Development, Assessment, and Implementation of Metrics to Improve Innovative Thinking through Project-Based Design Courses

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Outline

• Research objectives
• Research methods
  – Creative Product Semantic Scale (CPSS)
  – Data
• Analysis
  – Can CPSS be used to predict performance of final products?
  – Can CPSS be used to predict creativity of final products?
  – Can CPSS be used to identify sustainable design concepts?
• Project outcomes
• Future work
Motivation

- As many as a half of student teams change design concepts before final testing
- Difficult to predict performance of final products without building prototypes
Research Objectives

• Develop metrics to predict performance and creativity of final products at the design concept selection stage

• Establish guidelines to identify sustainable design concepts using metrics

• Implement metrics in design class to improve student’s innovative thinking
Research Methods
Metrics

• Creative Product Semantic Scales (CPSS) [O’Quin and Besemer, 1989]
  – 55 items (bipolar semantic scales)
  – Evaluate creative products
  – Has not been used to predict performance of products
• Three dimensions
  – Novelty (newness)
  – Resolution (fits or meets the needs of the problematic situation)
  – Elaboration and Synthesis (combines unlike elements into a refined, developed, coherent whole)
• 11 subscales
  – 5 items in each subscale
<table>
<thead>
<tr>
<th>Novelty</th>
<th>Original</th>
<th>Over Used 1---2---3---4---5---6---7 Fresh</th>
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<tbody>
<tr>
<td></td>
<td>Predictable 1---2---3---4---5---6---7 Novel</td>
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<td>Usual 1---2---3---4---5---6---7 Unusual</td>
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<td>Unique 1---2---3---4---5---6---7 Ordinary</td>
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<td>Original 1---2---3---4---5---6---7 Conventional</td>
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<td>Stale 1---2---3---4---5---6---7 Startling</td>
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<td>Surprising</td>
<td>Customary 1---2---3---4---5---6---7 Surprising</td>
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<td>Astonishing 1---2---3---4---5---6---7 Commonplace</td>
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<td>Shocking 1---2---3---4---5---6---7 Old Fashioned</td>
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<td>Astounding 1---2---3---4---5---6---7 Common</td>
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<td>Germinal</td>
<td>Warm Over 1---2---3---4---5---6---7 Trendsetting</td>
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<td>Revolutionary 1---2---3---4---5---6---7 Average</td>
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<td>Significant 1---2---3---4---5---6---7 Insignificant</td>
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<td>Inessential 1---2---3---4---5---6---7 Essential</td>
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<tr>
<td></td>
<td>Logical 1---2---3---4---5---6---7 Makes Sense</td>
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<tr>
<td>Resolution</td>
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<td>Workable 1---2---3---4---5---6---7 Useful</td>
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<td>Disordered</td>
<td>1---2---3---4---5---6---7</td>
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<td>Arranged</td>
<td>1---2---3---4---5---6---7</td>
<td>Disarranged</td>
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<tr>
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<td>1---2---3---4---5---6---7</td>
<td>Disorganized</td>
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<td>Complete</td>
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<td>Awkward</td>
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<td>Unattractive</td>
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<td>1---2---3---4---5---6---7</td>
<td>Straightforward</td>
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<tr>
<td>Simple</td>
<td>1---2---3---4---5---6---7</td>
<td>Complex</td>
</tr>
<tr>
<td>Plain</td>
<td>1---2---3---4---5---6---7</td>
<td>Ornate</td>
</tr>
<tr>
<td>Complicated</td>
<td>1---2---3---4---5---6---7</td>
<td>Uncomplicated</td>
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<tr>
<td>Boring</td>
<td>1---2---3---4---5---6---7</td>
<td>Interesting</td>
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<tr>
<td>Meaningful</td>
<td>1---2---3---4---5---6---7</td>
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<tr>
<td>Mystifying</td>
<td>1---2---3---4---5---6---7</td>
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<td>1---2---3---4---5---6---7</td>
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<td>1---2---3---4---5---6---7</td>
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<td>Unexplained</td>
<td>1---2---3---4---5---6---7</td>
<td>Self-Explanatory</td>
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<td>Skillful</td>
<td>1---2---3---4---5---6---7</td>
<td>Bungling</td>
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<tr>
<td>Well Made</td>
<td>1---2---3---4---5---6---7</td>
<td>Botched</td>
</tr>
<tr>
<td>Crude</td>
<td>1---2---3---4---5---6---7</td>
<td>Well crafted</td>
</tr>
<tr>
<td>Meticulous</td>
<td>1---2---3---4---5---6---7</td>
<td>Sloppy</td>
</tr>
<tr>
<td>Careless</td>
<td>1---2---3---4---5---6---7</td>
<td>Careful</td>
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</tbody>
</table>
# CPSS Definitions

<table>
<thead>
<tr>
<th>CPSS Dimensions and Subscales</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Novelty</strong></td>
<td>Extent of newness(^1)</td>
</tr>
<tr>
<td><strong>Original</strong></td>
<td>Unusual or infrequently seen(^1)</td>
</tr>
<tr>
<td><strong>Surprising</strong></td>
<td>(Revolutionary that forces a shift in the way that reality is perceived by users(^1))</td>
</tr>
<tr>
<td><strong>Germinal</strong></td>
<td>Likely to suggest additional future creative products(^1)</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Degree to which the product fits or meets the needs of the problematic solution(^1)</td>
</tr>
<tr>
<td><strong>Valuable</strong></td>
<td>Judged worthy by users because its fits needs(^1)</td>
</tr>
<tr>
<td><strong>Logical</strong></td>
<td>Follows the accepted and understood rules for the discipline(^1)</td>
</tr>
<tr>
<td><strong>Useful</strong></td>
<td>Has clear, practical applications(^1)</td>
</tr>
<tr>
<td><strong>Elaboration and Synthesis</strong></td>
<td>Degree to which the product combines unlike elements into a refined developed, coherent whole, statement or unit(^1)</td>
</tr>
<tr>
<td><strong>Organic</strong></td>
<td>Has a sense of wholeness or completeness(^1)</td>
</tr>
<tr>
<td><strong>Elegant</strong></td>
<td>Solution is expressed in a refined, understated way(^1)</td>
</tr>
<tr>
<td><strong>Complex</strong></td>
<td>Contains many elements at one or more levels(^1)</td>
</tr>
<tr>
<td><strong>Understandable</strong></td>
<td>Ability to communicate its function or message to its user or observer(^2)</td>
</tr>
<tr>
<td><strong>Well-Crafted</strong></td>
<td>Worked and reworked with care to develop it to its highest possible level for that point in time(^1)</td>
</tr>
</tbody>
</table>


Data Collection and Analysis

• Sophomore design class (ME 161, 2011 Fall)

• Procedure
  – Design process
  – Deliverables
  – Data
  – Analysis
Data Collection and Analysis

- Sophomore design class (ME 161, 2011 Fall)
- Procedure
  - Design process
  - Deliverables
  - Data
  - Analysis (Performance)
Data Collection and Analysis

• Sophomore design class (ME 161, 2011 Fall)

• Procedure
  – Design process
  – Deliverables
  – Data
  – Analysis (Creativity)
Data Collection and Analysis

- Sophomore design class (ME 161, 2011 Fall)
- Procedure
  - Design process
    - Concept generation
    - Concept selection
    - Proof of concept
    - Final testing
  - Deliverables
    - Concept sketch
    - POC prototype
    - Final product
  - Data
    - CPSS
    - CPSS
    - CPSS
  - Analysis (Sustainability)
    - Classification tree
• Design and prototype innovative toys that can deliver 30 foam stamps and a basket to the top of a stairs
Design Project

• Design and prototype innovative toys that can deliver 30 foam stamps and a basket to the top of a stairs
### Performance Summary

- **Normalized performance**
  - Maximum score 1

<table>
<thead>
<tr>
<th>Design strategy (2011 Fall)</th>
<th>1 team</th>
<th>2 teams</th>
<th>5 teams</th>
<th>1 team</th>
<th>1 team</th>
<th>13 teams</th>
<th>2 teams</th>
<th>1 team</th>
</tr>
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<tbody>
<tr>
<td>Catapult</td>
<td>0</td>
<td>0.09</td>
<td>0.19</td>
<td>0</td>
<td>0</td>
<td>0.34</td>
<td>0.07</td>
<td>0</td>
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<tr>
<td>Catapult + sled</td>
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<tr>
<td>Extending arm (Diagonal)</td>
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<tr>
<td>Extending arm (Rise and tilt)</td>
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<tr>
<td>Shooting</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle/tank</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle (Rise and move forward)</td>
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<tr>
<td>Vehicle + rotating arm</td>
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</tr>
</tbody>
</table>
Design Outcomes

Catapult & sled
Extending arm (Rise and tilt)
Vehicle/tank
Vehicle (Rise and move forward)
Example of Deliverables and Data

- 24 teams
- Three deliverables per team
- Each deliverable is evaluated by 55 CPSS items
- Three dimension and 11 subscale scores are calculated

Concept sketch  POC prototype  Final prototype

55 CPSS item scores  55 CPSS item scores  55 CPSS item scores
Analysis
Q1: Can CPSS Predict Performance?

- Sophomore design class (ME 161, 2011 Fall)

- Procedure
  - Design process
    - Concept generation
    - Concept selection
    - Proof of concept
    - Final testing
  - Deliverables
    - Concept sketch
    - CPSS
    - POC prototype
    - CPSS
    - Final product
  - Data
    - CPSS
  - Analysis (Performance)

Correlation

Testing results
Q1: Can CPSS Predict Performance?

- **Dimensions**

  ![Graph showing correlation between CPSS and performance](image)

  - Correlation > 0.5 statistically significant at 5% level

  - Correlation = 0.89
    - Slope = 0.15
    - p-value = 9.811e-09 **

  - Correlation = 0.65
    - Slope = 0.17
    - p-value = 0.0026268 **

  - Correlation = 0.03
    - Slope = 0.02
    - p-value = 0.92
**Q1: Can CPSS Predict Performance?**

Stable (all subscale with correlation >0.5)

- **Dimensions**

  ![Graph showing correlation between CPSS dimensions and performance](image)

  **Subscales**

  ![Graph showing correlation between CPSS subscales and performance](image)

  Correlation > 0.5 statistically significant at 5% level
Q1: Can CPSS Predict Performance?

- **Items**
  - Less stable

Correlation vs. Items

- Novelty
- Resolution
- CPSS
- Elaboration and Synthesis

Graph showing correlation between CPSS and performance.
Q2: Can CPSS Predict Creativity?

- Sophomore design class (ME 161, 2011 Fall)
- Procedure
  - Design process
  - Deliverables
  - Data
  - Analysis (Creativity)
Q2: Can CPSS Predict Creativity?

Stable (all subscale with correlation >0.5)

• Dimensions

**Subscales**

- Novelty
- Resolution
- Elaboration and Synthesis

**Graphs:**

- CPSS (POC) -> CPSS (Final)
- CPSS (Concept) -> CPSS (Final)
Q2: Can CPSS Predict Creativity?

- Items

- Correlation

- Novelty

- Resolution

- Elaboration and Synthesis
Summary

• **Performance** of a product
  – Can reasonably be predicted from concept sketches
  – Use one of *Novelty* subscales
    • Original, Surprising, or Germinal
    • Each subscale requires five-item evaluations

• **Creativity** of a product
  – Can reasonably be predicted from concept sketches
  – Use one of *Novelty* subscales
  – Prediction improves if *POC prototypes* are built
Q3: Can CPSS Predict Sustainable Concepts?

- Sophomore design class (ME 161, 2011 Fall)

- Procedure
  - Design process
    - Concept generation
    - Concept selection
    - Proof of concept
    - Final testing
  - Deliverables
    - Concept sketch
    - POC prototype
    - Final product
  - Data
    - CPSS
  - Analysis (Sustainability)
    - Classification tree

Methods

Outcomes

Future work
Q3: Can CPSS Predict Sustainable Concepts?

- Classification tree
  - Subscales

2.9 < Useful < 4.5

4.5 < Useful
  - Complex < 2.9
  - Unchanged

2.9 < Useful < 4.5
  - Useful < 2.9
  - Changed

Useful < 4.5
  - Useful < 4.5
  - Unchanged

2.9 < Useful < 4.5
  - Useful < 2.9
  - Changed

Useful < 4.5
  - Useful < 4.5
  - Unchanged

2.9 < Useful < 4.5
  - Useful < 2.9
  - Changed
Q3: Can CPSS Predict Sustainable Concepts?

- Combinations of
  - One subscale of Resolution
  - One subscale of Elaboration and Synthesis

- Stability of classification tree
  - 45-100%

- Misclassification rate
  - 8-46%

- Cannot arbitrarily choose a combination
Project Outcomes
Design Course Changes

- Sophomore design class (ME 161, 2012 Spring)
  - Past design process
    - Concept generation ➔ Concept selection ➔ Proof of concept ➔ Final testing
    - Concept sketch ➔ POC prototype ➔ Fully-functional prototype
  - New design process
    - Concept generation ➔ Concept selection ➔ Testing 1 ➔ Testing 2
    - Concept sketch ➔ Fully-functional prototype ➔ Fully-functional prototype
Research Outcomes

• Collaboration
  – Rochester Institute of Technology (RIT)
  – Possible external grant proposal submission

• Publication
  – Conference paper submitted
    • ASME 2011 International Design Engineering Technical Conferences
  – Journal paper to be submitted
Future Plan

• Further investigate CPSS
  – Missouri S&T
  – RIT

• Develop user-friendly metrics
  – On-line CPSS

• Implement metrics in class
  – ME 161 - Sophomore design class (Missouri S&T)
  – ME 261 - Senior capstone design class (Missouri S&T)
  – Senior capstone design class (RIT)
Acknowledgements

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