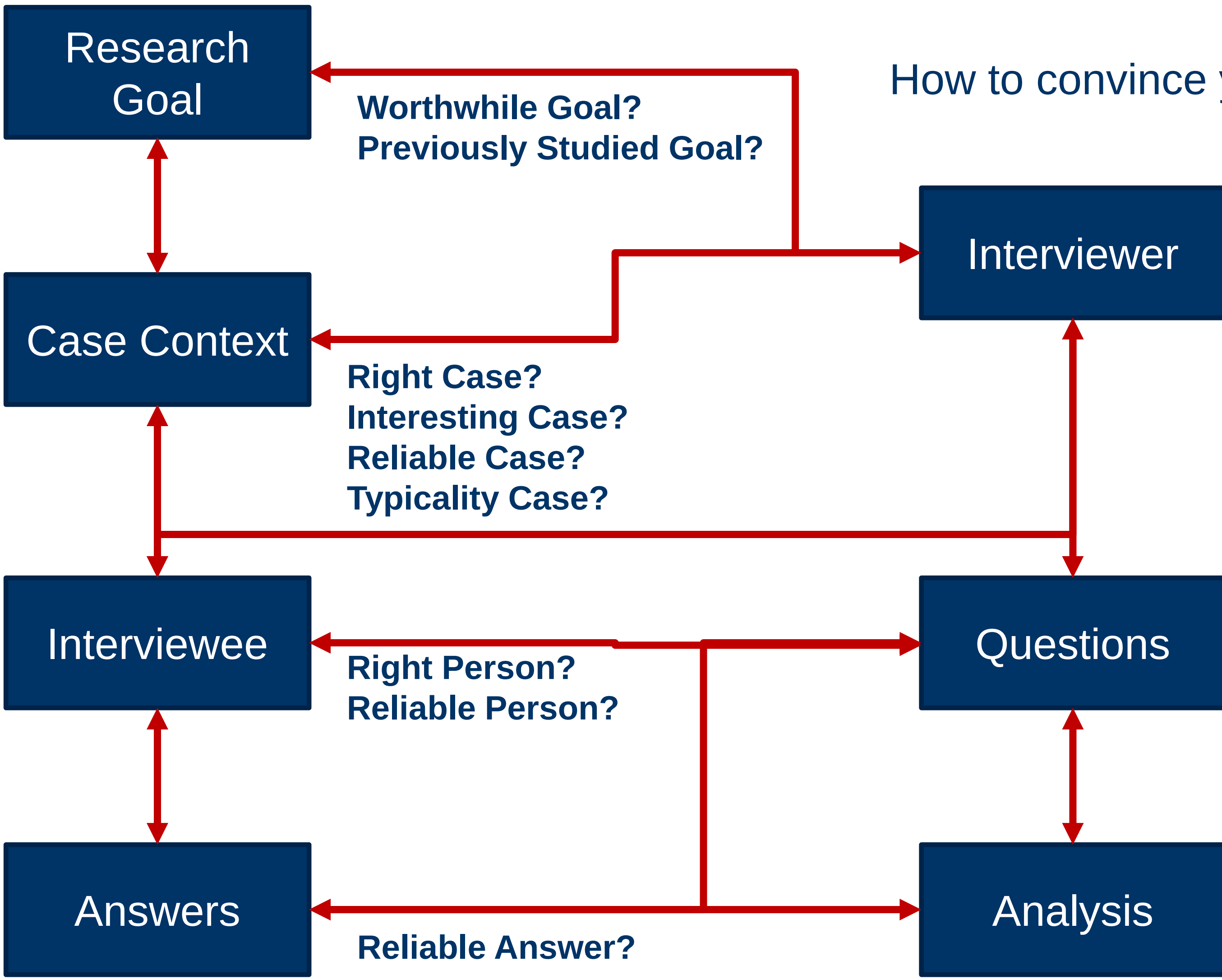
- One question at a time
- Ask short questions for long answers
- Expose the VALUE to them to help you with your work
  - Make it of INTEREST for the interviewee
- Listening vs. talking
- Avoid leading or confounding questions
  - You do this, right?
  - You do not really do that, do you?
- Show respect
  - Be early, they are the expert, you are the guest,
- Be flexible

May 24, 2017 (am)

HOW TO REPORT

Qualification of Research

How to convince your reader?



Competent Researcher?

Triangulated within?
Triangulated across?

Objective Analysis?
Detailed Analysis?
Provided Data?

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Context of Study

- Purpose of the Research Study
  - Make it explicit
  - Justify
- Purpose of the Interview
  - Make it explicit
  - Justify
- Additional Research Methods Used
  - Make it explicit
  - Justify (triangulation)
- Context of the Study
  - Make it explicit
  - Justify

Explicit and Justified – Builds Confidence

Context of Study

Citation	Purpose of Research Study	Purpose of Interview	Additional Research Methods	Context of Study
(Aurisicchio et al. 2013)	U	V	E & Y & O	A
(Achiche et al. 2013)	T	M	M, Q	unreported
(Veldman and Alblas 2012)	U	C	D	Q
(Shankar et al. 2012)	U	V	D	U
(Ahmad et al. 2012)	T	V	M	E
(Vianello and Ahmed 2012)	U	C		G
(Rexfelt et al. 2011)	T	V	X	U
(Pasqual and De Weck 2012)	T	V	M	E
(López-Mesa and Bylund 2011)	U	C	O	U
(Jagtap and Johnson 2011)	U	C	D	A
(Tribelsky and Sacks 2010)	T	V	D & O	C
(Legardeur et al. 2010)	U	X	E	U
(Eckert and Clarkson 2010)	U	C	E	A & U
(Wasiak et al. 2010)	U	V	D	X
(Keraron et al. 2009)	T	E	D	A & G
(Romero et al. 2008)	U	X	M	F
(Kloss-Grote and Moss 2008)	T	X & E	D	A
(El-Tayeh et al. 2008)	T	V	X	unreported
(Reymen et al. 2006)	U	C		M, S, R (acad)
(Donaldson 2006)	U	C		Highly mixed (simple)
(Demian and Fruchter 2006)	U	C	E	C
(Almefelt et al. 2006)	**Understanding**	**Core**	**Document analysis**	**U (automotive)**
(Zika-Viktorsson and Ritzén 2005)	U	C		U & Q
(Gil et al. 2004)	T	U	D & M & O	C
(Eckert et al. 2004)	U	C		A
(Beskow and Ritzén 2000)	T	C		F
(Newstetter 1998)	U	V	E	M (acad)
(Cross and Cross 1998)	U	V	P	U
(Eppinger et al. 1997)	T	E	M	F
(Ehrlenspiel et al. 1997)	U	V	V & D	M (acad)

Purpose of Study: U = Understanding; T = Tool
Purpose of Interview: C = Core; E = Evaluation; M = Motivation; V = Verification; X = Explanation; U = Unclear
Additional Methods: D = Document analysis; E = Ethnography; M = Modeling; O = Observation; P = Protocol Analysis; Q = Questionnaire; V = Video; X = Experimentation; Y = Diary
Context: A = Aerospace; U = Automotive; M = Mechanical; F = Manufacturing; G = Gas; C = Construction; E = Electronics; Q = Equipment; S = Software; R = Architecture; X = Complex Systems

Details on People

- Organization
  - How many companies
  - How many departments
  - How many disciplines
- Interviewee
  - How many people
  - Positions of the people
- Relationship with the Interviewer
  - Is there a relationship (is this potential for bias)
- Interviewer
  - Single or multiple

Details – Allows for Replication

People

Citation	Organization	Interviewee	Relationship	Interviewer
(Aurisicchio et al. 2013)	1 company	10 engineers (average experience, and SD provided)		
(Achiche et al. 2013)	5 different companies, but domain unknown	5 managers & (minimum of 8 years in PD)		
(Veldman and Alblas 2012)	2 companies different industries (Gas and Machinery)	11 formal (managers, engineers, design, manufacturing, purchasing, maintenance) & 30 informal (managers, engineers, etc.); REPORTED in TABLE		
(Shankar et al. 2012)	1 company	6 engineers + 1 manager (details presented in table)	Employee	S
(Ahmad et al. 2012)	Single	1 manager + 1 engineer & Group discussion		
(Vianello and Ahmed 2012)	4 instances (oil rigs) for one company	18 interviews; Table provided		
(Rexfelt et al. 2011)	Automotive OEM; Traffic Control; University	10 participants from experiment	Coach	
(Pasqual and De Weck 2012)	Single	1 lead systems engineer		
(López-Mesa and Bylund 2011)	Single company	Phase 1: 20 individual sessions (1 pair session; Reported in table) & Phase 2: 11		S
(Jagtap and Johnson 2011)	Single	3 designers		S
(Tribelsky and Sacks 2010)	Multiple companies/projects	8 project leaders & 3 client reps & 3 design leaders	affiliation gave access	
(Legardeur et al. 2010)	Primarily 1 company (and partners)	Multiple (exact number unknown)	"partner" – joined the company	
(Eckert and Clarkson 2010)	Multiple companies, multiple domains	18 + 2 additional case studies		S & P
(Wasiak et al. 2010)	Single	Multiple (different roles)		
(Keraron et al. 2009)	2 companies (different domains)	30 maintenance – aerospace & Unknown – gas		
(Romero et al. 2008)	5 enterprises (different departments within)			
(Kloss-Grote and Moss 2008)	1 company (3 projects)	6 (3 managers and 3 engineers)		
(El-Tayeh et al. 2008)				
(Reymen et al. 2006)	12 case studies (4 in software, architecture, mechanical)	2 junior+2 experts for each discipline (12 total)		
(Donaldson 2006)	20+ firms and 30+ enterprises	Number unknown: engineers, designers, artisans, fundis, students, faculty, NGO, government		
(Demian and Fruchter 2006)	1 main + four others (same discipline0	Engineers (unknown); Architect, engineer, manager		
(Almefelt et al. 2006)	**Supply/design chain**	**Unknown (24 interviews with 25 people); Engineers, managers, purchasing, etc.**	**Previously worked on project**	**Pair**
(Zika-Viktorsson and Ritzén 2005)	5 companies, different domains	14 upper level & 40 project		
(Gil et al. 2004)	Unknown	Senior (22: engineers, 10: customer reps, project managers)		
(Eckert et al. 2004)	1 company	22 senior designers		
(Beskow and Ritzén 2000)	4 companies	30 used (from 78 collected); Varied hierarchies and functions		
(Newstetter 1998)	1 class, multiple teams	Unknown (at least 4 students; 1 prof.)	Team member	S
(Cross and Cross 1998)		1 designer		
(Eppinger et al. 1997)				
(Ehrlenspiel et al. 1997)			Teacher	

Interviewee: S = Single; P = Pair; T = Team

Interview Process Details

- Interview
  - Details on the location
- Type of Interview
  - Helps in determining the repeatability of this
    - Structured, Semi-Structured, Informal, Debrief
- Supplemental Materials and Recording
  - If forms, prototypes, models, etc. are used during the conversation, this adds context
  - Method of recording is critical for objectivity test
- Duration of Interview
  - Simple detail with value of building confidence

Details – Supports Replication and Builds Confidence

Interview Process

Citation	Interview	Type	Material or Recording	Duration Interview (minutes)
(Aurisicchio et al. 2013)	In context (during work activities by a "shadow")	M	Audio	
(Achiche et al. 2013)	Company office & video conference	M	Table (form) to complete	
(Veldman and Alblas 2012)	On site	M & I	Post interview transcript coding in MS Excel	
(Shankar et al. 2012)	On site	M	Populated matrix was refined during interview	
(Ahmad et al. 2012)		I	Discussion included a refined model in the new tool	
(Vianello and Ahmed 2012)	Company site	M	Audio recording	15-45
(Rexfelt et al. 2011)		I		
(Pasqual and De Weck 2012)				
(López-Mesa and Bylund 2011)	Phase 1: On-site ("separate") & Phase 2: On-site ("on the go")	S & M	Audio recording and transcription	60-120
(Jagtap and Johnson 2011)		M	Audio recording	60-90
(Tribelsky and Sacks 2010)				
(Legardeur et al. 2010)		M	Actor Network	
(Eckert and Clarkson 2010)	On-site	M	Post interview reflections provided	30-120
(Wasiak et al. 2010)		M		
(Keraron et al. 2009)		M	Recorded/transcribed (200 pages text)	
(Romero et al. 2008)			Process diagrams to augment / inform the interview	
(Kloss-Grote and Moss 2008)		S	Classification tree	90
(El-Tayeh et al. 2008)		D		
(Reymen et al. 2006)			Evaluation sheet, Summary of previous interviews, Transcription	
(Donaldson 2006)				
(Demian and Fruchter 2006)	One site (office and construction site) & Off-site			60
(Almefelt et al. 2006)	**On-site (relaxed atmosphere)**	**M**	**Piloted the interview; Transcript approval**	**60**
(Zika-Viktorsson and Ritzén 2005)		M	Transcription	60
(Gil et al. 2004)		M	Follow-up interviews	60-120
(Eckert et al. 2004)	On-site	M	Questions evolved and subsequent interviewees validated previous	60
(Beskow and Ritzén 2000)	On-site	M	Different questions for each case, but some overlapping	
(Newstetter 1998)				
(Cross and Cross 1998)		I		
(Eppinger et al. 1997)				
(Ehrlenspiel et al. 1997)				

Type of Interview: S = Structured; M = Semi-Structured; I = Informal; D = Debrief

Content of Interview

- Questions Provided
  - Are the actual questions used (some or all) explicitly found in paper?
- Answers Provided
  - Are example answers from the interviewees provided?
- Summary Provided
  - Is a summary of the interview provided that captures the results concisely?
- Discussion on the Interview
  - How much space or effort is spent discussing the interview (research instrument) rather than the inferences?

Details – Can I Replicate this "Experiment"

Content of Interview

Citation	Questions	Answers	Summary	Interview (paragraphs)	Country of Researcher
(Aurisicchio et al. 2013)				1	GB
(Achiche et al. 2013)				4	CA; IT; DK
(Veldman and Alblas 2012)	Y		Frequency Table	2	NL
(Shankar et al. 2012)	Y	Q	Yes (table and text)	7	US
(Ahmad et al. 2012)				1	GB
(Vianello and Ahmed 2012)	Y	Y	Analysis (Kappa); Results in tables	4	DK
(Rexfelt et al. 2011)		Y	Nominal	1	SE
(Pasqual and De Weck 2012)				<1	US
(López-Mesa and Bylund 2011)	Y	Y	Text and tables	6	SE
(Jagtap and Johnson 2011)	Y	Y	Yes	6	GB
(Tribelsky and Sacks 2010)				2	IL
(Legardeur et al. 2010)				1	FR
(Eckert and Clarkson 2010)				3	GB
(Wasiak et al. 2010)				1	GB; AU
(Keraron et al. 2009)			Text	2	FR
(Romero et al. 2008)				1	ES
(Kloss-Grote and Moss 2008)	A	Y		3	DE, GB
(El-Tayeh et al. 2008)				<1	AE; GB
(Reymen et al. 2006)	Y	S	Yes (body of paper)	9	GB
(Donaldson 2006)				<1	US
(Demian and Fruchter 2006)		Y		1	GB; US
(Almefelt et al. 2006)	**Yes**	**Yes**	**Discussion**	**9**	**Sweden**
(Zika-Viktorsson and Ritzén 2005)				9	SE
(Gil et al. 2004)				1	GB; US
(Eckert et al. 2004)				5	GB
(Beskow and Ritzén 2000)				11	SE
(Newstetter 1998)				<1	US
(Cross and Cross 1998)				1	GB
(Eppinger et al. 1997)				<1	US
(Ehrlenspiel et al. 1997)	Y			1	

Questions Provided: Y = Yes; A = Full question databank made available
Answers Provided: Y = Yes; S = Samples; Q = Direct Quotations

Proposal for What to Report

- Good Research Paper Stuff
  - Motivation, Why this tool is important, Why this approach is used…
  - **Because this is good research stuff…**
- Interview Details
  - People, Company, Type, Duration, …
  - **Because details are needed to repeat or contextualize**
- Interview Design
  - Strategy, Other methods, Volume of material collected…
  - **Because this justifies the approach you took**
- Analysis of Interviews
  - Recording, Questions, Answers, Summary…
  - **Because this makes your conclusions more objective**

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What to Report (General)

Item	Type	Justification	Eckert, 2010
Number of Interviewees	Numeric	Breadth and depth of the interview. Gives confidence and range. (Low numbers require additional justification)	18
Number of Interviews	Numeric	Same people interviewed multiple times (triangulate or deep dive or grounding). Interviewees might be in groups (social dynamics of conversation).	18
Description of Interviewees	Text	Functional roles, training, experience, etc. are important for data source justification. Develop trust in the interviewee.	Engineers Engineering managers Business managers Purchasing Manufacturing
Interviewer(s)	Type	Confidence in data collection. Experience in interviewing (first time effort vs. lots of experience in interviewing)	Single
Duration of Interview	Numeric range	Provides a sense of the depth of the interview	~30 – 120 minutes
Period (time frame) of interviews	Dates	Provides context given external history (interviews in airline safety in 2001 – before or after 9/11) Must think about archival considerations (what is important to know in 30 years about this interview set?) Duration of the project can improve confidence (interviews over 3 years vs. 1 week)	Autumn of 2000
Location description	Text	Provides confidence in the voracity of the responses. Enhances the contextualization of the interview.	On-site, UK
Type of interview (level of structure)	Type	Explains the degree of expansion allowed in the data collection and the depth of discovery. Was it for pattern matching or for data collection? (informal, semi-structured, structured, questionnaire)	Semi-structured
Materials used during interview	Text	What information is used during the interview to inform and gather information. If critical element of the study, then it should be discussed in a full section of the paper.	

What to Report (Interview Design)

Item	Type of Data	Justification	Example Source (Eckert, 2010)
Selection strategy (for interviews)	Text	Provides confidence in the initial data sources. Did you randomly pick an interviewee or were they recommended to you by another interviewee or manager? Is there a previous working relationship between the interviewer and the interviewee? This can build confidence in the honesty of the responses.	Planned by senior manager
Role of interview in study (intentional interview vs. retrospective mining of collected)	Text	The reader needs to understand how interviewing as a tool/method is useful to help ask or answer the questions of your research. (question finding, question answering, model building, verification, or tool/model evaluation)	Explain planning practice in projects
Additional methods (document analysis, observation)	Text	The triangulation with different methods to arrive a same inference increases the confidence in the work. Confidentiality of the documents may preclude detailed inferencing that can be supported instead with detailed interviews.	Cross case analysis with other observation and interview case studies
Timeline of interviews/research	Graphic	Provides the reader with an understanding of the mixed methods and how/when the interviews are conducted. Provides the evolution of the question development if interviews are done in series or independently. Is there a level of convergence reached? Are the interviews done in batches for corroborating previous?	NA
Volume of collected information	Numeric	Lines of transcripts, hours of interview, number of unique utterances	NA
Verification strategy	Text	Provides confidence in the findings and inferences made.	Summaries provided and reviewed to organization

What to Report (Analysis Process)

Item	Type of Data	Justification	Example Source (Eckert, 2010)
Recording strategy	Text	Informs the type of data that is collected and analyzed and how the interview might have been conducted	
Example Questions (topics)	Text	Reader needs to see HOW you arrived at the inferences. Perhaps not for all the questions, but at least for an example. This provides the tools for repeating this type of research. Does this strategy agree with the type of interview, the goal of interview, and the purpose of research	
Example Answers/Responses	Text	Responses can add credibility to the procedure of analyzing the interviews Responses can add credibility to the inferences that are drawn.	
Strategy of Analysis	Text	Reader needs to know how you are converting the information gathered in the interviews	

Reporting on Research

- **Truth Value** (Ability to establish confidence in truth of the findings)
  - **Credibility** (Extent to which the results appear to be adequate representations of the situation under study)
- **Applicability** (Ability to generalize from the findings to other contexts or settings)
  - **Transferability** (Extent to which findings from one study in one context will apply to other contexts)
  - **Analytical Generalizations** (Extend to which theory developed from one case is extended to other situations with similar conditions)
- **Consistency** (Consistency of Data)
  - **Dependability** (Extent to which the coherence of the internal process and the way the researcher accounts for changing conditions in the phenomena)
  - **Recoverable** (Extent to which the research process is completely exposed for others to critical scrutiny)
- **Neutrality** (Findings are function solely of the informants and conditions of research)
  - **Confirmability** (Extent to which interpretation are the result of participants and the phenomenon as opposed to researcher bias)