ARIZONA STATE UNIVERSITY

DESIGN AUTOMATION LAB

CreativeIT – Major Grant # 1002910

Understanding & Aiding Problem Formulation in Conceptual Design

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OVERVIEW

Research Questions

- What is the relationship between problem formulation and creative outcome in engineering design?
- Can a computational framework provide a means to study this relation more objectively?
- Is it possible to build an interactive computer tool that aids problem formulation leading to creativity?

Research Tasks

1. Conduct exploratory protocol studies: collect preliminary data on problem formulation;
2. Develop a data structure (P-map) for problem representation;
3. Construct an interactive computer system that facilitates data collection and analysis;
4. Conduct experiments to understand the role of creativity in problem formulation.

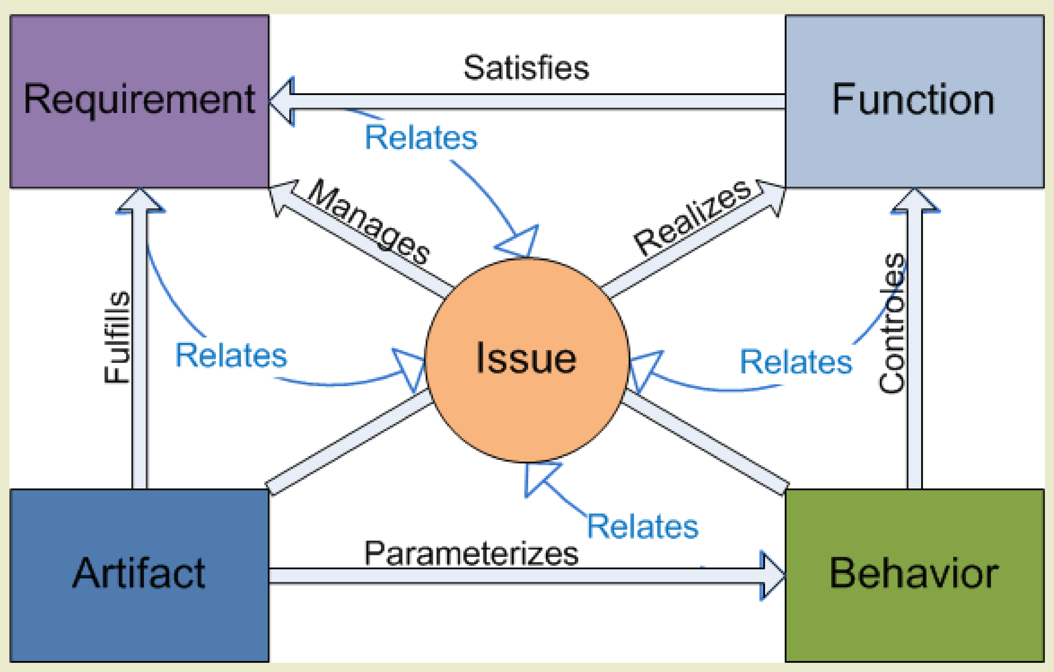
Motivation/Hypotheses

- problem formulation plays a key role in overall creativity [1,2]
- problem formulation and structuring process is a key difference between uncreative and creative designers; poor designers construct formulations that retain surface features of the problem design statement, whereas creative designers will use abstract problem representations that are more flexible and dynamic. [3,4,5]
- The most productive explorations arise from questions that cause designers to shift perspective, reformulate, and/or re-encode. [6]

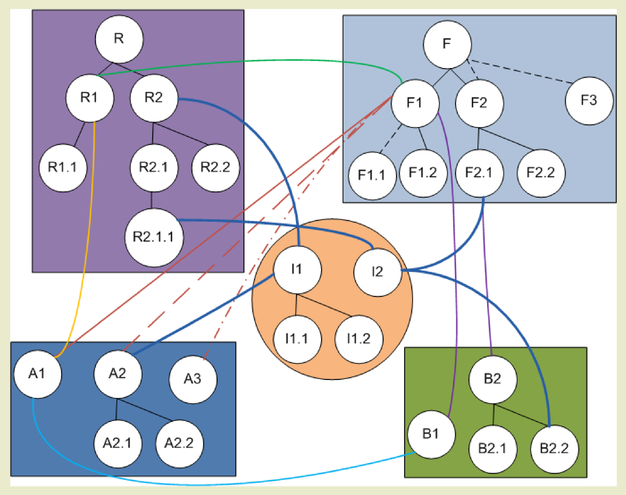
Current Status

Tasks 1 and 2 are completed; tasks 3 and 4 are in progress.

Problem Map Framework



- The *P-map* framework
  - Five groups of entities: Requirement, Function, Artifact, Behavior, and Issue
  - Each group built around main entities, supporting entities, and mandatory or optional attributes
  - A hierarchical structure with disjunctive decompositions
  - Distinct pair relations among four groups with issues relating to any composition of the other groups
- Designers construct multiple representations of problems to discover gaps, inconsistencies and conflicts [7, 8]→multi-state representation
- Representations are multi-modal [9]



- Motivating examples in engineering design
  - Task-episode accumulation model [10]
  - Linkographs of conceptual and figural representations [7]
  - Task-Operator-Phase model [11]
  - F-B-S [12], S-B-F [13]
- Motivating examples in computer science
  - Concept maps [14]
  - Semantic networks [15]
  - Problem-behavior graph [16]

These models are at coarse levels, not structured, and not flexible.

YEAR 1: Exploratory Studies

Exploratory Protocol study for developing Problemization Ontology:

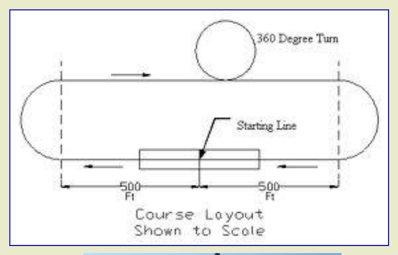
Think-aloud protocol
All participants do the same problem

Participant selection

Expert designers in companies (HP, Intel)
Senior undergrad students in mechanical engineering at ASU
Creativity is based on scores from a divergent thinking test [17]

Problem Selection

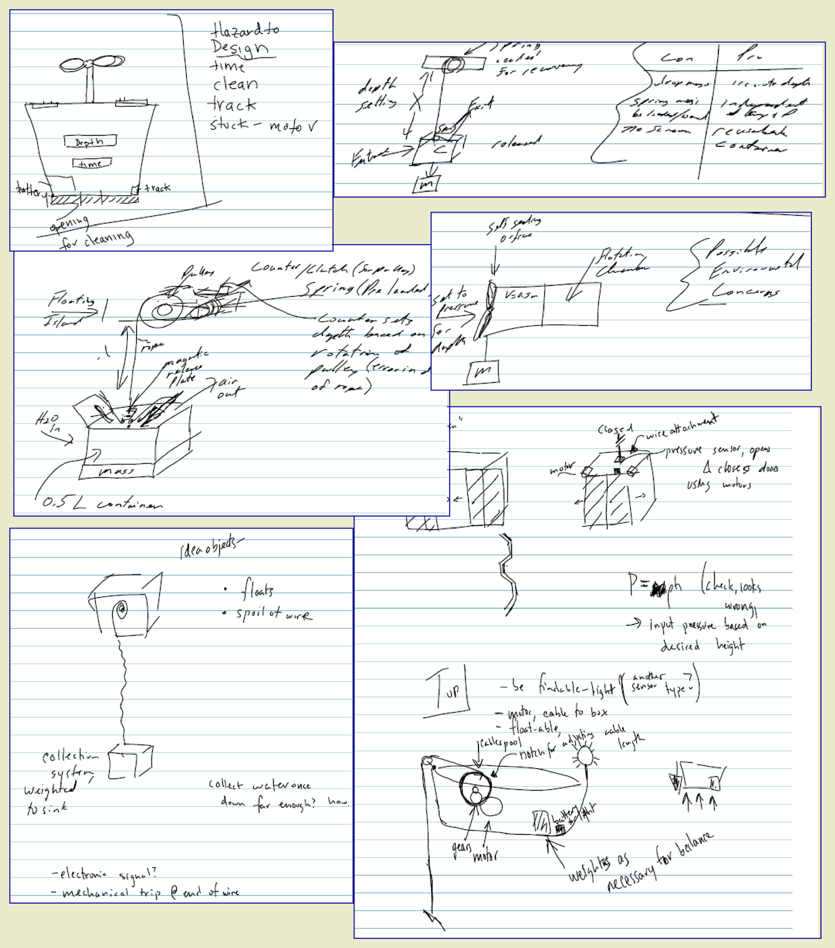
Rich enough for wide range of designs
No clear single best solution
Low dependence on domain specific knowledge
Achievable in desired timeframe (1 hour for conceptual design phase alone)



Design Problems

Problem 1: AIAA 2011 competition. Design of a model aircraft packable in a carry-on luggage; hand-launched. Scored based on max # of lapses in 4 minutes, max payload to weight ratio of external load and max # of golf balls carried in fuselage.

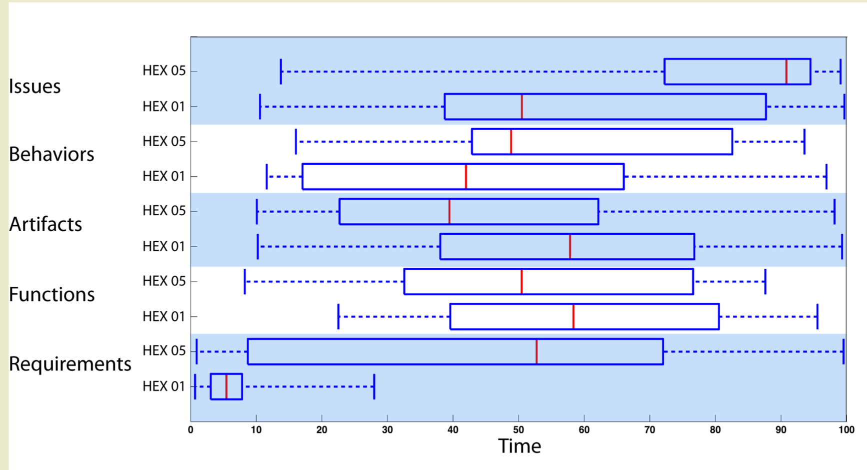
Problem 2: Design of a mechanical device to be used from a rowboat to collect 0.5 liter of fresh-water sample from lakes down to max 500 m depth adjustable within 10 m, Float on the surface until picked up. Reliable, easy to use, reusable, and inexpensive.

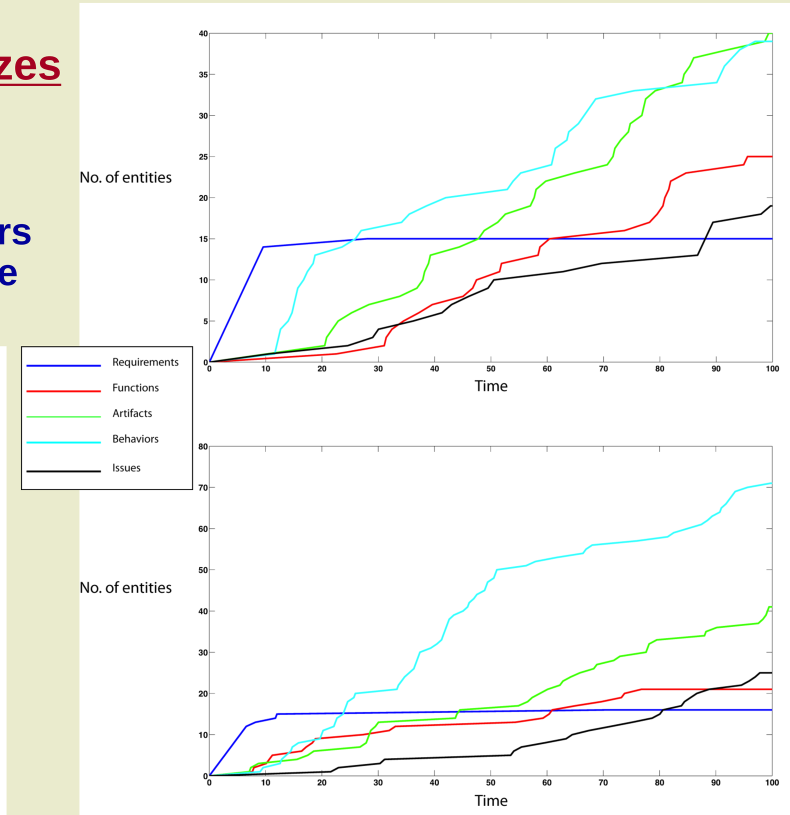


New Avenues for Research in Design: Computational Analysis for Large Sample Sizes

Preliminary Results

- Coding protocols with a P-map schema makes it easier to reach consistency among different coders
- The computational framework enables quantitative and qualitative analyses





Possible Quantitative Results

- Comparison of number of different entities
- Comparison of emergence of entities in time
- Correlating framework measures with outcome-based metrics

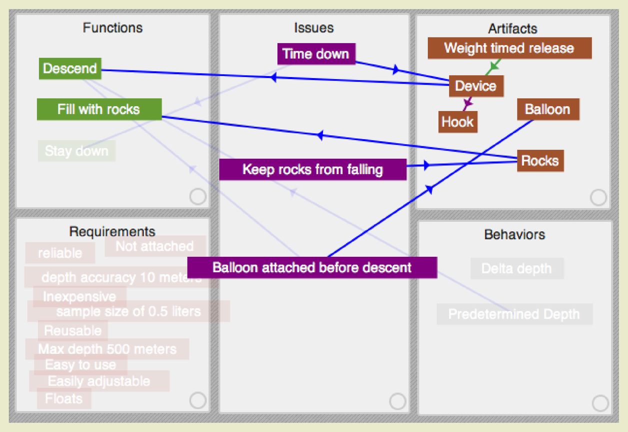
Possible Qualitative Results

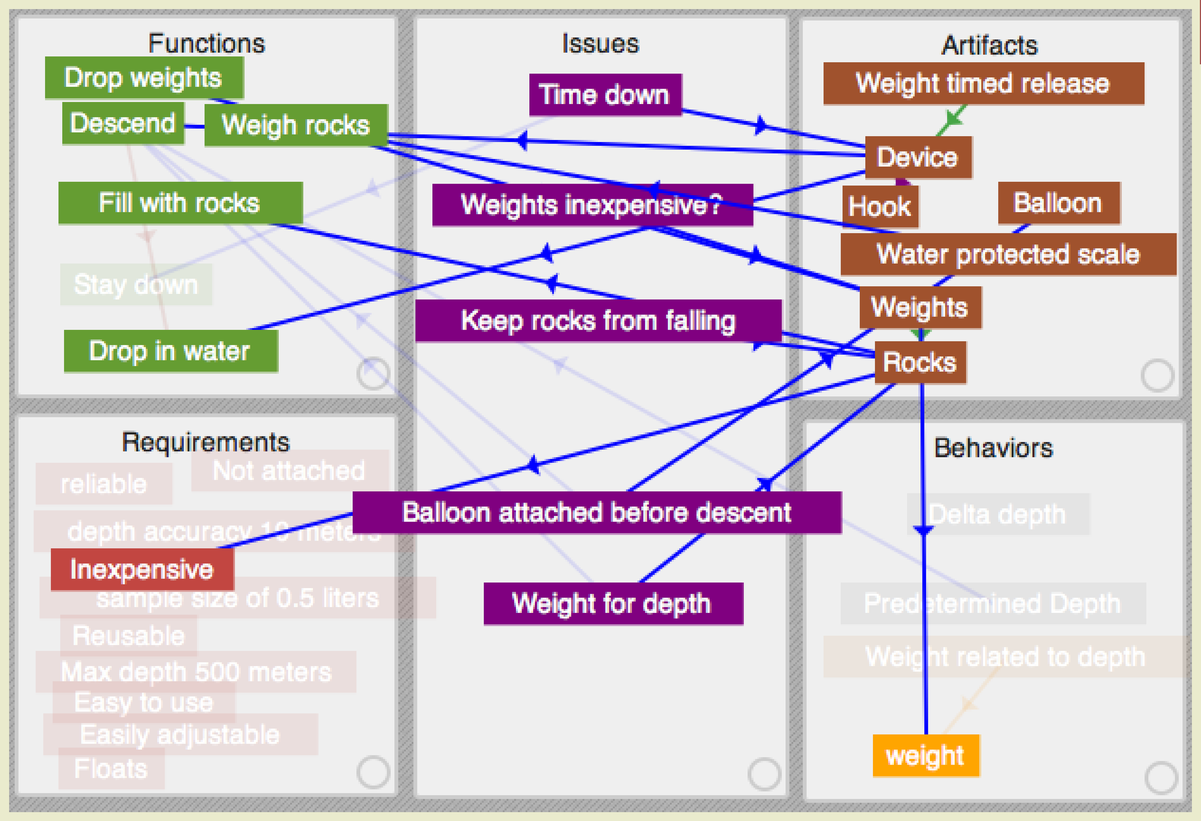
- Highlighting key issues
- Abstracting an artifact and specifying another type of it
- Use of analogies

YEAR 2: "Problemizer" Tool

Version 1

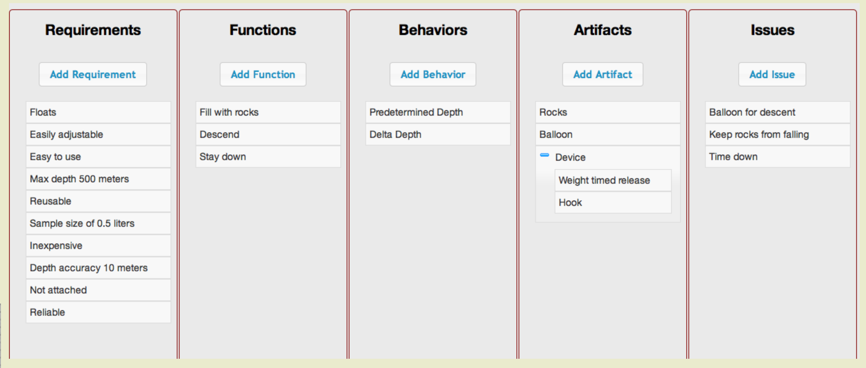
- Data entry: filling in semi-structured sentences
- Data display: clicked entities and the entities that they are connected to, show up opaque.

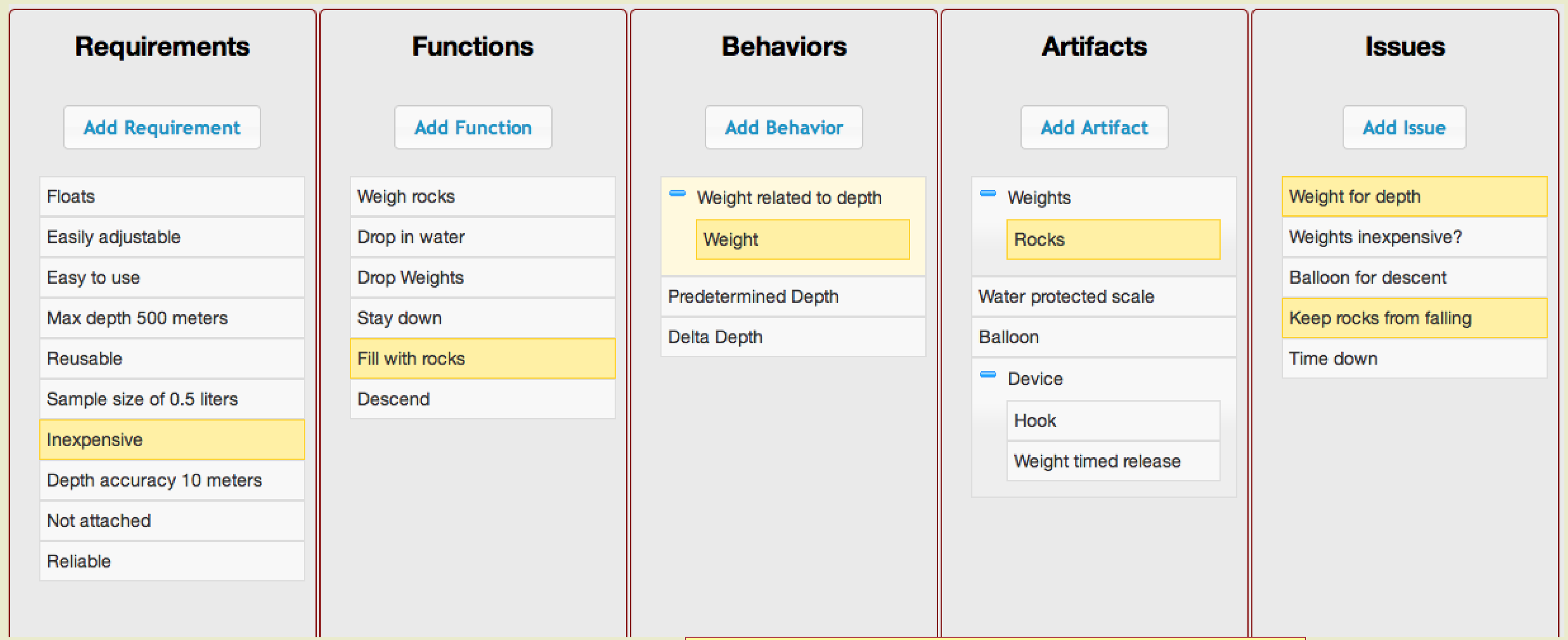




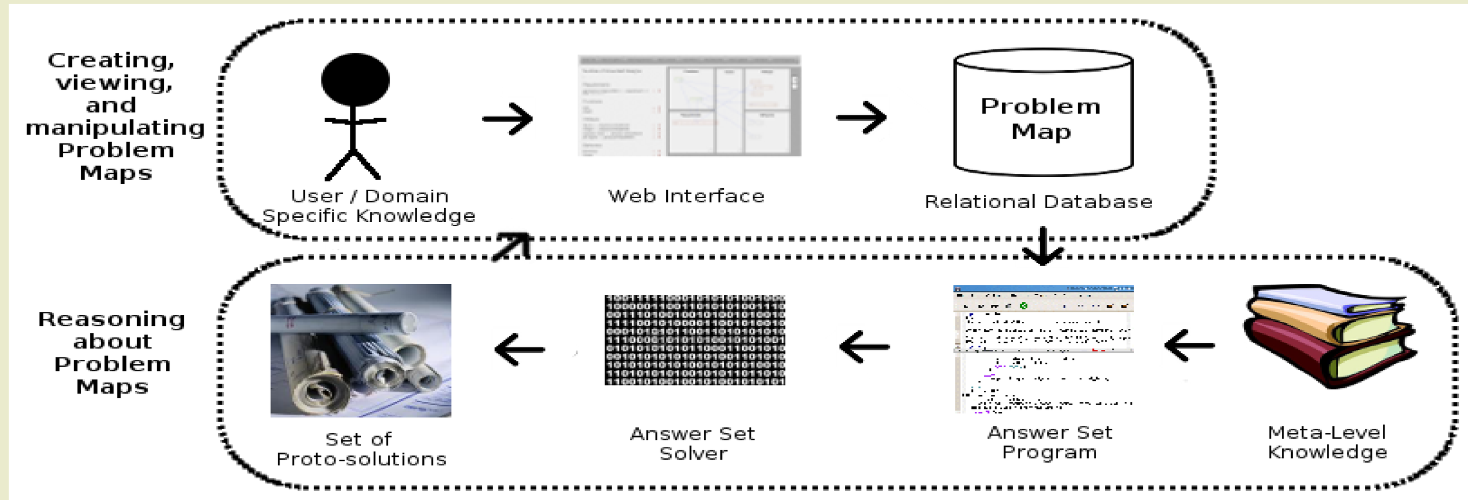
Version 2

- A tabular display to handles the growing complexity of the p-maps
- A disjunctive hierarchy: in one instance a device may decompose into one set of children and in another instance a different set
- The user has the option to switch between different hierarchical decompositions at any time
- Moused-over entities appear highlighted along with all of connected entities





Internal Representation & Reasoning



The tool can output Problem Maps in a logical formalism (Answer Set Prolog), which facilitates reasoning.
We have defined basic meta-level knowledge that governs what constitutes a consistent problem-solution set. When combined with Answer Set Programming these can be used to output all the proto-solutions contained within a Problem Map.
We hope to evaluate various creativity metrics in real-time based on these problem-solution sets and provide feedback to the designer to aid in designer creativity.

```
issue(iu_comfortable_support_at_flat_position,"deflection")
issue(iu_support_weight_at_flat_position, "load on a cantilever causes high bending stress")
relates(iu_comfortable_support_at_flat_position, fn_supporting_in_flat_position)
relates(iu_support_weight_at_flat_position, ph_bending_stress)
relates(iu_support_weight_at_flat_position, rq_support_250lb_weight)
relates(iu_support_weight_at_flat_position, sl_pivoting_recliner)
parentOf(iu_comfortable_support_at_flat_position, iu_support_weight_at_flat_position, iu_hy1)
```

YEAR 3: Confirmatory Studies

Experiment 1: Framework Evaluation

- Criteria: 1a)domain independence; 1b)richness; 1c)compactness; 1d)unambiguity; 1e)flexibility
- Effects:
  - 1b)amount of protocol data that can be coded
  - 1c)no. of predicates to code a protocol
  - 1d)no. of similar predicates coded
- Factors (levels):
  - 1b&1c)framework (P-map, FBS)
  - 1d) raters
- Constants:
  - 1b&1c&1d)protocol or verbalized data segment
- Noise factors:
  - 1b&1c)raters

Experiment 2: Tool Effectiveness

- Criteria: effectiveness of the tool in formulating problems for designers of different levels of experience and creativity
- Effects: design outcome (rated by a panel of judges)

- Factors (levels):
  - Experience (novice, expert)
  - Creativity (less creative, more creative)
  - Tool (pen & paper, interactive aid)

- Noise factors: design problems, since each designer cannot work on the same problem once without the tool and once in the tool

Experiment 3: Effectiveness of the tool with assisting features

- Criteria: effectiveness of the tool with hints to assist designers in formulating problems

- Effects: design outcome (rated by a panel of judges)

- Factors (levels):
  - Experience (novice, expert)
  - Creativity (less creative, more creative)
  - Tool (simple tool, assisting tool)

- Noise factors: design problems

Data mining
Supervised learning

Factorial DOE

Experiment 4: Relation between problem formulation and creative outcome

- Designers work on problems in the tool. There will be a search for correlations among different measures within the framework, subjects of different levels of experience and creativity, and creative outcome.

- Types of framework measures: count, sequence, hierarchy, connectedness, shift of attention

- The outcome will determine best practices which will be incorporated in the tool as hints

- Noise factor: design problems

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PROJECT PUBLICATIONS

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4. Danielescu A., Dinar M., Maclellan C., Shah J. J., Langley P., 2012, "Towards a Formal Representation Model of Problem Formulation in Design," Proceedings of ASME DETC, Chicago, Illinois, USA. [in press]