Design Signatures: Empirically Based Representations of Design Processes

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Starting with a story . . .

There are these two young fish swimming along and they happen to meet an older fish swimming the other way, who nods at them and says “Morning... how’s the water?”

And the two young fish swim on for a bit, and then eventually one of them looks over at the other and goes “What the hell is water?”
Several young engineers are in a product design meeting.

An old engineer stops by the meeting to see how things are going, and as she heads out the door after getting an update she says “be sure to be aware of your design process”

After she leaves, one of the young engineers turns to the others and says “what the hell is a design process?”
Hard to describe, represent, teach processes

Charkha sculpture, Mumbai; Mountain Devil Lizard Dreaming, Gloria Petyarre; Geoffrey Mann, “Attracted to Light”; Adulthood II, Hilma af Klint
“Spend another day...”

“Super valuable! Much more compelling to see real data, detail, makes me believe, instead of tuning out “prescribed” info, can’t trust how they derived it b/c don’t know. Spend another day in our class talking about this research please!”
Many Collaborators...

Collaborators, co-authors, and research team members include Robin Adams, Arif Ahmer, Brad Arneson, Theresa Barker, Maria Buan, Emma Bulojewski, Mary Besterfield-Sacre, Jim Blair, Carie Bodle, Laura Bogusch, Jim Borgford-Parnell, Karen Bursic, Ryan Campbell, Monica Cardella, Soomin Chang, Justin Chimka, Dharma Dailey, Kate Deibel, Zach Goist, Brian Hayes, Melissa Jones, Aaron Joya, Allison Kang, Deborah Kilgore, Kristina Krause, Vipin Kumar, Alex Lew, Terri Lovins, Stefanie Lozito, Janet McDonnell, Kenya Mejia, Annegrete Mølhav, Andrew Morozov, Susan Mosborg, Carie Mullins, Heather Nachtmann, Wai Ho Ng, Will Richey, Eddie Rhone, Axel Roesler, Wendy Roldan, Jason Saleem, Giovanna Scalone, Kathryn Shroyer, Elvia Sierra-Badillo, Shaunte Smith, Roy Sunarso, Steve Tanimoto, Jennifer Turns, Hannah Twig-Smith, Cheryl Wang, Ken Yasuhara, and Mark Zachry...

...and over 75 additional undergraduate students
My backstory: career goal

► Help engineering students think about impact of engineering on society and globe
  ● consider context and think broadly as they engage in engineering

► How could engineers consider context?
  ● as they engage in design

► Therefore – deeply study engineering design processes
Goal: deeply understand engineering design processes to enable informed teaching

- Compare “should” with “actually do” for engineering designers
  - Decision theory/ Behavioral decision theory
  - Capture “actually do”
- Audience: engineers
  - Convinced by quantitative data
  - Large sample sizes
- Embarked on quest
  - Collect large corpus of verbal protocol data
  - Of engineers with various levels of expertise
  - Create quantitative measures from verbal data to enable comparisons
  - A gamble...hopefully something useful shows up!
A research program...

- My research program – to understand how engineers design
  - Understand design expertise
- With the long term goal to figure out how to teach engineering students about the importance of understanding context
Today’s Agenda

► Introduction
► Researching design
► Teaching design
► Wrapping-up

Charkha sculpture, Mumbai
Today’s Agenda

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Charkha sculpture, Mumbai
Examining Design Expertise

- 177 individuals solved design problems
  - 401 problems solved
  - 298 verbal protocols
- 177 individuals
  - Various levels of expertise
  - 149 engineering students
  - 19 practicing engineering experts
  - 4 educators (IE, 2 ME, Nuclear physics)
  - 5 domain experts (playground design, landscape architecture)

Atman, August 2018
Examining Design Expertise: Corpus of data

Individuals (177)

Instances of Problem Solving (401)

Problems (4)

Playground (<3 hr protocol)

Ping Pong (<30 min protocol)

Street Crossing (<30 min protocol)

Midwest floods (list of factors)

* = second protocol at later time period with same participant
Examining Design Expertise: Playground Problem

- **Task**
  - Design a playground for a fictitious neighborhood

- **Participants**
  - First-year engineering students \((n = 26)\)
  - Graduating senior engineering students \((n = 24)\)
  - Practicing engineering experts \((n = 19)\)

- **Verbal protocol analysis**
  - Individuals had up to 3 hours in a lab setting
  - Think-aloud protocol
  - Segment and code transcripts with design process codes
Problem statement: Design a playground

► Subject to a set of constraints
  ● most of the children who will use the playground will range from 1 to 10 years of age.
  ● Twelve children should be kept busy at any one time.
  ● There should be at least **three different types of activities** for the children.
  ● Must be **safe** for the children,
  ● Must **remain outside** all year long,
  ● Must **not cost too much**, 
  ● Must comply with the **Americans with Disabilities Act**.

► Your design should use materials that are available at any hardware or lumber store.

► The playground must be ready for use in 2 months.
Why a playground?
Design activity codes

7 Engineering Design Textbooks

Content Analysis

(Identification of a Need)
Problem Definition
Information Gathering
Generation of Ideas
Modeling
Feasibility of analysis
Evaluation
Decision
Communication
(Implementation)
Examining design expertise: A body of work
Design process timelines

► A tracing of design activities over time
► Each instance of a design process leaves a unique design signature

PD: Problem Definition
GATH: Gathering Information
GEN: Generating Ideas
MOD: Modeling
FEAS: Feasibility Analysis
EVAL: Evaluation
DEC: Decision Making
COM: Communication
Design timeline representations

“Hmmm do you have a list of materials”
First-year and senior design processes?

 ► Please sort the 6 timelines in your packet into two groups of 3:
   ● Timelines from first-year students
   ● Timelines from graduating seniors

 ► Hint
   ● in each group there is a timeline for an individual who created a low, medium and high quality artifact

September, 2018
What we found

Expertise

First-Year Students

Graduating Students

Artifact Quality

Low

Med

High

Atman, August 2018
Graduating seniors were significantly more likely first-year students to...

- have higher-quality designs
- scope the problem more effectively by considering more categories of information
- make more transitions among design activities
- progress farther in the design process

(Atman, Chimka, Bursic, & Nachtmann, 1999)
Engineering experts
Engineering experts were significantly more likely than students to...

- spend more time solving the problems in all design stages
- consider more objects in their design process
- scope the problem more effectively by gathering more information (explicitly) and covering more categories
- exhibit a “cascade” pattern of transitions

(Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007)
Percent Cascade* Shape

Engineering Experts  
\[n = 19\]

Graduating Students  
\[n = 24\]

First Year Students  
\[n = 26\]

% “Cascade” Shape

* “Cascade” not “Waterfall”
Timelines as canvas for research results
Timelines as canvas: Problem scoping before focus on modeling
Timelines as canvas: Problem scoping and gathering information throughout process
Timelines as canvas: Transitions
Timelines as canvas: Stay the course
Timelines as canvas: Ideal project envelope

Graduating Senior (Quality Score = 0.63)

* Result from Borgford-Parnell et al., 2010
Timelines as canvas: considering context
What about the rest of the data?

Individuals (177)

Instances of Problem Solving (401)

Problems (4)

Playground (≤3 hr protocol)

Ping Pong (≤30 min protocol)

Street Crossing (≤30 min protocol)

Midwest floods (list of factors)

= second protocol at later time period with same participant
We see similar patterns — more experience, more complex processes

(Figure from upcoming “Design Timelines: Concrete & Sticky Representations of Design Process Expertise”, Design Studies, Nov, 2019)
Individuals, Design a playground

- Undergraduate engineering students from a different institution

(Deibel, Atman, Saleem, Kang, & Ng, 2007)
Individuals, Design a playground

Domain (playground design) experts (n=4)

Engineering faculty (n=4)

(Atman, Turns, Cardella, & Adams, 2003; Krause, Atman, Borgford-Parnell, & Yasuhara, 2013)
Individuals, Within-subject longitudinal (n:32 First Year, 61 Graduating; 18 w/in subject)

- Design a Ping-pong Ball Launcher
- Design a Street Crossing System

(Cardella, Atman, Turns, & Adams, 2008)
Teams, Design a digital pen (n=1)

(Atman, Borgford-Parnell, Deibel, Kang, Ng, Kilgore, & Turns, 2009)
Timelines as canvas: other frames e.g., Schon’s reflection-in-action
Timelines as canvas: music
Design soundtracks

Original Senior C (927) - Tonal Soundtrack


Tonal Soundtrack: Original Senior C (927)
The Tonal version of design soundtracks is the most literal of all versions. Each design activity is mapped to a specific pure tone on the pentatonic scale, with Problem Definition (PD) having the highest pitch. The start and stop of each tone is sharp and tightly tied to the underlying time-series data.

As with all design soundtracks, each activity's sound is piped to either the right or left ear. This separation is noted in the sound samples table to the right.

Sound Mapping
- PD - Problem Definition
- E6 Tone (left ear)
- GATH - Gathering Information
- D6 Tone (right ear)
- GEN - Generating Ideas
- C5 Tone (left ear)
- MOD - Modeling
Design Soundtracks
Design Soundtracks
Timelines as canvas: Design signatures
Signatures can vary according to function
Design signatures can vary according to function

► Choose a design signature up front
► Use it as a guide for check-ins throughout
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► Wrapping-up

Charkha sculpture, Mumbai
So now what?

- Translating research to practice
- My design challenge
  - how can these findings be useful for teaching design?
Broad design teaching landscape

► Capstone design
► Freshman design
► Design spine
► Disciplinary design
► Maker spaces
► Service learning
► ......
Inside the larger landscape, typical process representations

HCDE Model

IDEO Model
Affordances of timelines – concrete & sticky

- Specific instance
- Time is explicit
- Abstract concepts made visible
- Grounded in data
- Can personally identify with
- This makes them both
  - concrete
  - sticky
Affordances of timelines:
Abstract concepts made visible

HCDE Model

Pivots
Persistence

Atman, July 2018
Timelines: Being grounded in data resonates with students

“Realizing that taking your time is important, realizing that higher quality designs gather data and define the problem more thoroughly BEFORE modelling which is SO COOL to see as statistically relevant because now I can PROVE to people that understanding the problem FIRST is crucial for success.” (CE student)
Timelines as teaching tools: Some examples as inspiration

- Card sorting task
- Presentations
- Coding sheet for “fishbowl” design challenge (20 minutes)
- Classroom activity (45 minutes)
- Two design briefs (one week each)
- Seminar (10 weeks)
Timelines as teaching tools: Some examples as inspiration

- Card sorting task
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What similarities and differences do you see between the first-year and graduating senior engineering students?

Do these similarities also involve the quality scores? How so?
Multiple studies — similar results

► “The highest quality scores in both groups use a greater range of activities, instead of just modeling.”
► “Problem definition is key to the overall project. Remind yourself of what you are doing and what is really being asked. Pick your head up from the paper (modeling!) and analyze the problem.”
► “Success is strongly correlated with gathering data and defining the problem early on.”

(Borgford-Parnell, Deibel & Atman, 2010)
Multiple studies – similar results

Question 3 Design Codes: "Will information from this exercise affect how you will design in the future? How?"

- Breadth [BREADTH]
- Iteration/Transitions [ITR]
- Project Wrap-Up [PW]
- Problem Scoping/Problem Framing [PS]
- Modeling [MOD]
- Time [TIME]
- Gathering Information [GATH]
- Design is a process (META)
- Design Shape [SHAPE]

(ASEE, 2019)
Timelines as teaching tools: Some examples as inspiration

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Coding sheet for design challenge

Built on workshop by Chong, Foster & Irish 2011
Looking back at end of quarter: did I learn something useful, was it worth my time...
Mapping to research on learning

- Neurons that fire together, wire together
- Prior conceptions
- Knowledge organization
- Motivation
- Metacognition
- Reflection

Ambrose et al., Bransford et al.
Timelines as teaching tools: Some examples as inspiration

- Card sorting task
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- Two design briefs (one week each)
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Create Design Process Representations

- McDonnell and Mølhave
  - Central Saint Martins College of Arts and Design, London

- Design Brief 1:
  - Create new design process representation from timeline data and coded transcripts

- Design Brief 2:
  - Engage with a design problem and record your process
  - Create new design process representation of your process

(Mølhave, McDonnell, & Atman, 2011; McDonnell & Atman, 2015)
Student representations of design

C – Memory Aid – representation of what to remember

(Atman et al., 2015)
Timelines as teaching tools: Some examples as inspiration

► Card sorting task
► Presentations
► Coding sheet for “fishbowl” design challenge (20 minutes)
► Classroom activity (45 minutes)
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► Seminar (10 weeks)
Current work - Design awareness seminar

- With Aaron Joya
- How move from knowing about a design concept to enacting it in design doing?
- ....design awareness
- 5 students
  - Grace Barar
  - Alison Gray
  - Khadijah Jordan
  - Rylie Sweem
  - Nicole Washington
Design awareness

Moving from knowing about a design concept to enacting it in design doing?

Design awareness seminar

- Tracing past process
- Concept mapping
- Ideate & prototype
- Design awareness tool

Atman, August 2018
Design awareness tool prototypes

Design Awareness Tracker

Prototype

- Two Magnetized Slots
- Display
- Stage of Design
- Clock
- Timer

Stages of Design

- Problem Definition
- Gathering Information
- Generating Ideas
- Feasibility
- Evaluation
- Decision
- Communication
- Implementation
Seeing the rest of the iceberg

Student take-aways?

Synonyms for design awareness
- Patterned chaos
- Imperfect is perfect
- Conscious design
- Non-linearity
- Fluidity
- Know the rules to break them
- Thinking about thinking
- Collaborative design with your unconscious mind
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Charkha sculpture, Mumbai
Hard to describe, represent, teach processes

Geoffrey Mann, “Attracted to Light”; Charkha sculpture, Mumbai, Hilma af Kline, Gloria Petyarre
Email from sophomore IE student

I've been talking to my friends (who didn't go) explaining to them how this is related to life and how we need to look at everything from several perspectives in order to get the most out of whatever you want to do. After about 20 minutes of explanation it seems they realize I'm crazy and move on with their day. But I think I really understand what your results say on numerous levels.

It's not that people avoid the path less taken but rather they don't even see the path less taken.

With that being said I appreciate you sharing your wisdom and wish you the best of luck!
Today discussed...

- Empirical research that describes complexity of design processes
- Timeline representations as *design signatures*
  - Concrete & sticky for students
- Warning, once you are captivated by timelines....
... you see them everywhere!
Timelines as canvas: An A cappella performance
Sound Improv Live!
More information about this work - draft

► Design Teaching/Learning

► Design Expertise

► Design Process Representations

► Design Awareness
Backup slides
Broader design research findings

Janet McDonnell summary of research on design expertise, “Paying attention to design process: Critically examining personal design practice”: Nigel Cross, “Design Thinking”, 2011

- ...designing is about problem framing as much as problem solving
- There is interplay and co-evolution between setting and solving
- Designers operate opportunistically for efficiency in response to what unfolds...sometimes mutually incompatible lines of approach in parallel
- Move fluidly between broad sweep of possibilities and a pursuit of fine detail
- Strategies can be explained as coping mechanisms for design situations characterized by uniqueness, incomplete information and uncertainty...
Design awareness

Connection with intention

Reflection throughout.
Why are timelines effective teaching tools? Comparing design process representations

Sample representations from the engineering texts

1. Identification of the problem.
2. Gathering needed information.
3. Search for creative solutions.
4. Step from ideation to preliminary designs (including modeling).
5. Evaluation and selection of preferred solution.
6. Preparation of reports, plans, and specifications.
7. Implementation of the design.

Synthesis Representation

- Identification of a Need
- Problem Definition (PD)
- Information Gathering (GATH)
- Generation of Idea (GEN)
- Modeling (MOD)
- Feasibility Analysis (FEAS)
- Evaluation (EVAL)
- Decision (DEC)
- Communication (COM)
- Implementation

See More Information at the end of this deck for citations
First-Year engineering students
Graduating engineering students
Student insights (n= 24)

Number of Students with Expressed Design Insight
(for whole exercise)

Design Insight

- Breadth
- Iteration
- Gathering Information
- Time
- Problem Definition
- Modeling

Number of Students with Expressed Design Insight

0 4 8 12 16 20 24

Atman, 2016 June
Selected student insights

...
Good design

context

Perspective

culture

Good Design
Design is messy!
Create a picture, diagram, or other representation that captures something significant about your learning today:

**CELT data**

- Personal
- Design
- Process

**Bread Crumbs**

- Link > Link > Link > Link > 

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**CELT data**

- Personal
- Design
- Process

**Bread Crumbs**

- Link > Link > Link > Link >
Teaching principles I draw on

- Prior conceptions matter
- Knowledge organization is important
- Neurons that fire together, wire together
- Motivation has huge impact
- Metacognition make it concrete
- Reflection reinforcement

Ambrose et al., Bransford et al.
Defining Design

- Going from state “A” to state “B”
  - “Everyone designs who devises courses of action aimed at changing existing situations into preferred ones” (Simon, 1969)

- Engineering is “design under constraint” (Bill Wulf, 1998)