Design Signatures:
Empirically Based Representations of Design Processes

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Preferred pronouns: she/her

University of Michigan, October 23, 2019

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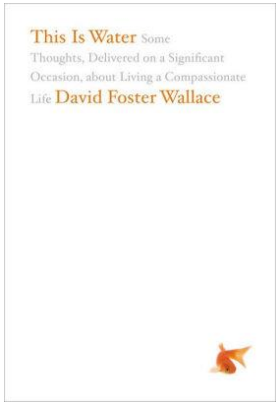
Starting with a story…

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?”



This is Water(David Foster Wallace)

Starting with a story… an engineering design version

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?”

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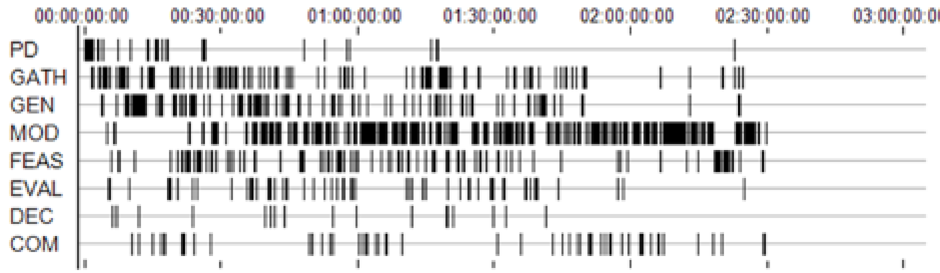
Hard to describe, represent, teach processes

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

"Spend another day…



What was the most important thing that you learned today? Why?

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!

"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!"

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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 Mølhave, 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 Twigg-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

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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

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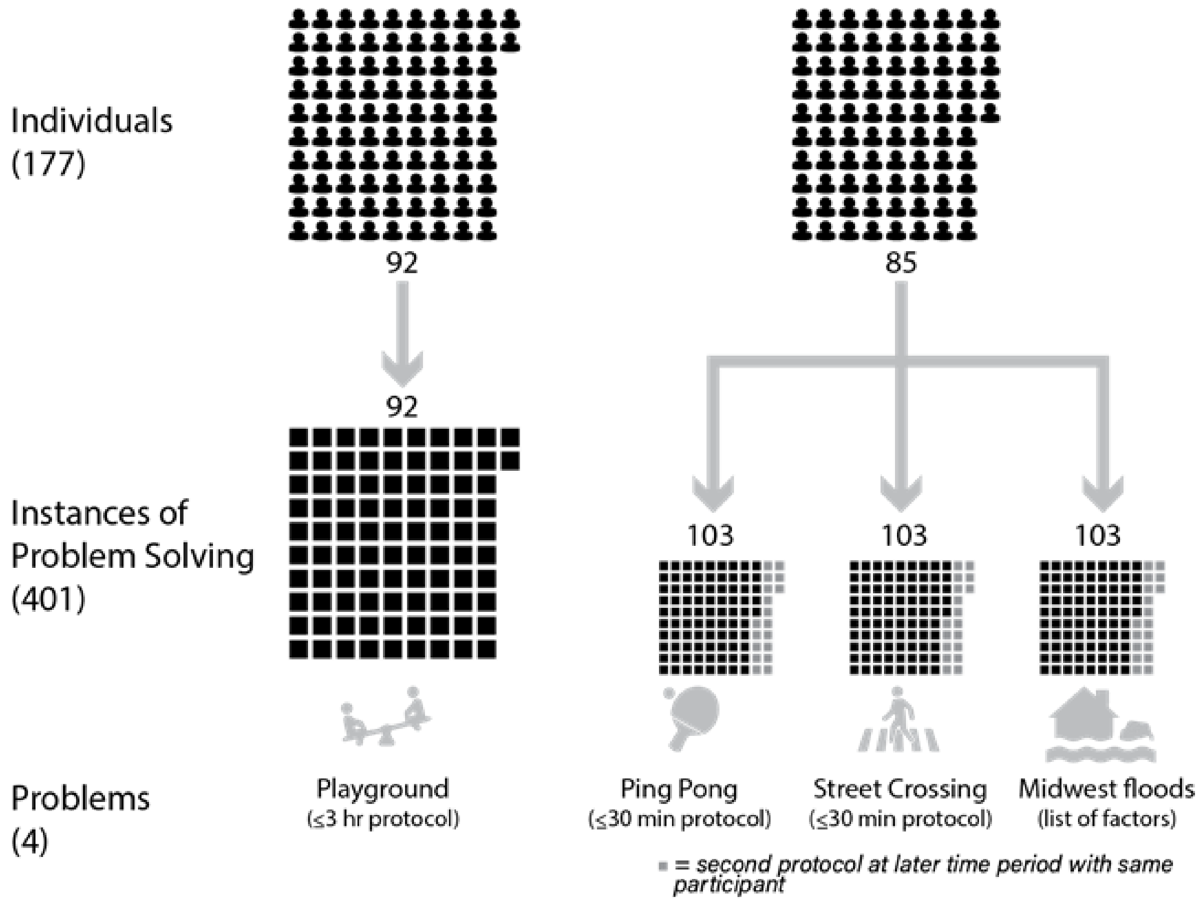
Examining Design Expertise

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

Examining Design Expertise: Corpus of data



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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

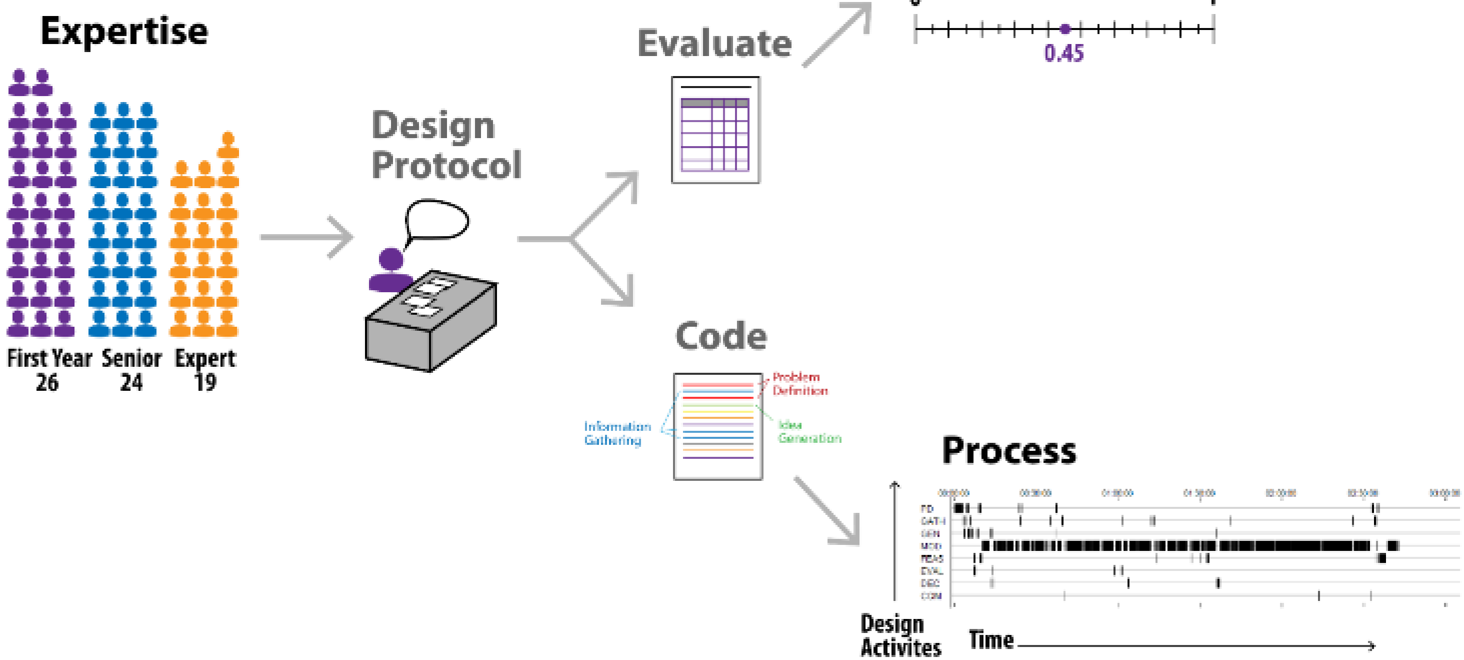
Content
Analysis

(Identification of a Need)
Problem Definition
Information Gathering

Generation of Ideas
Modeling
Feasibility of analysis
Evaluation

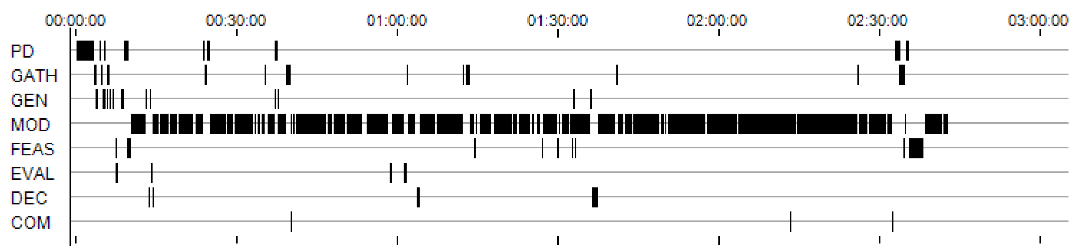
Decision
Communication
(Implementation)

Examining design expertise: A body of work



Design process timelines

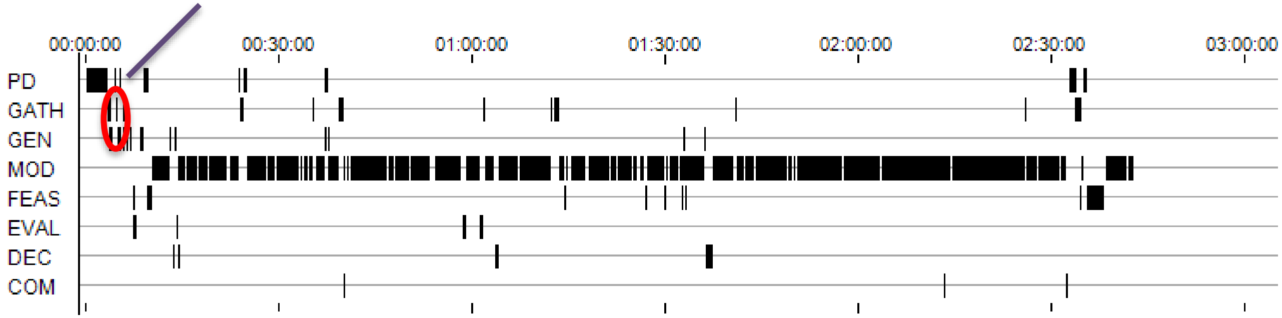
- A tracing of design activities over time
- Each instance of a design process leaves a unique *design signature*



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

Design timeline representations

“Hmmm do you have, a list of materials”



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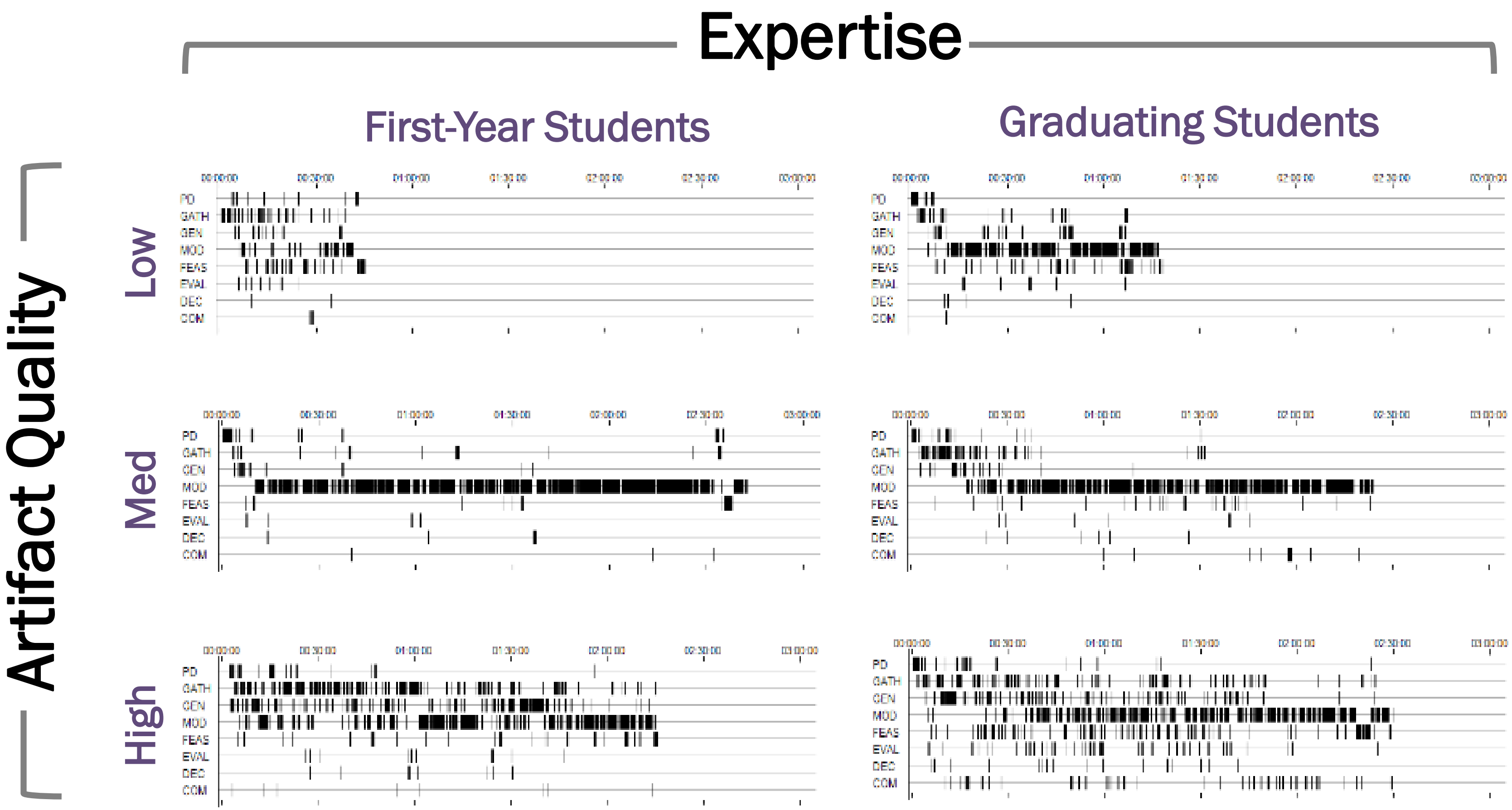
First-year and senior design processes?

- 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

What we found

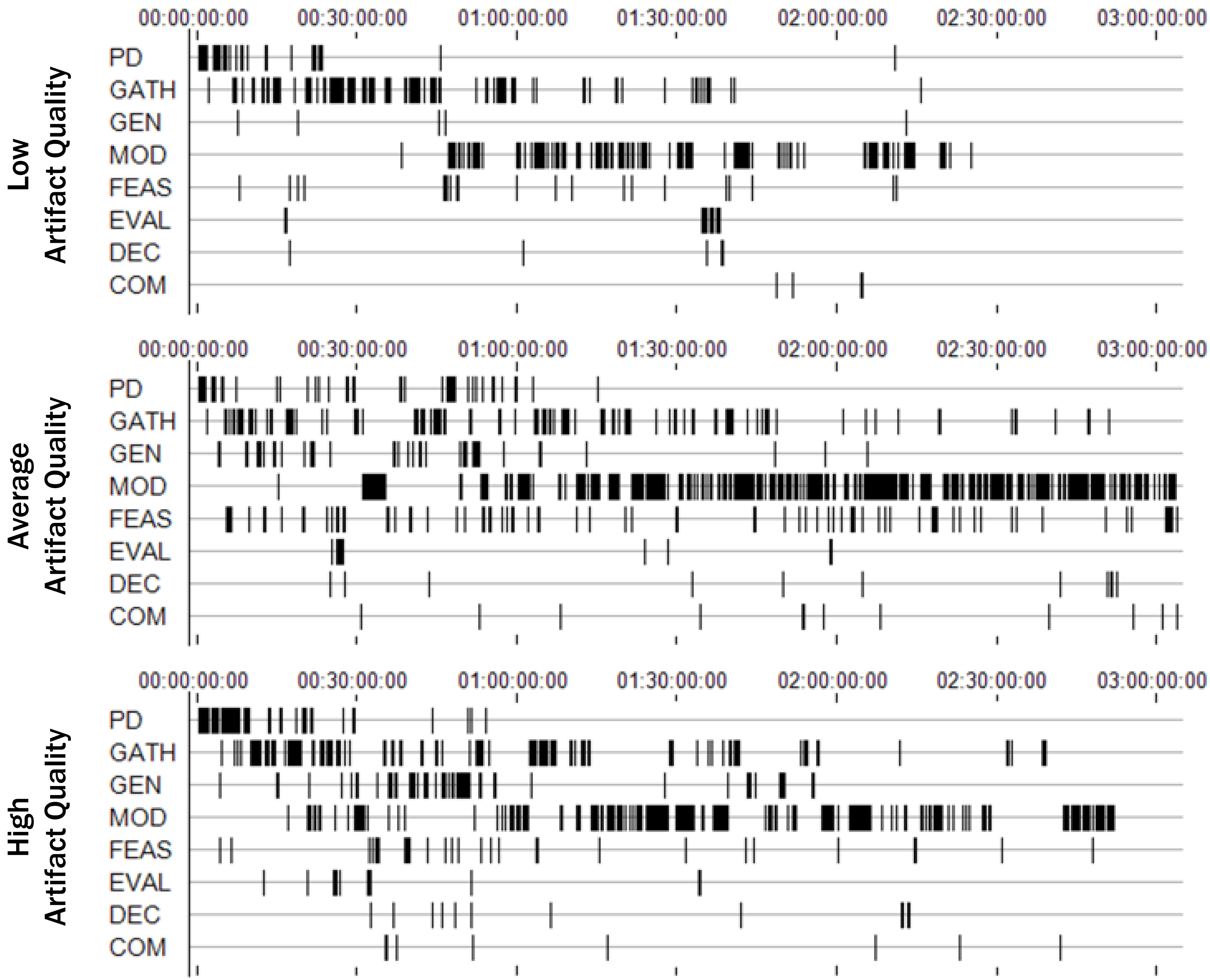


Design process research findings

- 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



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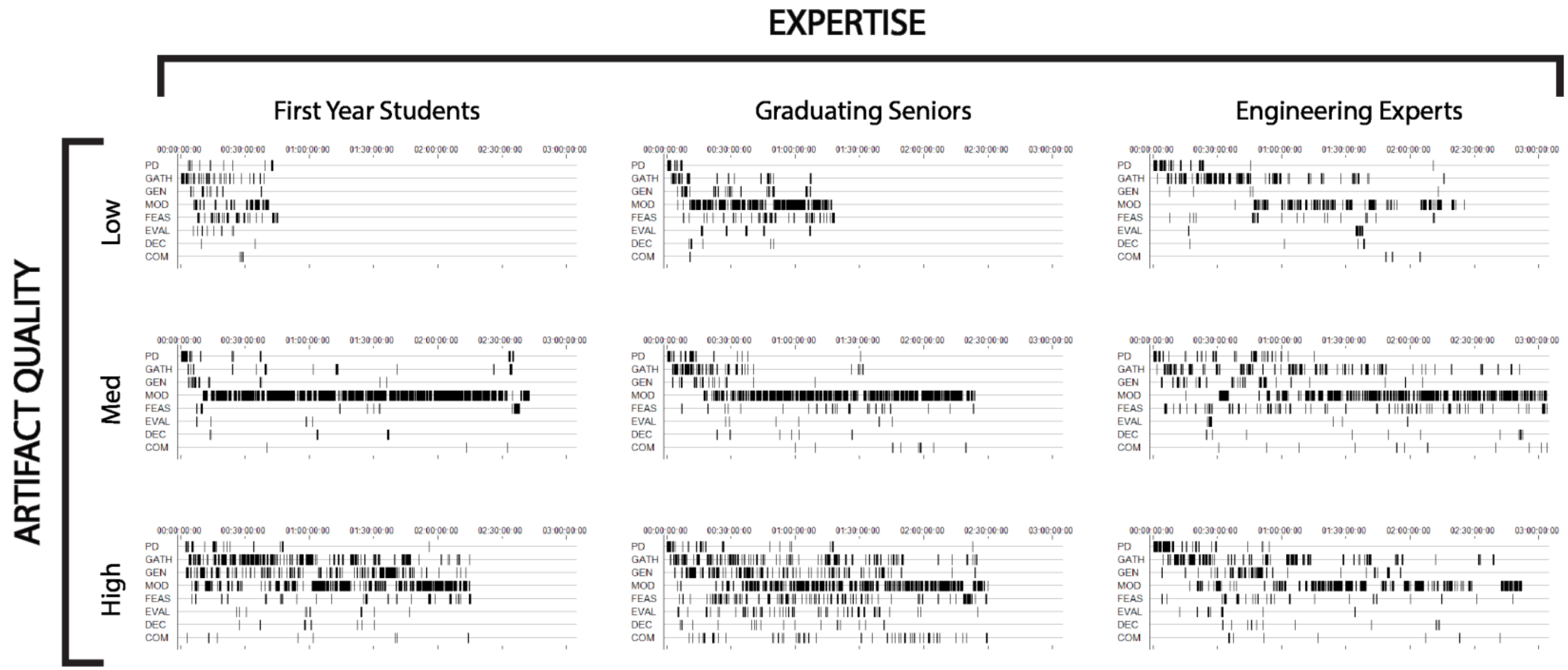

- Engineering experts were significantly more likely than students to…
  - spend more time solving the problems in all design stages
  - consider more objects in their design process
  - scope the problem more effectively by gathering more information (explicitly) and covering more categories
  - exhibit a “cascade” pattern of transitions

(Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007)

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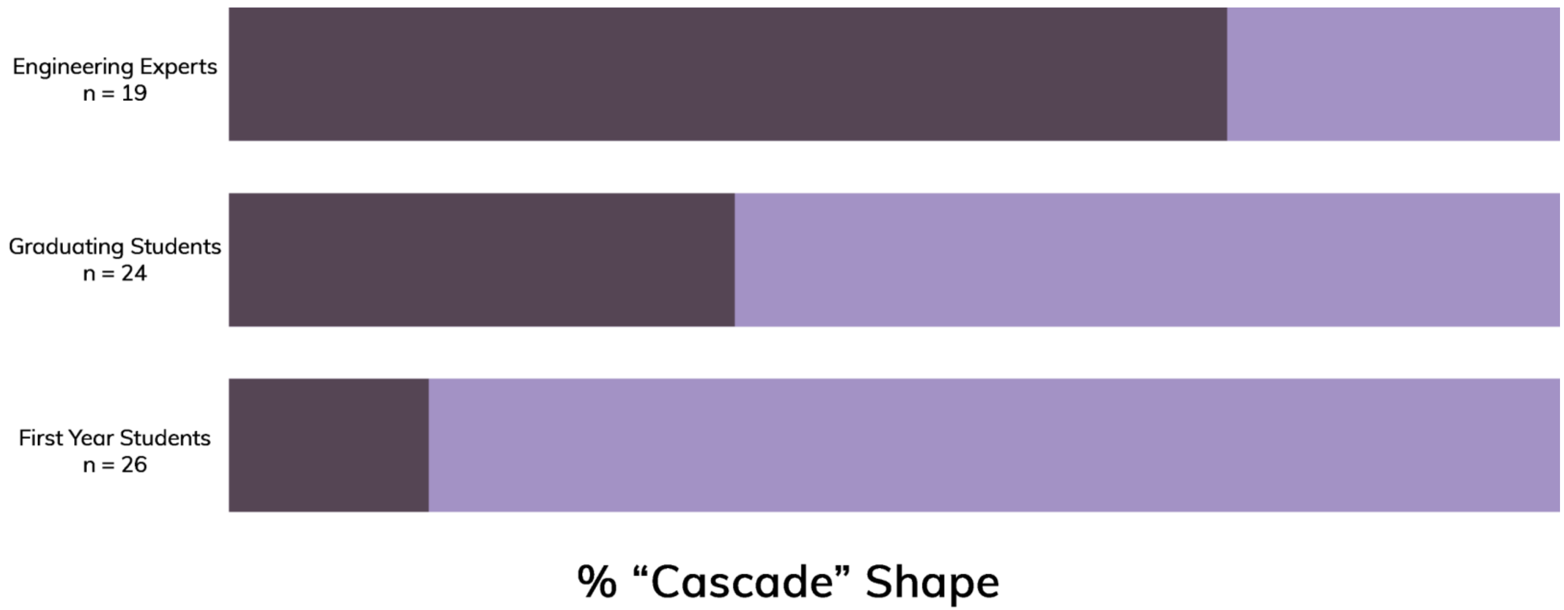
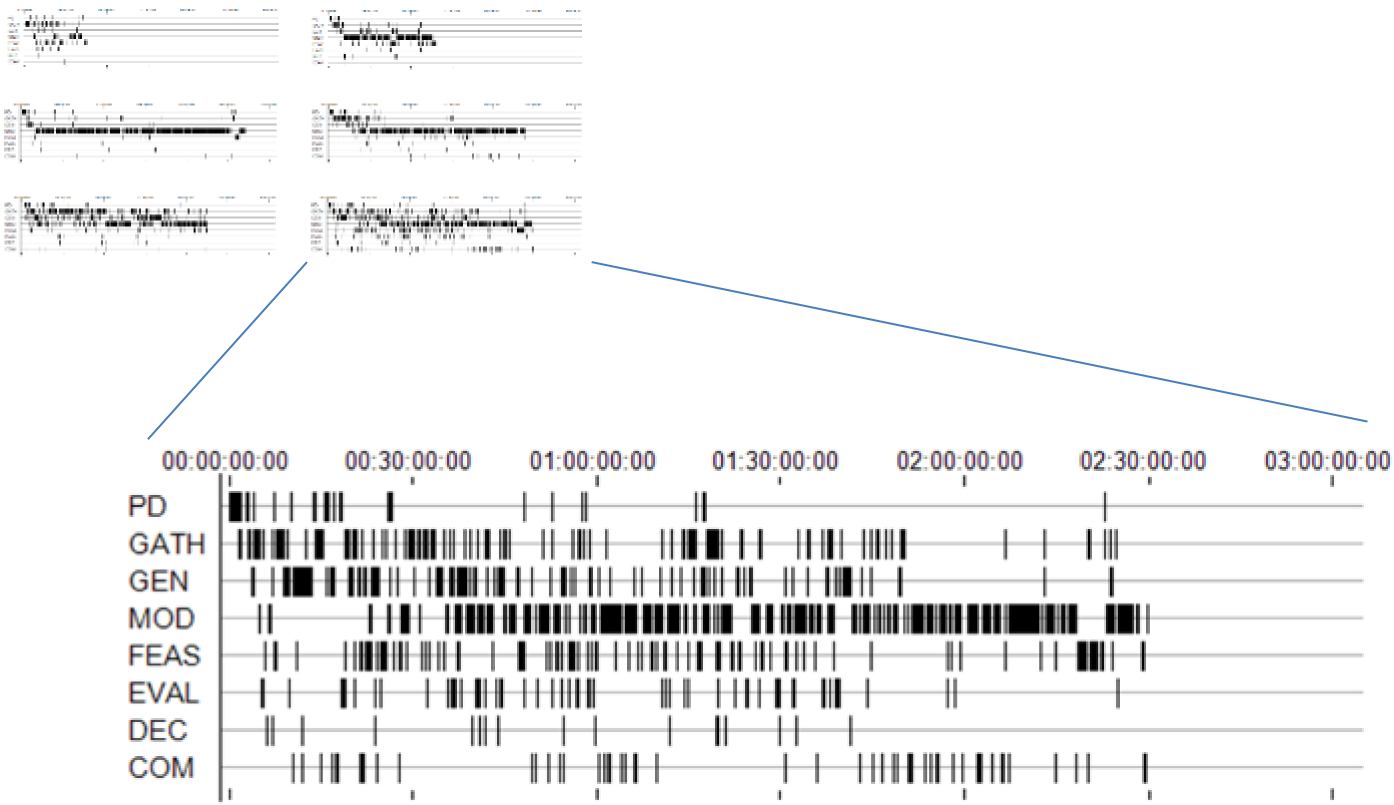
Percent Cascade* Shape



* "Cascade" not "Waterfall"

Timelines as canvas for research results



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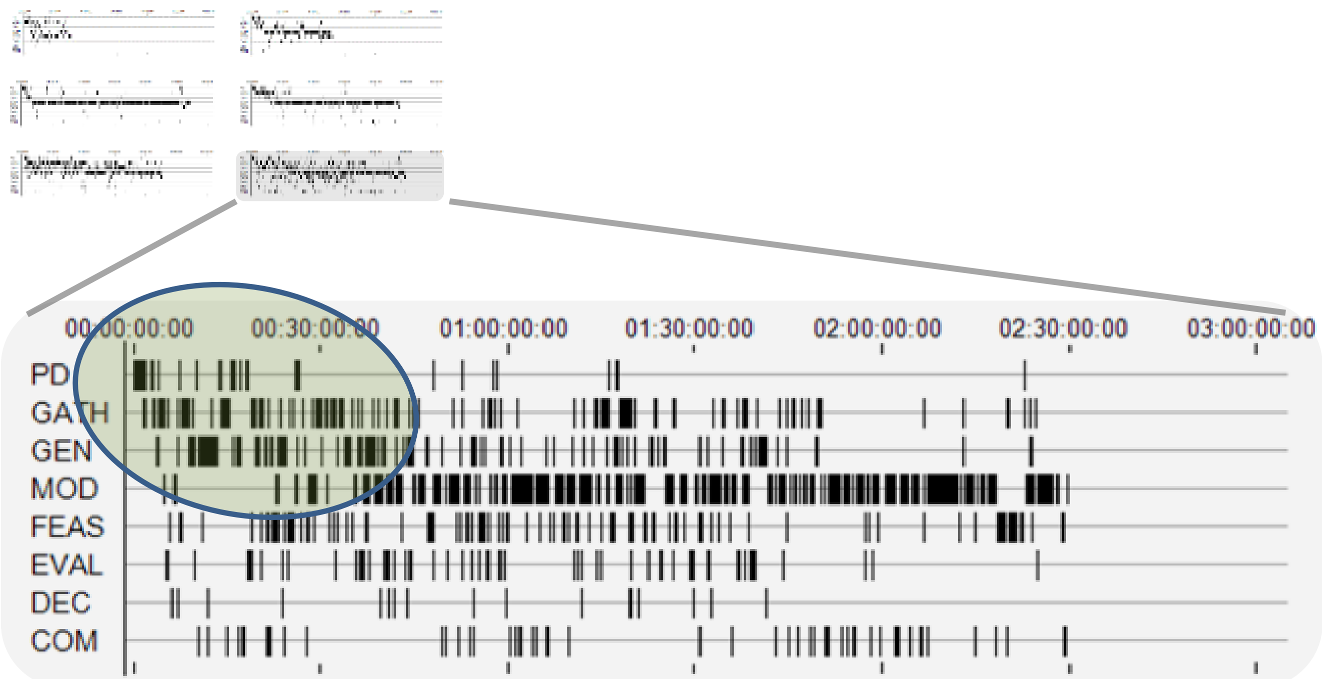
Timelines as canvas: Problem scoping before focus on modeling



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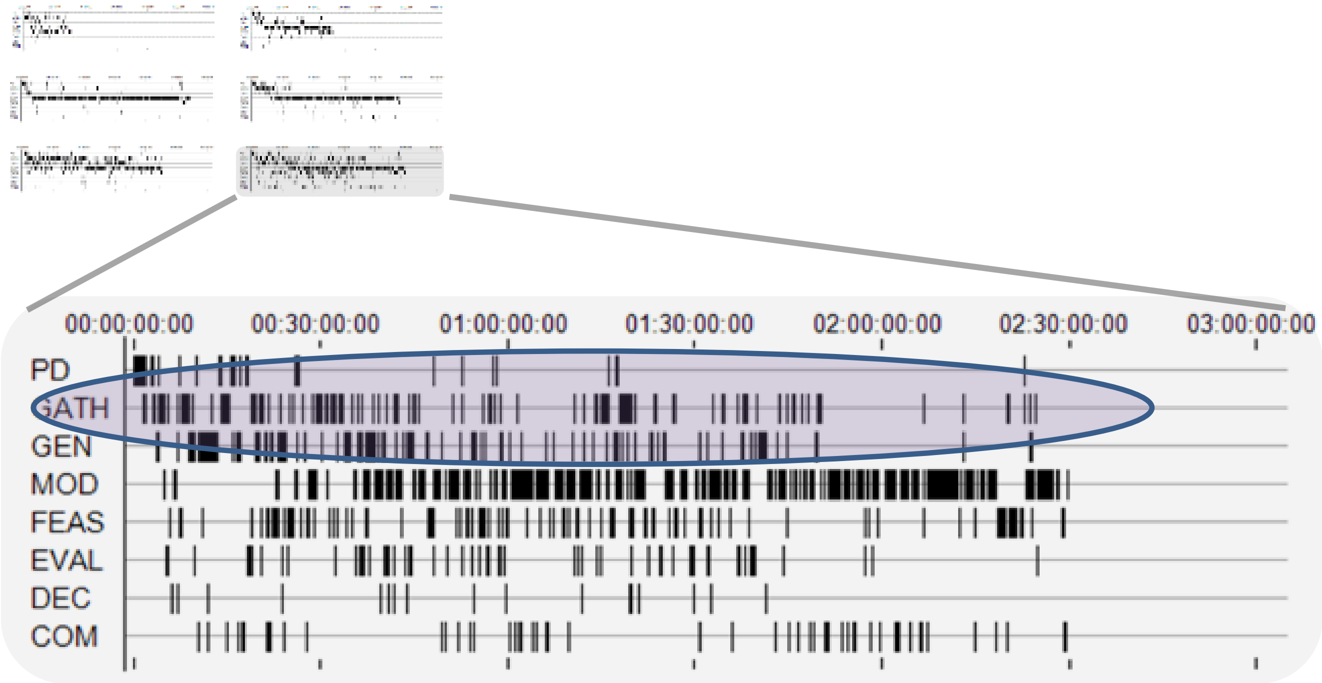
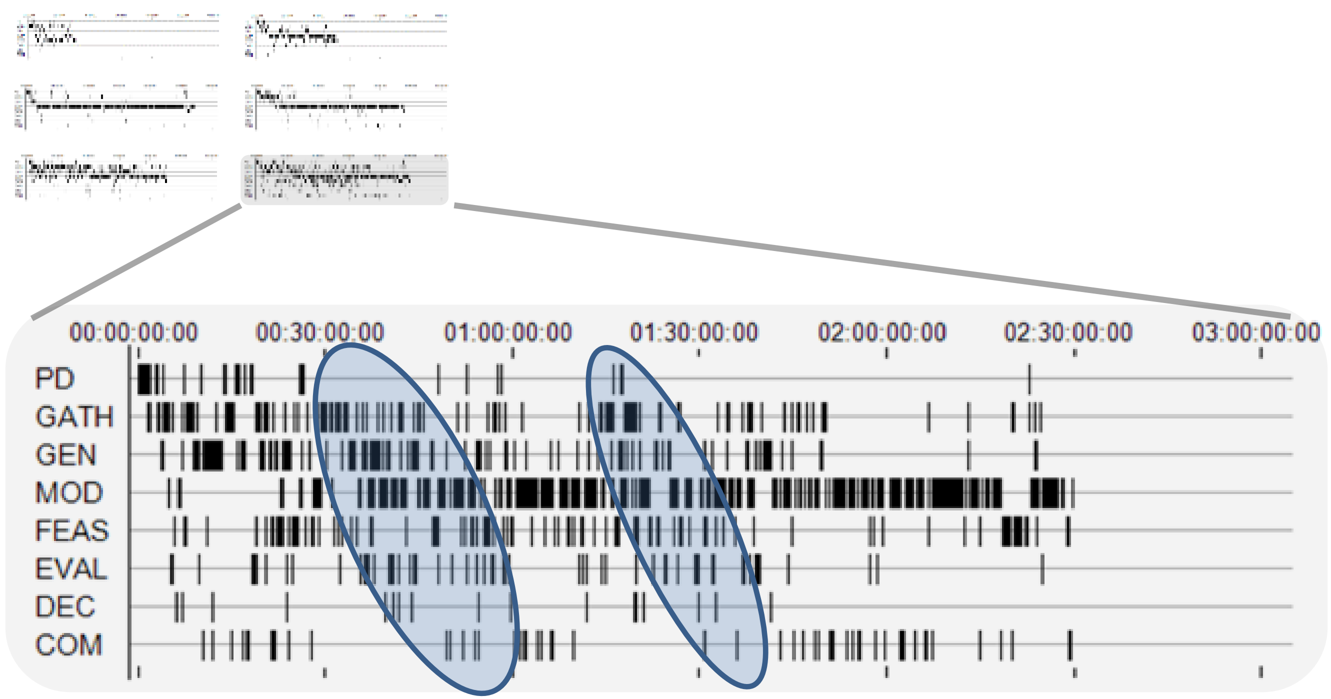
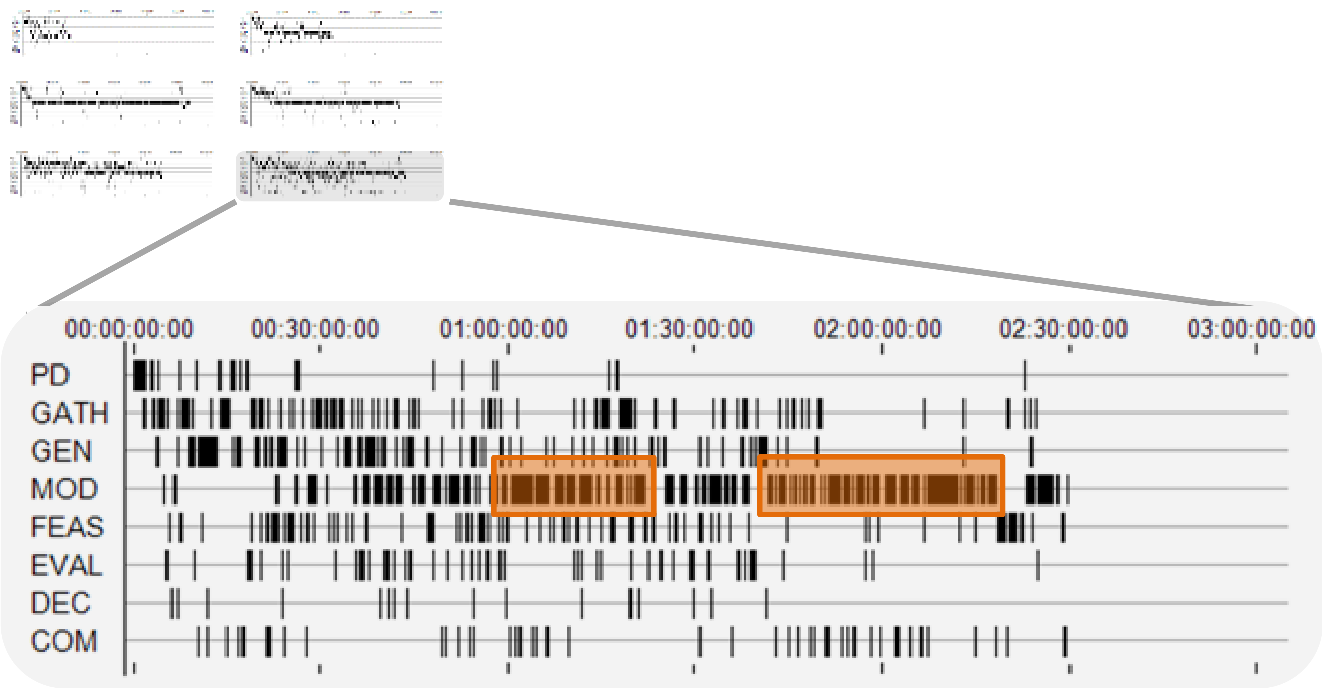
Timelines as canvas: Problem scoping and gathering information throughout process



Timelines as canvas: Transitions



Timelines as canvas: Stay the course



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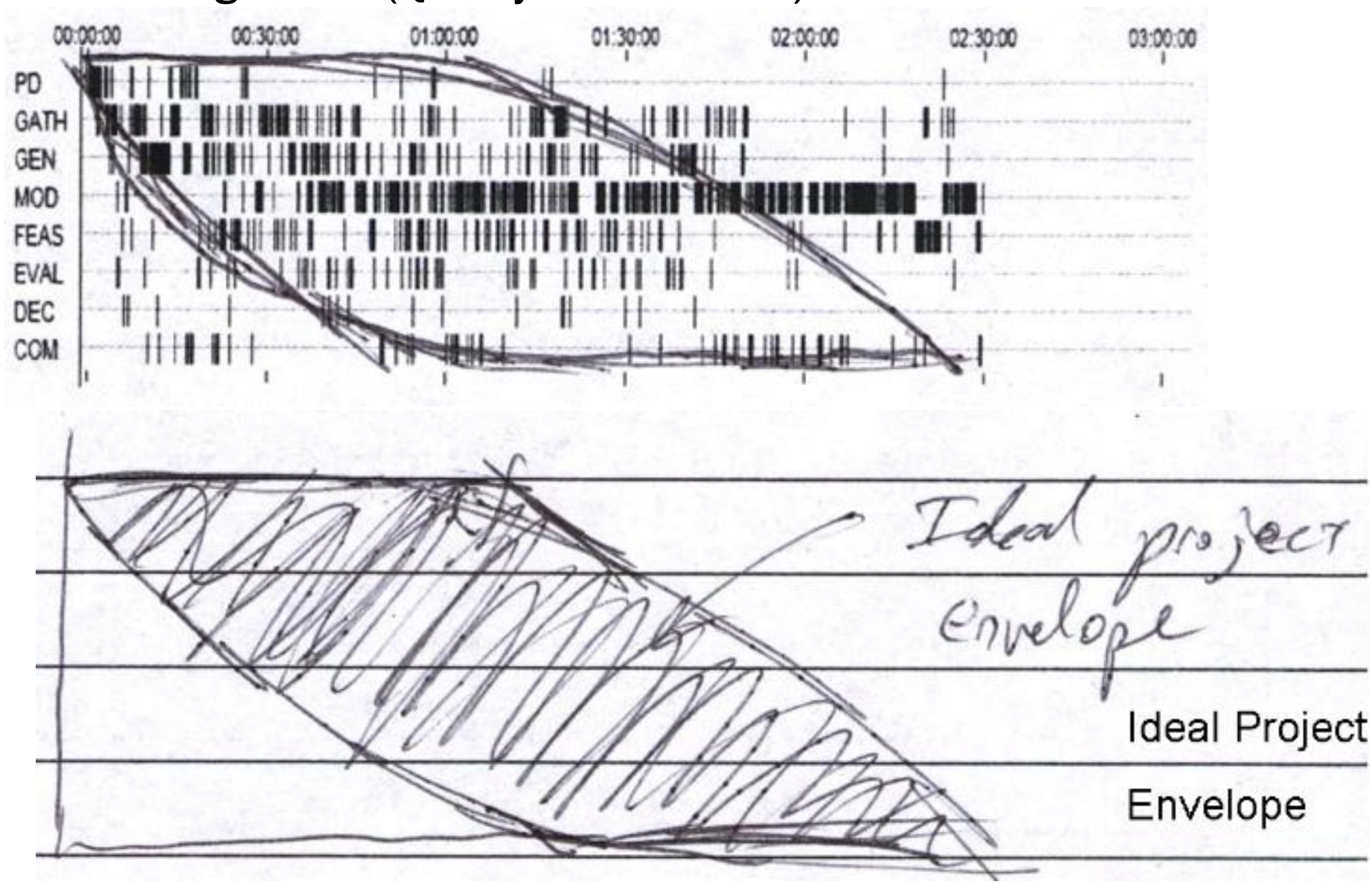
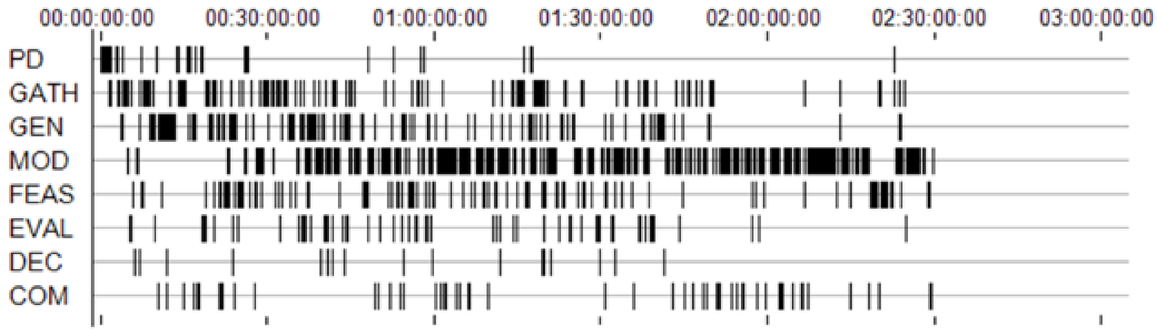
Timelines as canvas: Ideal project envelope

Graduating Senior (Quality Score = 0.63)



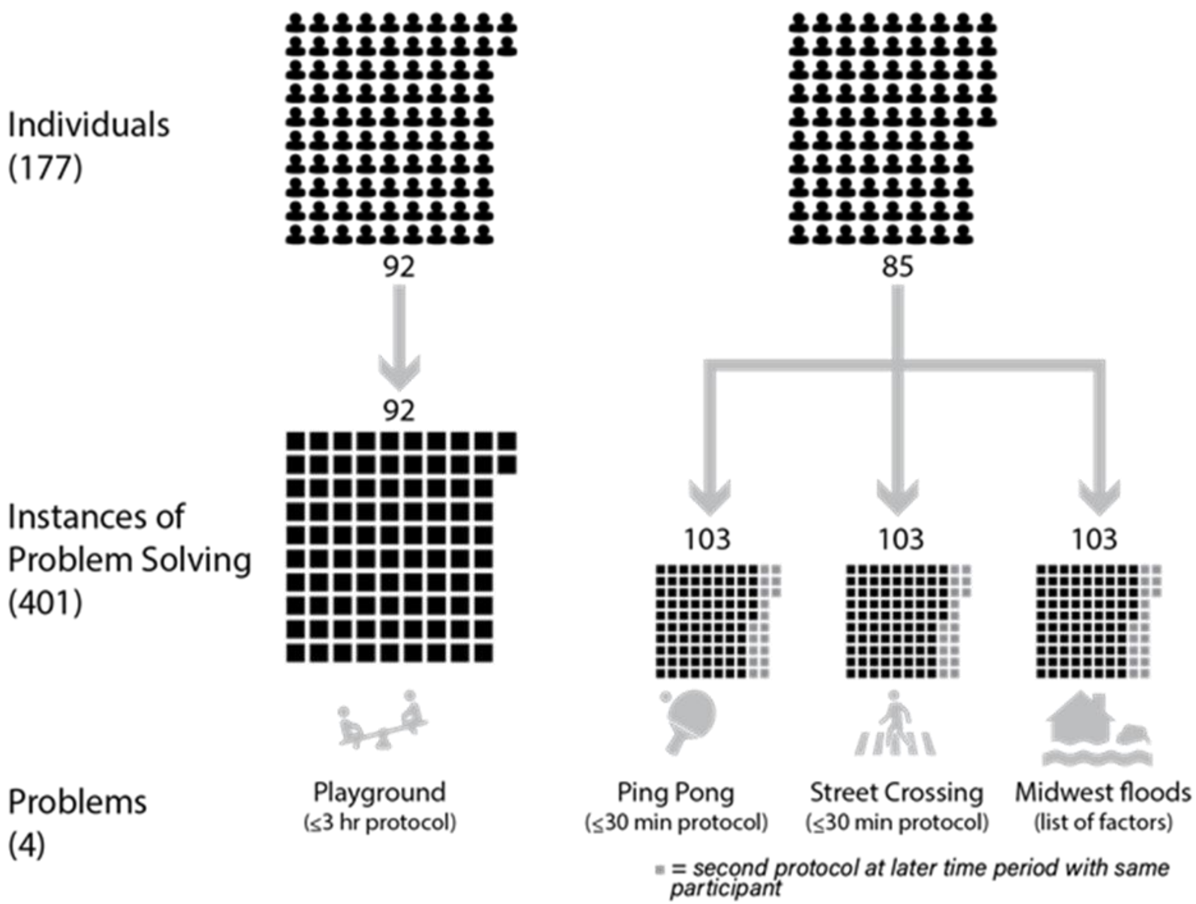
* Result from Borgford-Parnell et al., 2010

Timelines as canvas: considering context

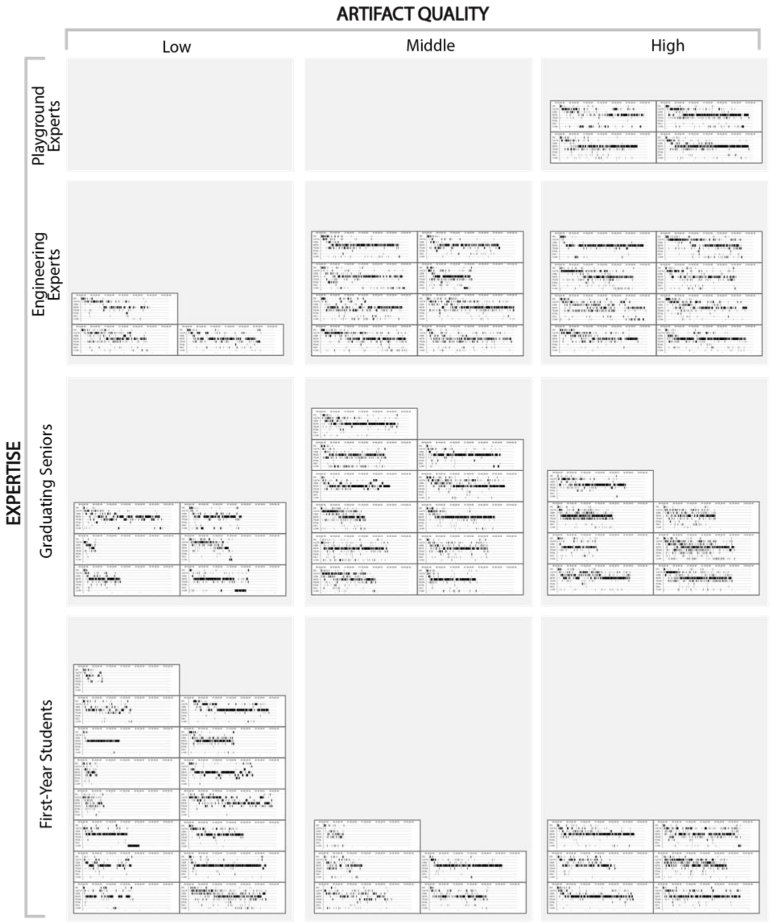


Edit this

What about the rest of the data?



We see similar patterns – more experience, more complex processes

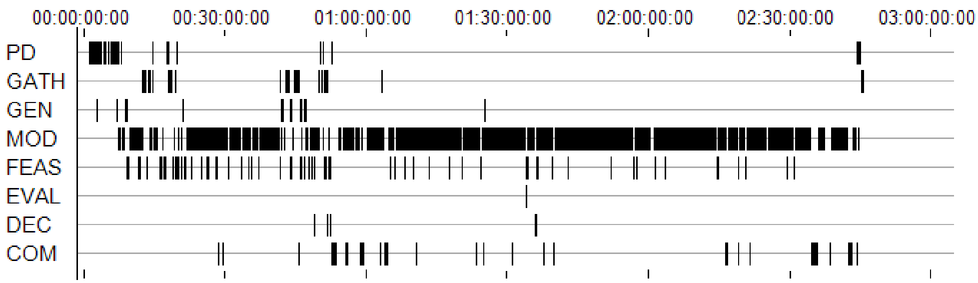


(Figure from upcoming "Design Timelines: Concrete & Sticky Representations of Design Process Expertise", *Design Studies*, Nov, 2019)

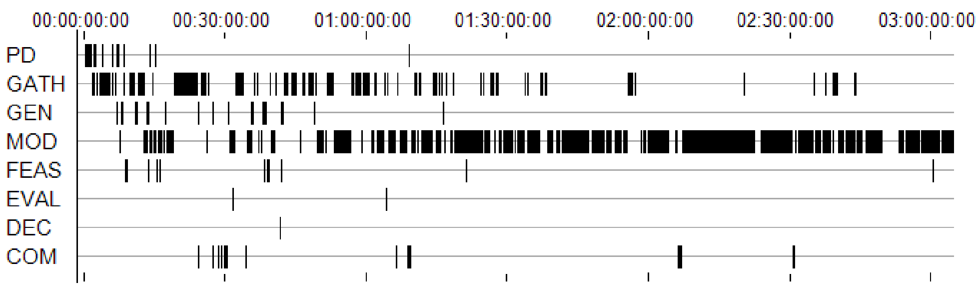
Individuals, Design a playground

- Undergraduate engineering students from a different institution

First-Year (n=6)



Graduating Senior (n=8)



(Deibel, Atman, Saleem, Kang, & Ng, 2007)

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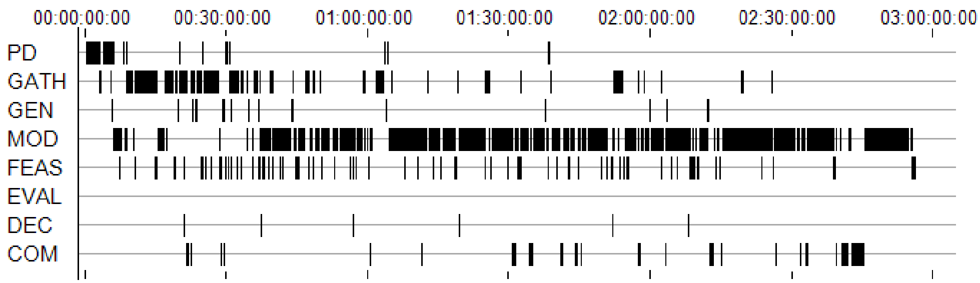
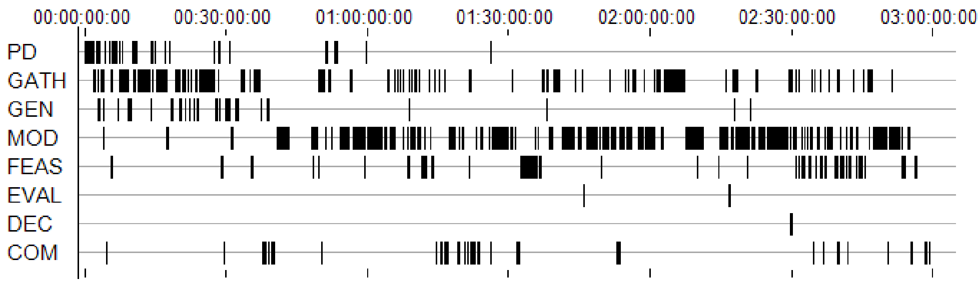
Individuals, Design a playground

- Domain (playground design) experts(n=4)



- Engineering faculty (n=4)



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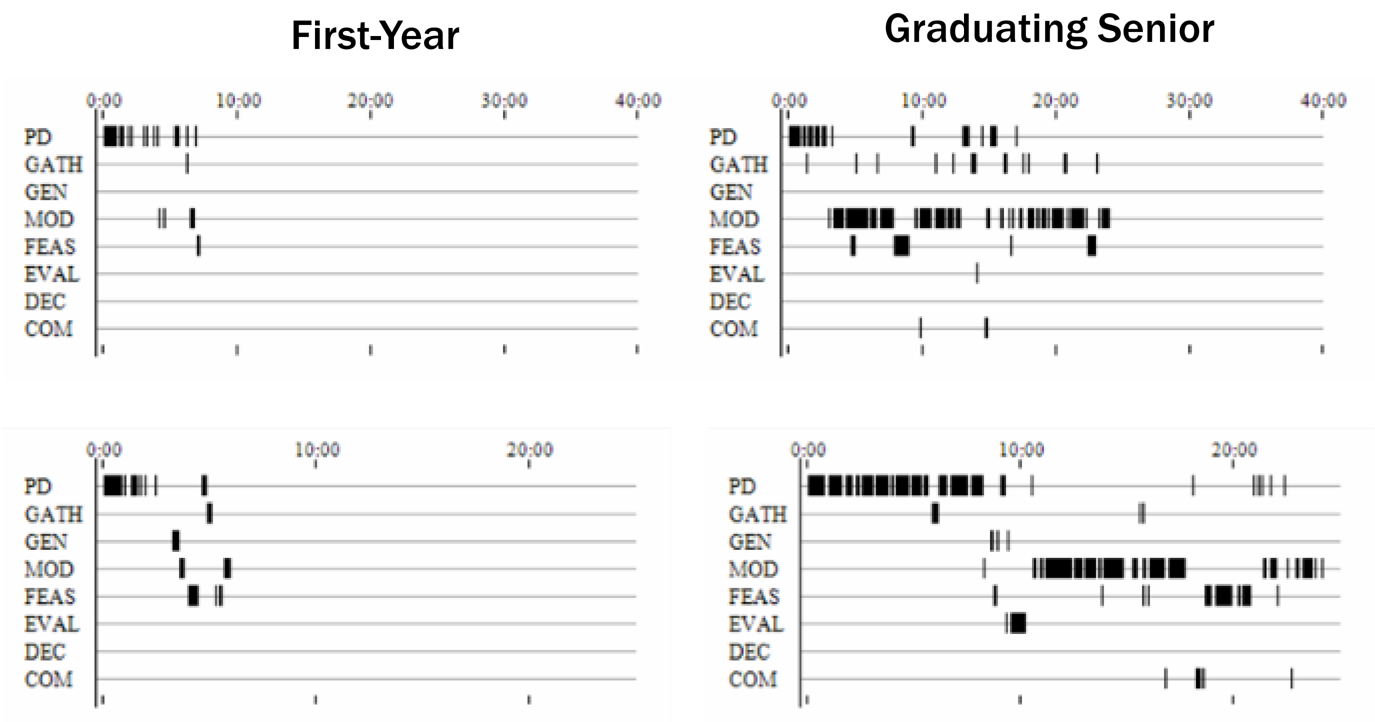
(Atman, Turns, Cardella, & Adams, 2003; Krause, Atman, Borgford-Parnell, & Yasuhara, 2013)

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)

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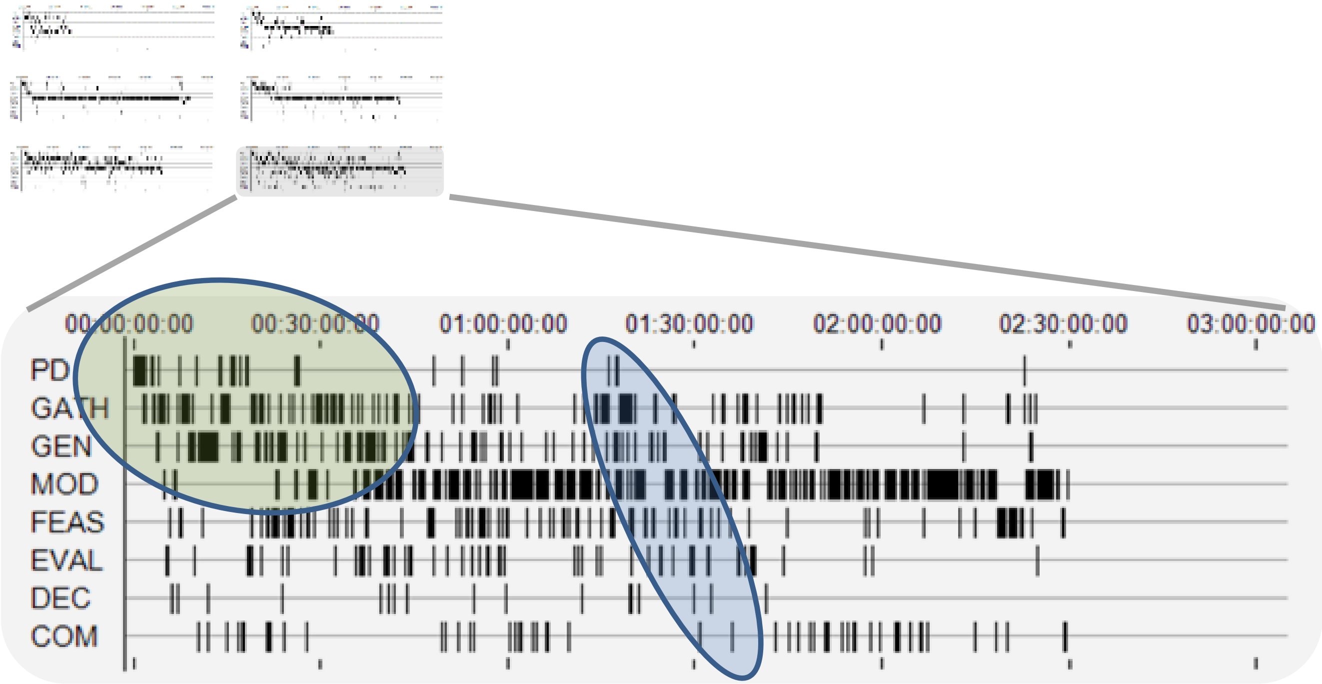
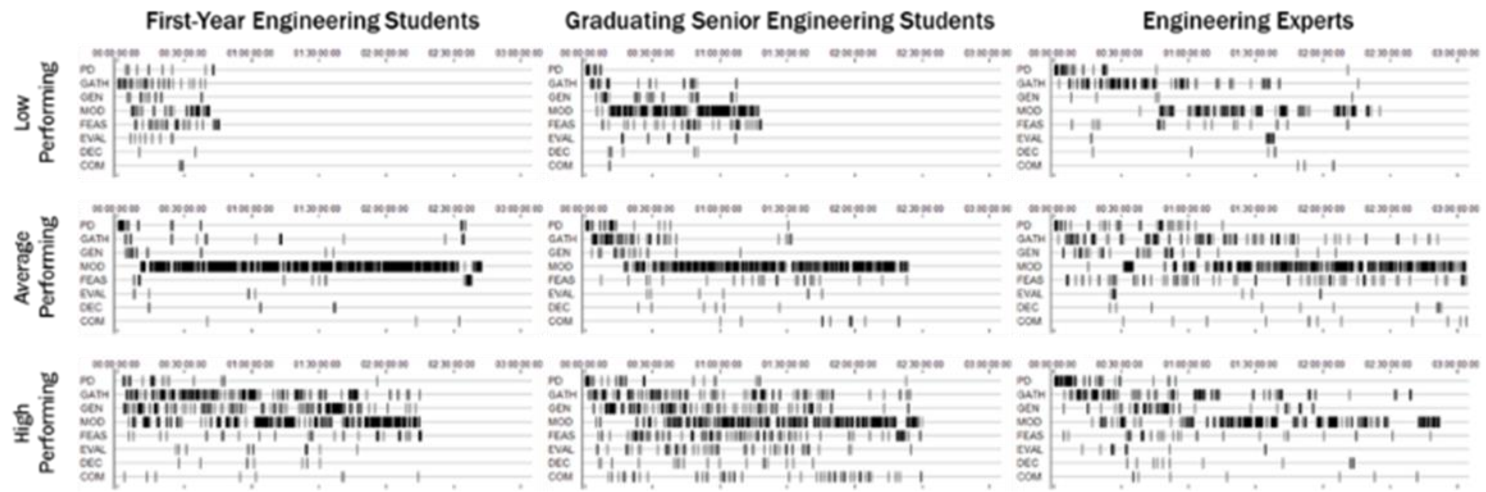
Timelines as canvas: other frames e.g., Schon's reflection-in-action



Timelines as canvas: music



Design soundtracks

Original Senior C (927) - Tonal Soundtrack

http://bit.ly/celtsoundtracks

Tonal Soundtrack: Original Senior C (927)

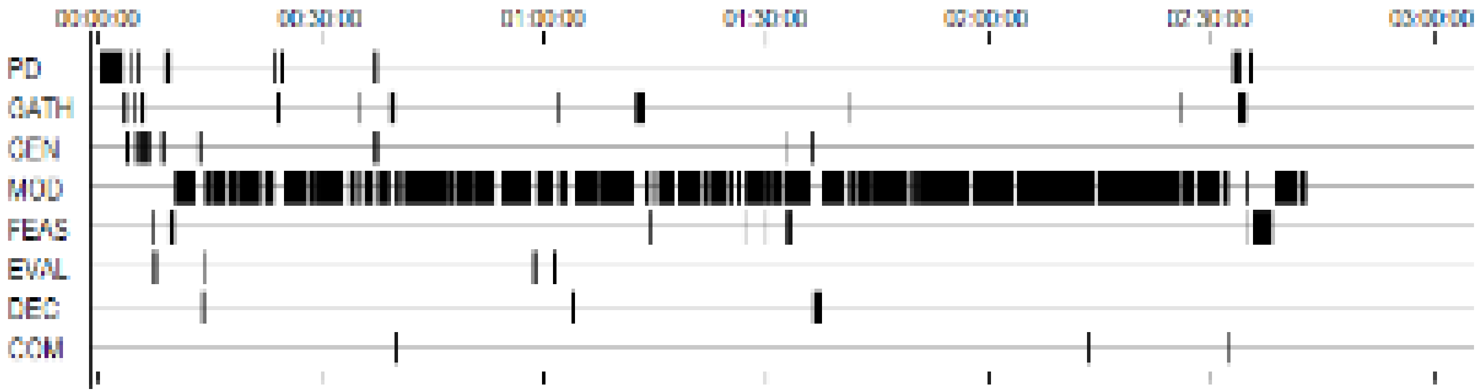
The Tonal version of design soundtracks is the most literal of all version. Each design activity is mapped to a specific pure tone on the pentatonic scale, with Problem Definition (PD) having the highest pitch. The start and stop of each tone is sharp and tightly tied to the underlying time-series data.

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.

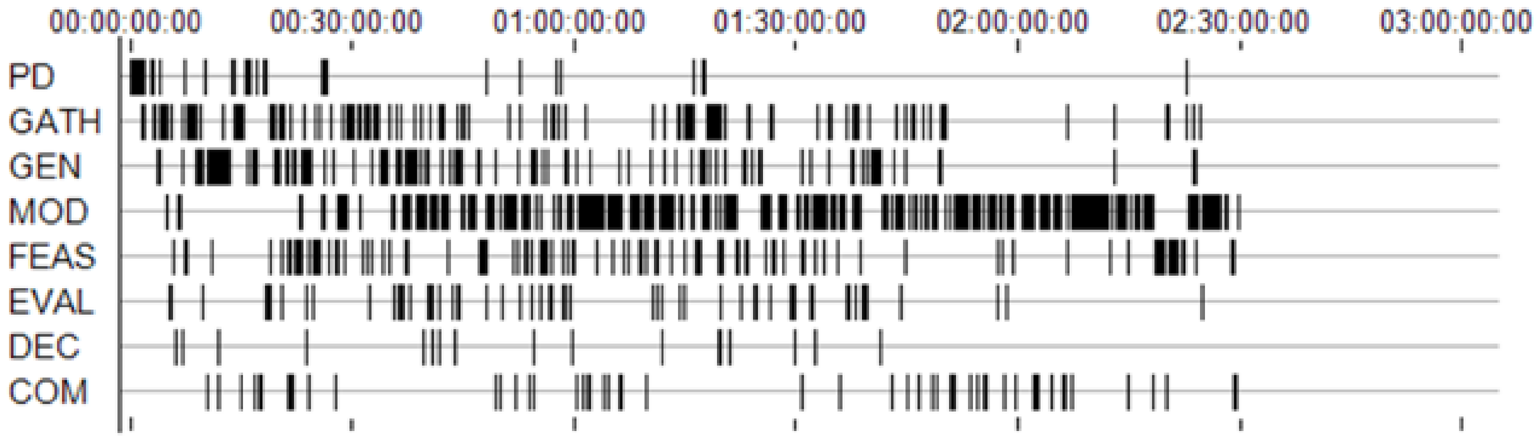
Sound Mapping

- PD - Problem Definition E6 Tone (left ear)
- GATH - Gathering Information D6 Tone (right ear)
- GEN - Generating Ideas C5 Tone (left ear)
- MOD - Modeling

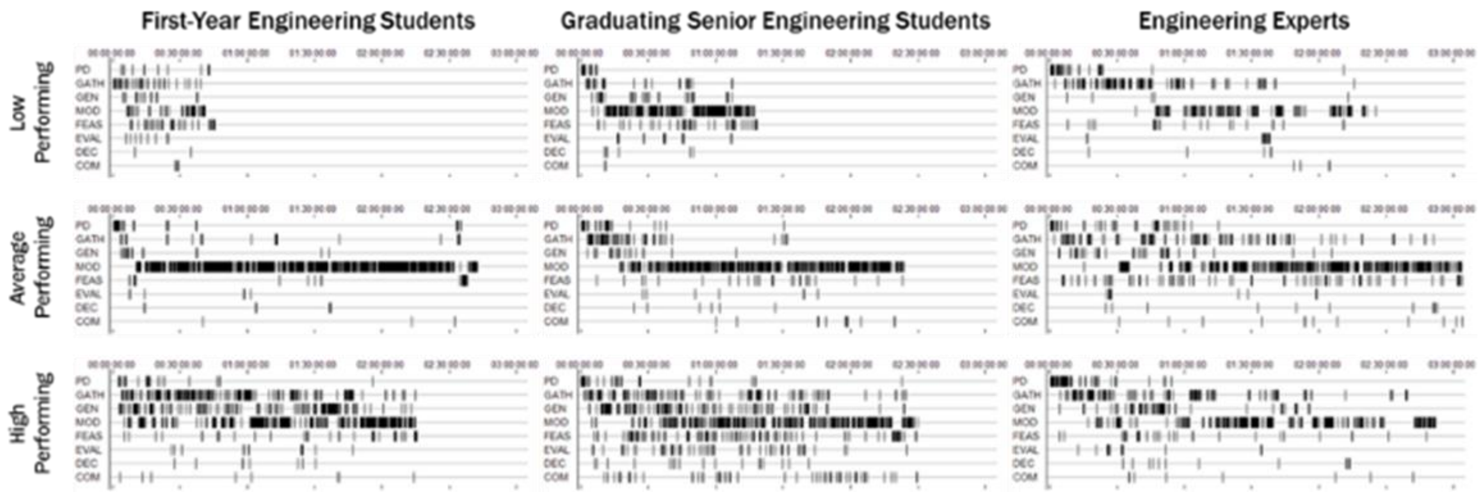
Design Soundtracks



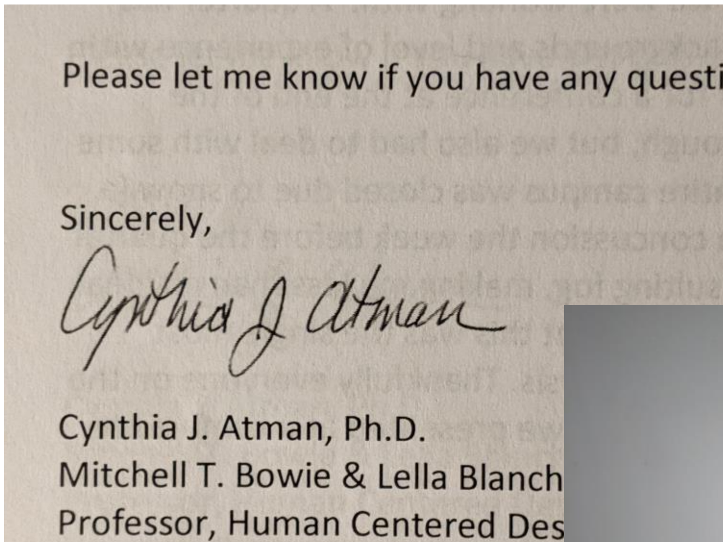
Design Soundtracks



Timelines as canvas: *Design signatures*



Signatures can vary according to function

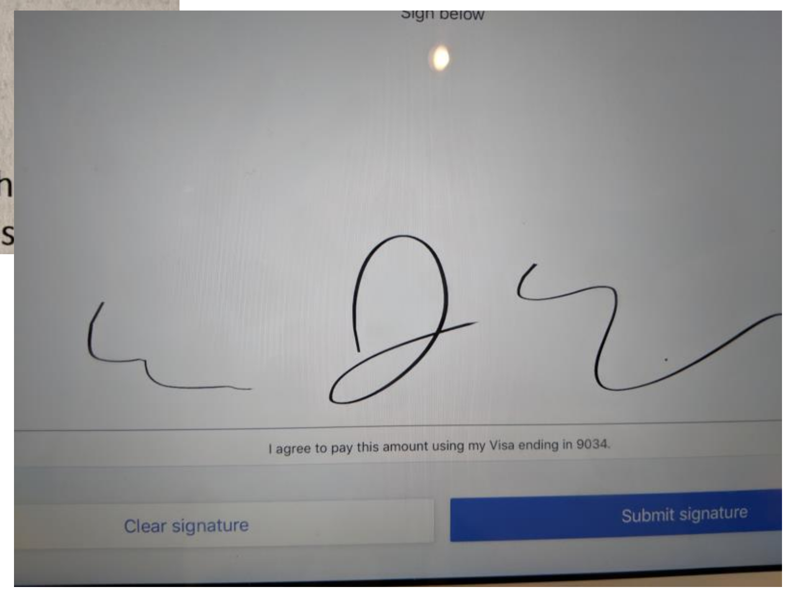


Please let me know if you have any questi

Sincerely,

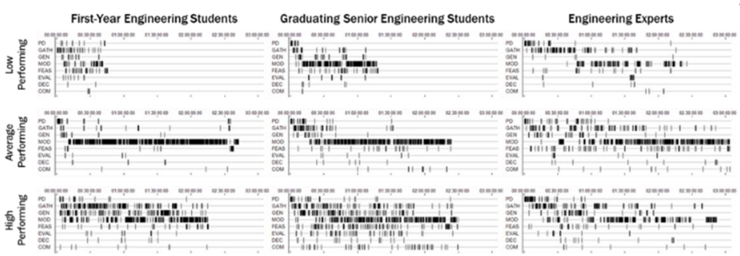
Cynthia J. Atman

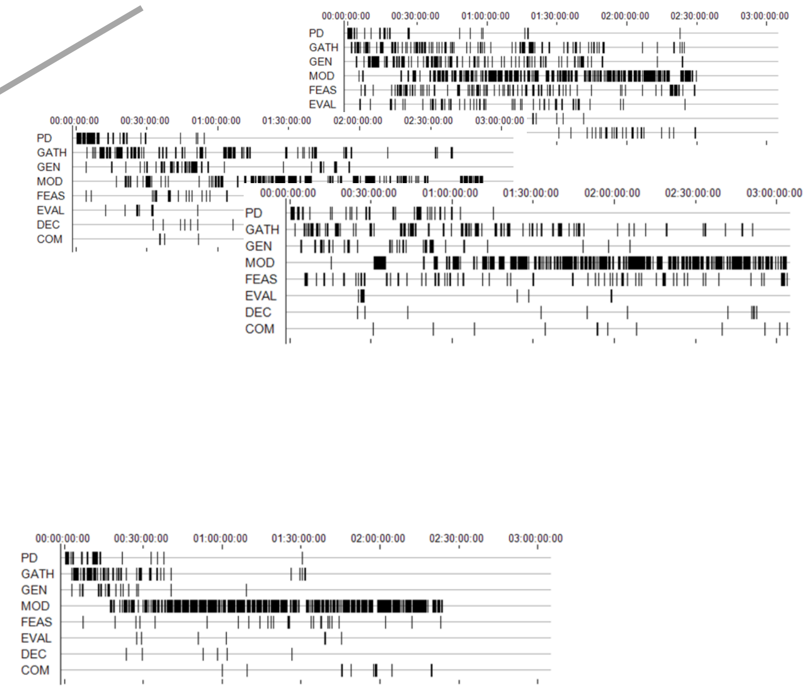
Cynthia J. Atman, Ph.D.
Mitchell T. Bowie & Lella Blanch
Professor, Human Centered Des



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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- Teaching design
- Wrapping-up

Charkha sculpture, Mumbai

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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
- ……

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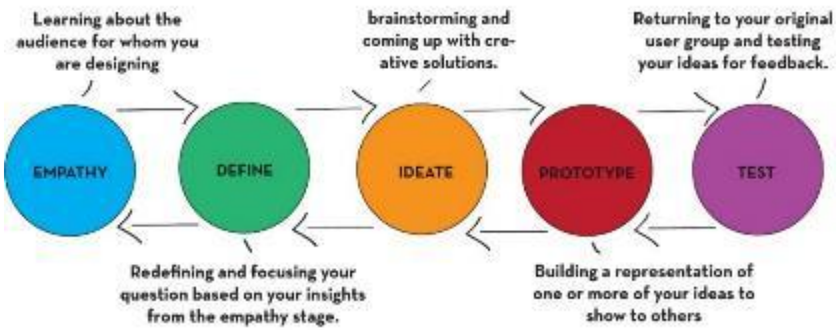
Inside the larger landscape, typical process representations

HCDE Model



IDEO Model

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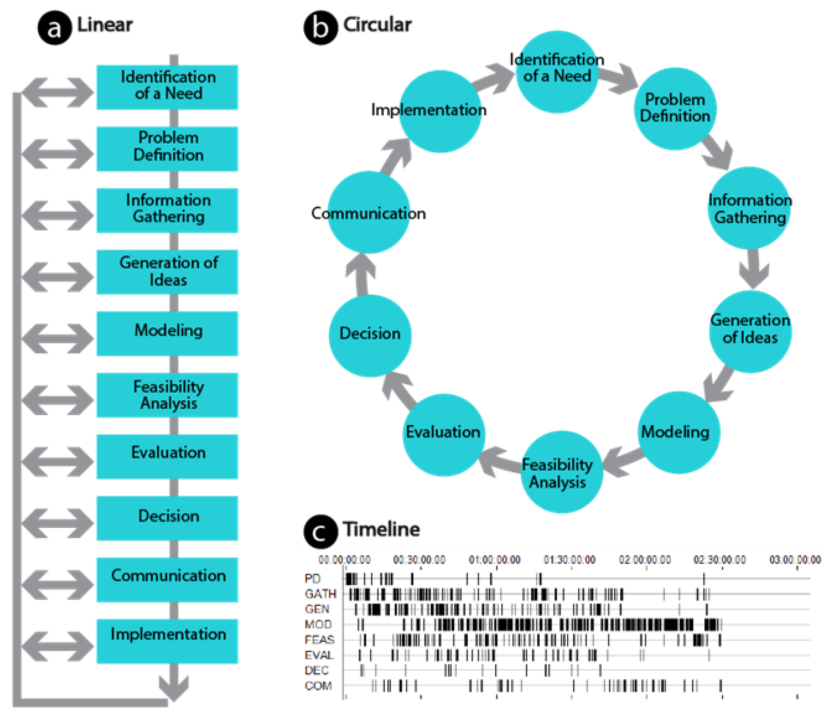
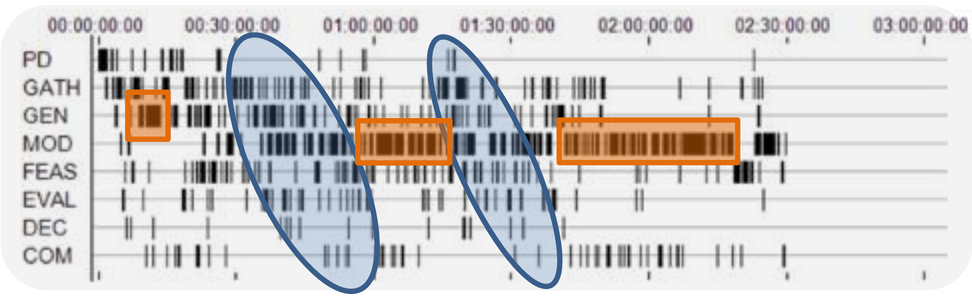
Affordances of timelines – concrete & sticky

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

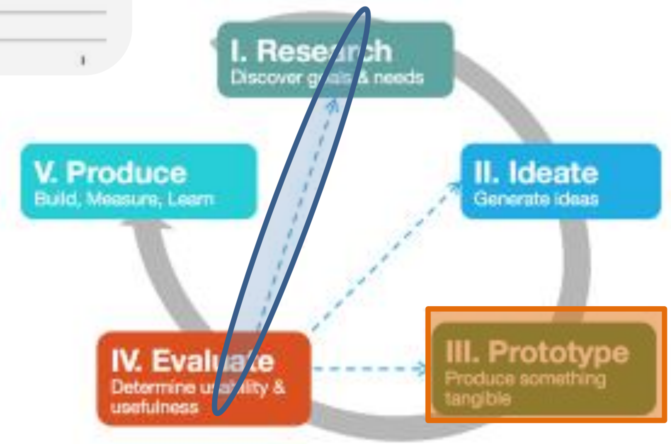


Affordances of timelines:
Abstract concepts made visible



Pivots

Persistence



HCDE Model

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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)

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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)
- Resources: https://bit.ly/DesignTimelines

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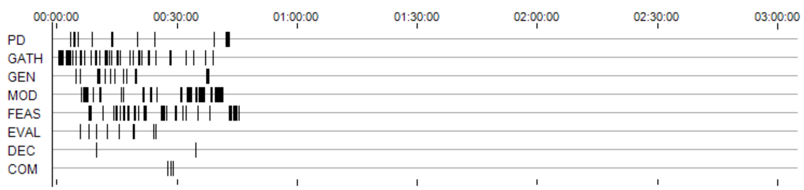
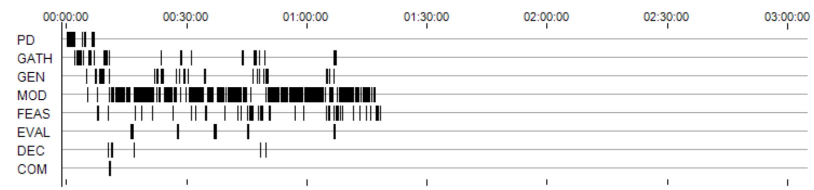
Classroom activity – about 45 minutes

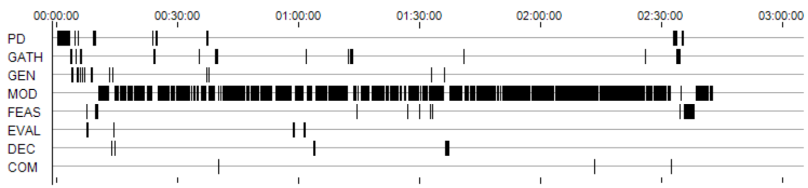
First-Year #1



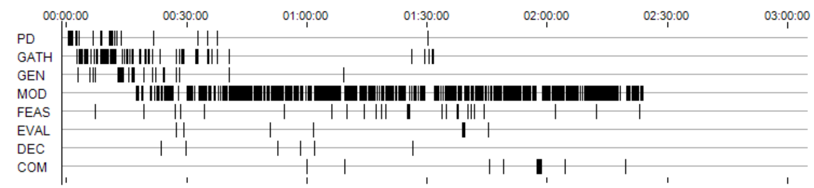
Graduating Senior #1



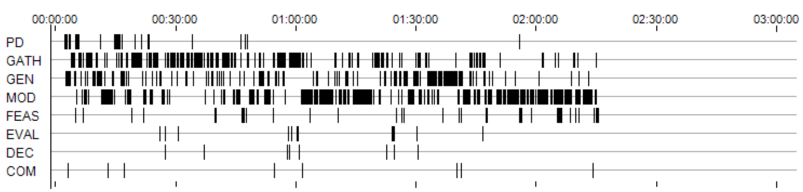
First-Year #2



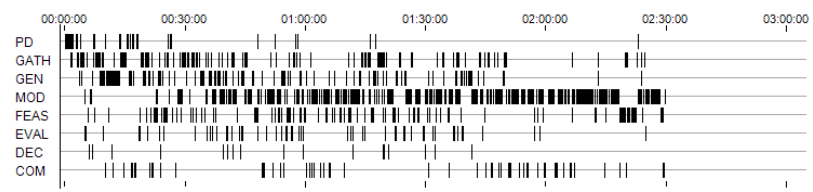
Graduating Senior #2



First-Year #3



Graduating Senior #3



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?

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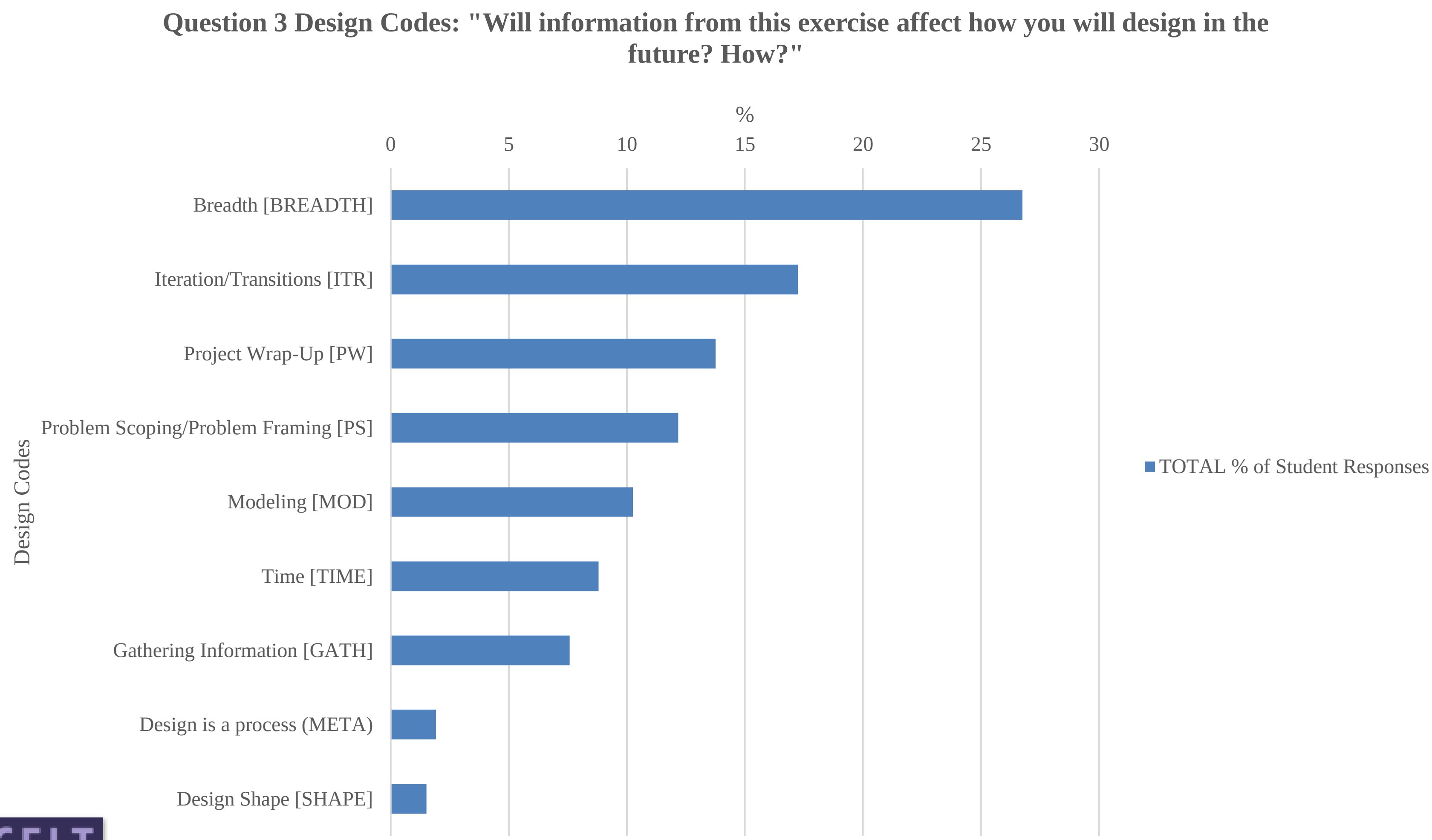
Multiple studies – similar results

- "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

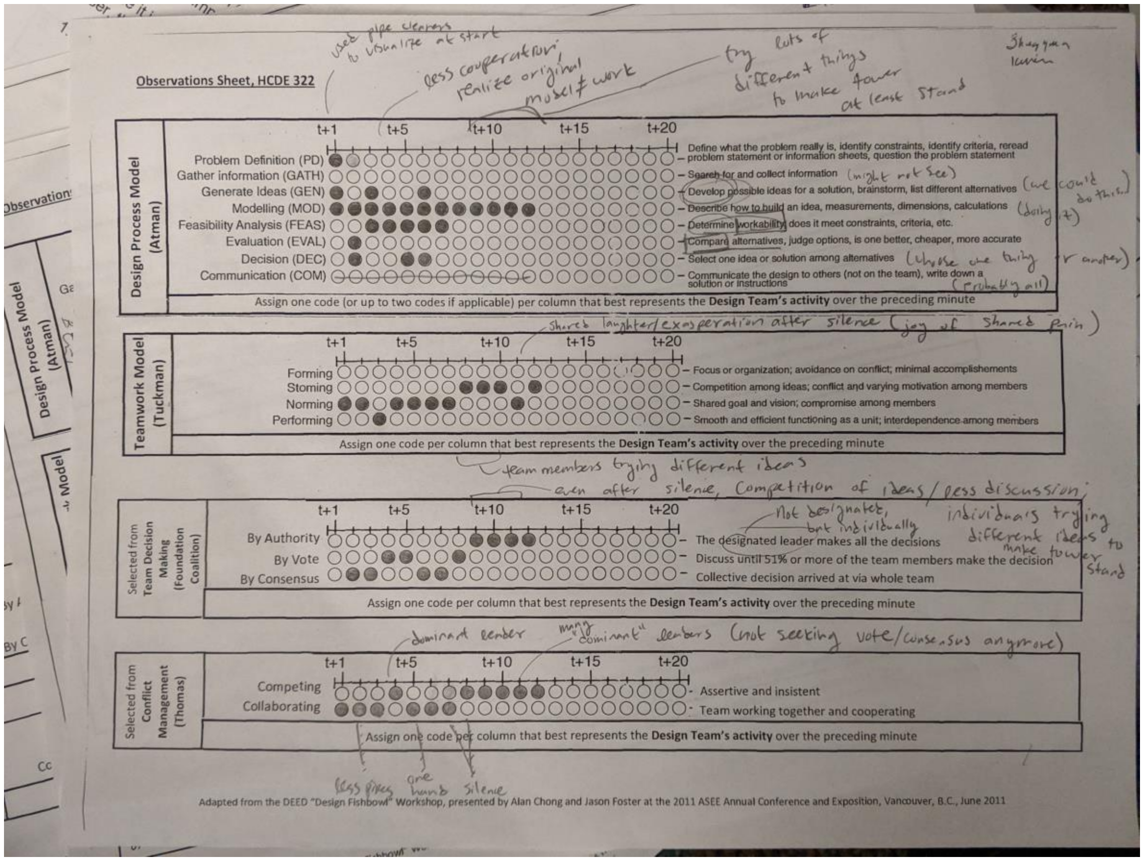


(ASEE, 2019)

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)
- Resources: https://bit.ly/DesignTimelines

Coding sheet for design challenge



Built on workshop by Chong, Foster & Irish 2011

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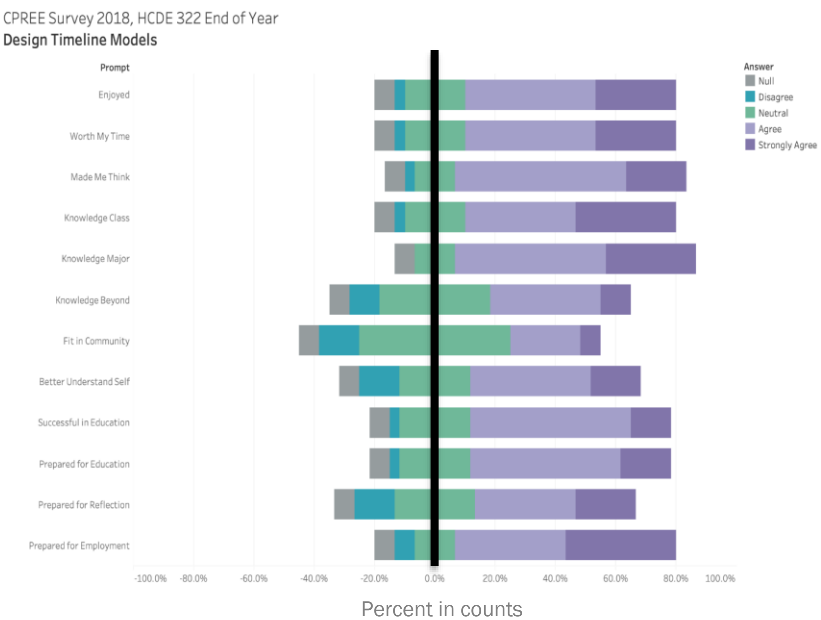
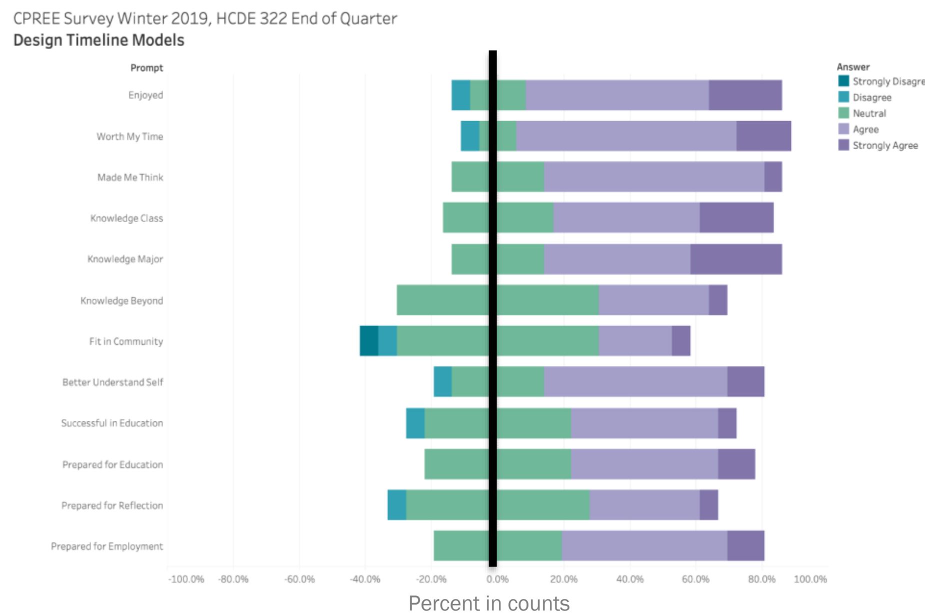
Looking back at end of quarter:

did I learn something useful, was it worth my time…



2018 (n=30)



2019 (n=18)

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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

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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

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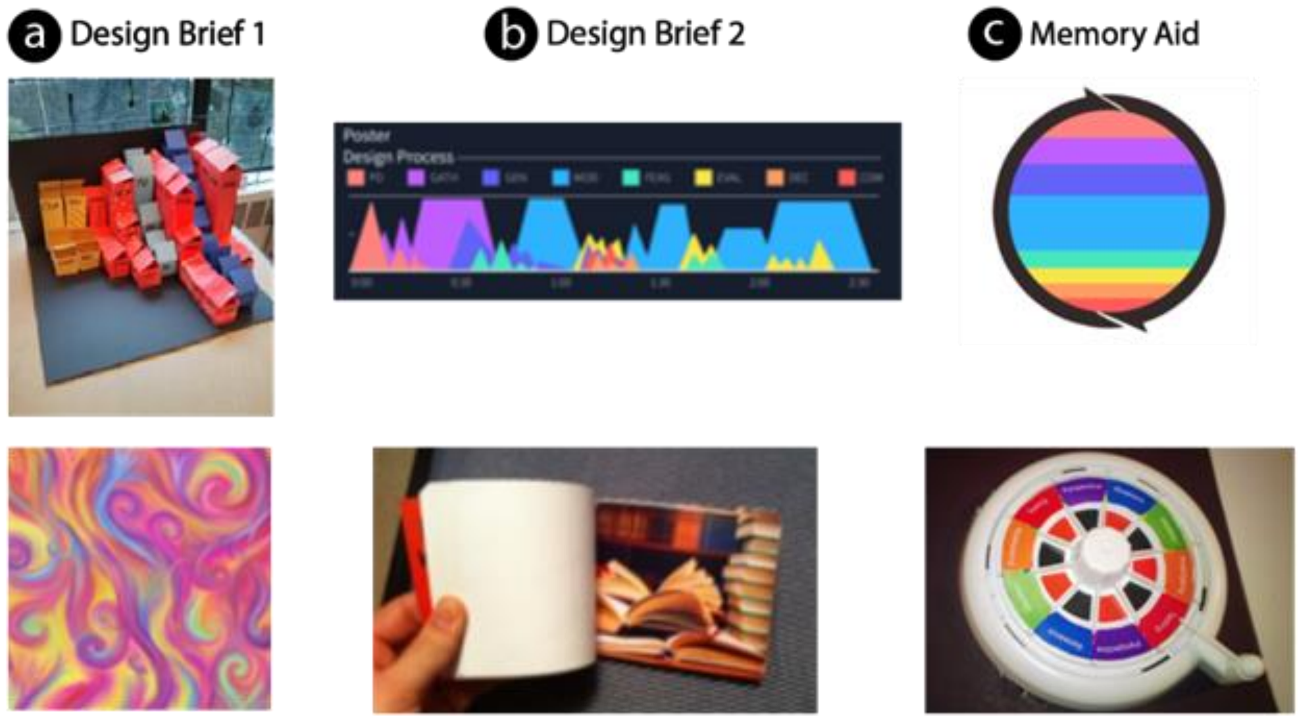
(Mølhave, McDonnell, & Atman, 2011; McDonnell & Atman, 2015)

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
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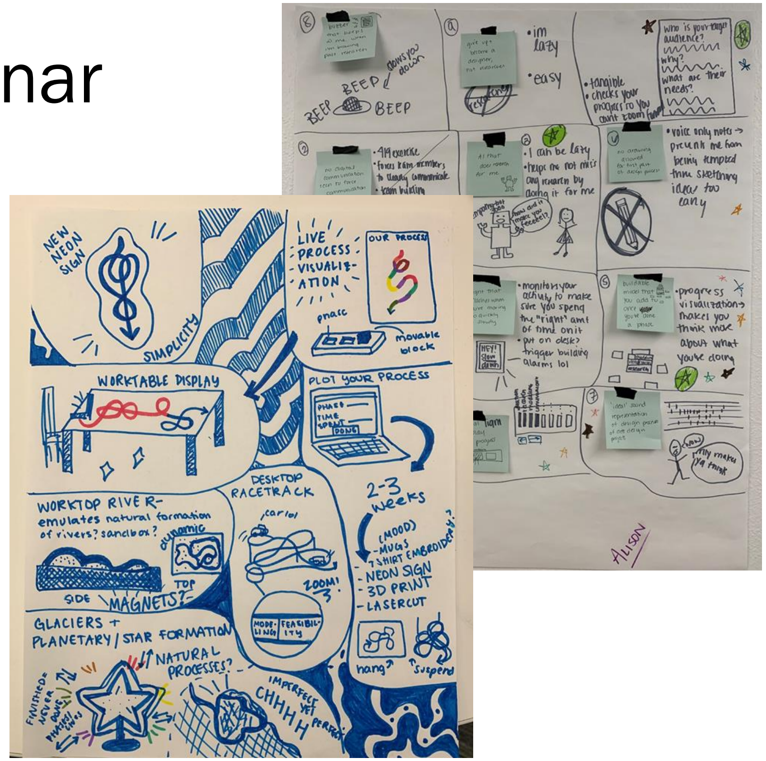
Current work - Design awareness seminar

- 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



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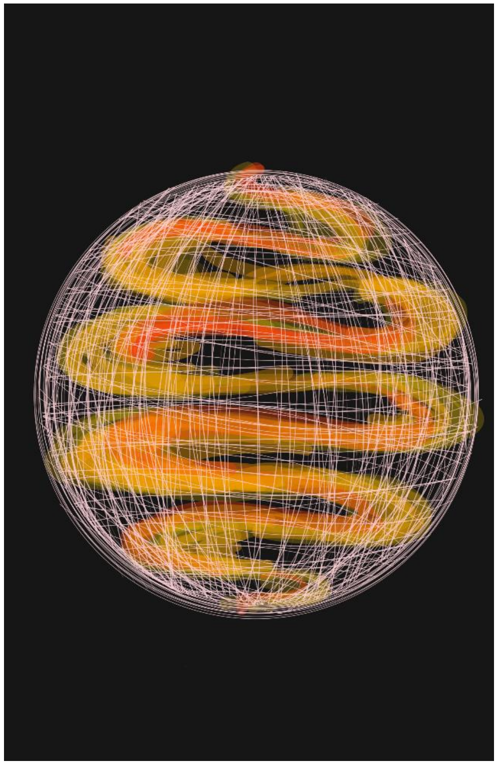
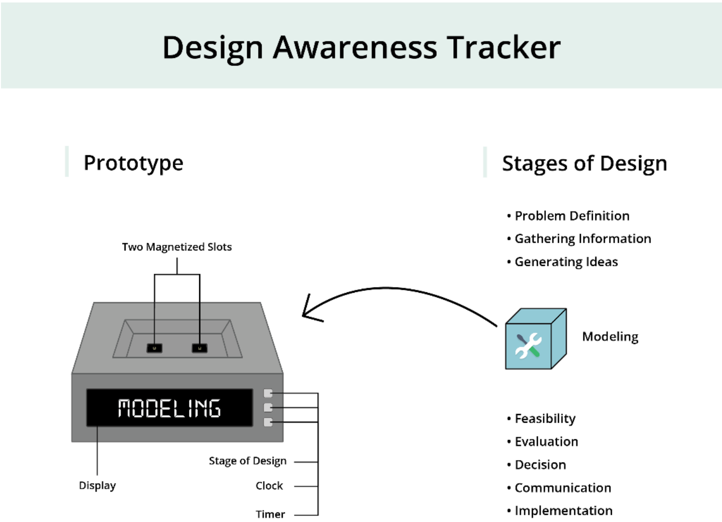
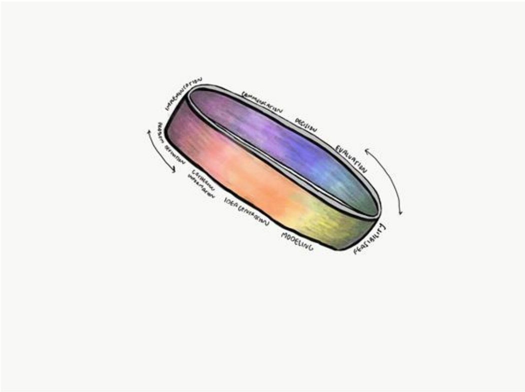
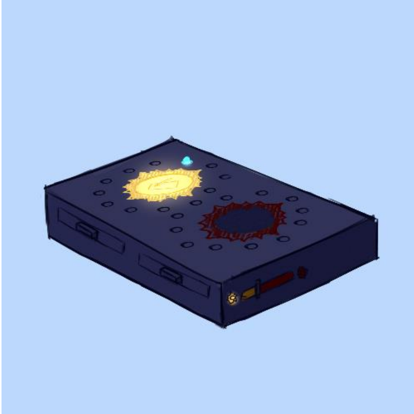
Design awareness tool prototypes



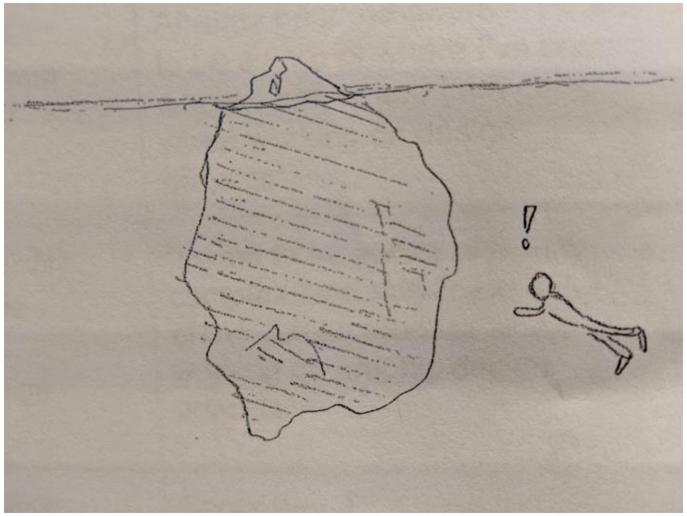






Seeing the rest of the iceberg

- 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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Today's Agenda

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

Charkha sculpture, Mumbai

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Hard to describe, represent, teach processes

Geoffrey Mann, “Attracted to Light”; Charkha sculpture, Mumbai, Hilma af Kline, Gloria Petyarre

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Presentation of research results

Email from sophomore IE student

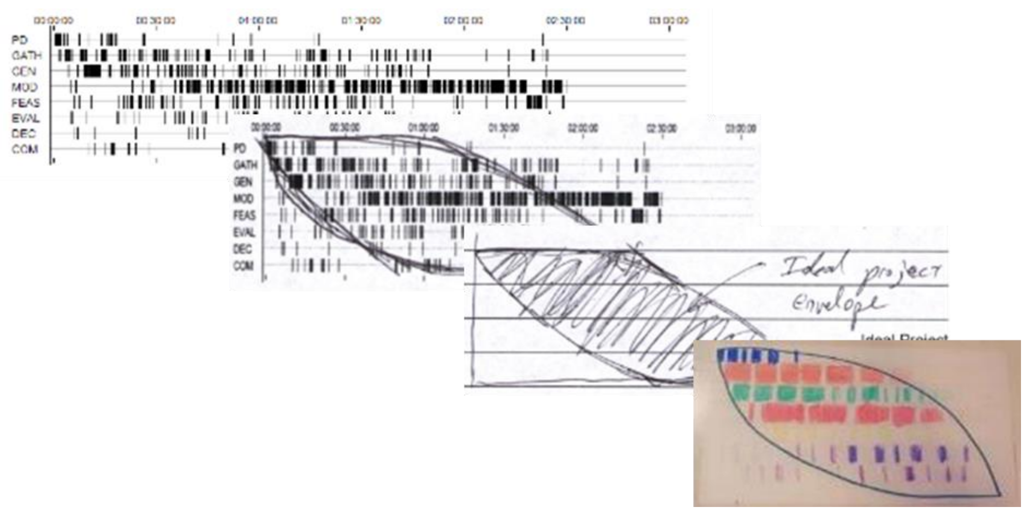
I've been talking to my friends (who didn't go) explaining to them how this is related to life and how we need to look at everything from several perspectives in order to get the most out of whatever you want to do. After about 20 minutes of explanation it seems they realize I'm crazy and move on with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

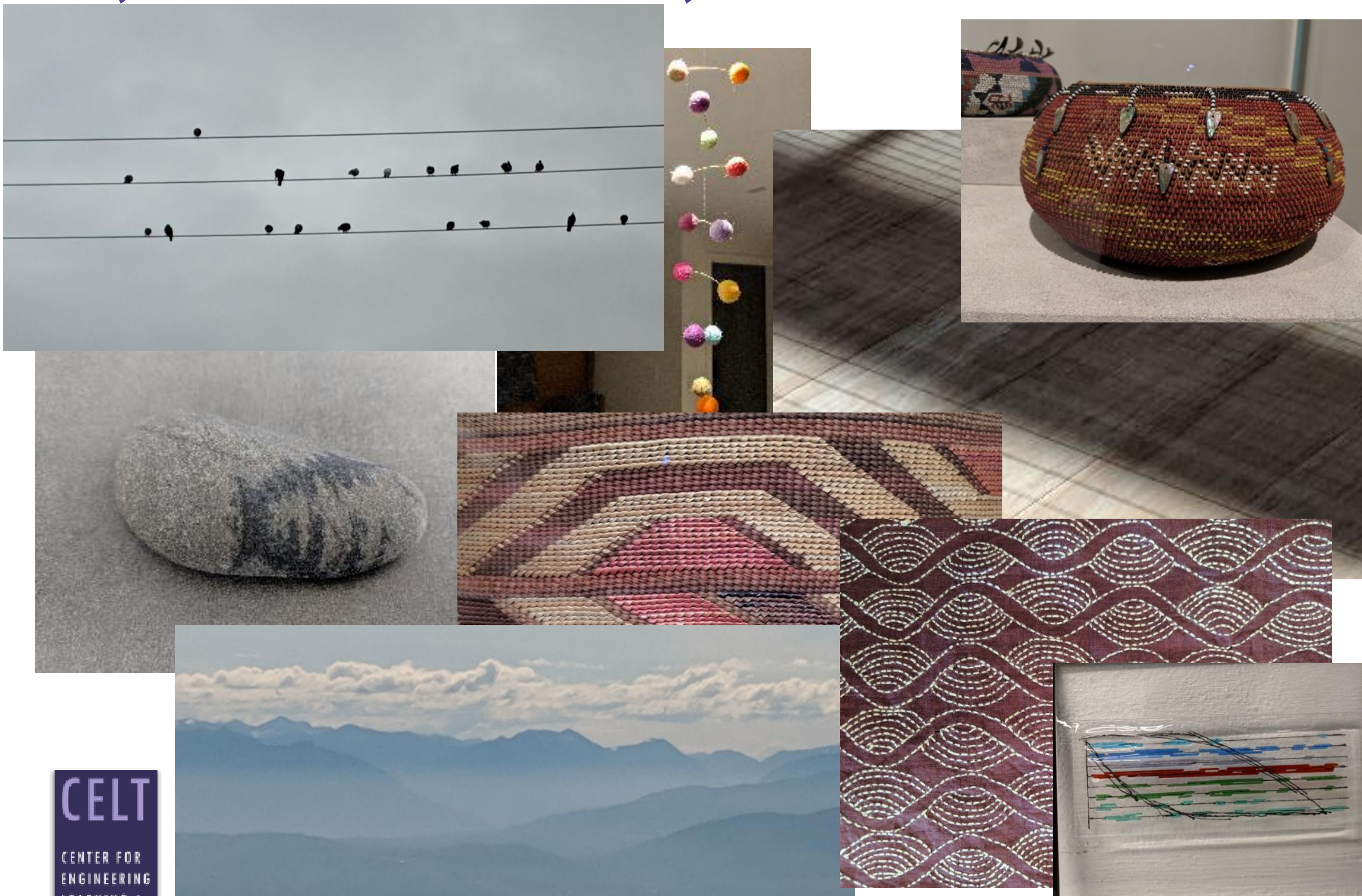
With that being said I appreciate you sharing your wisdom and wish you the best of luck!

Today discussed…

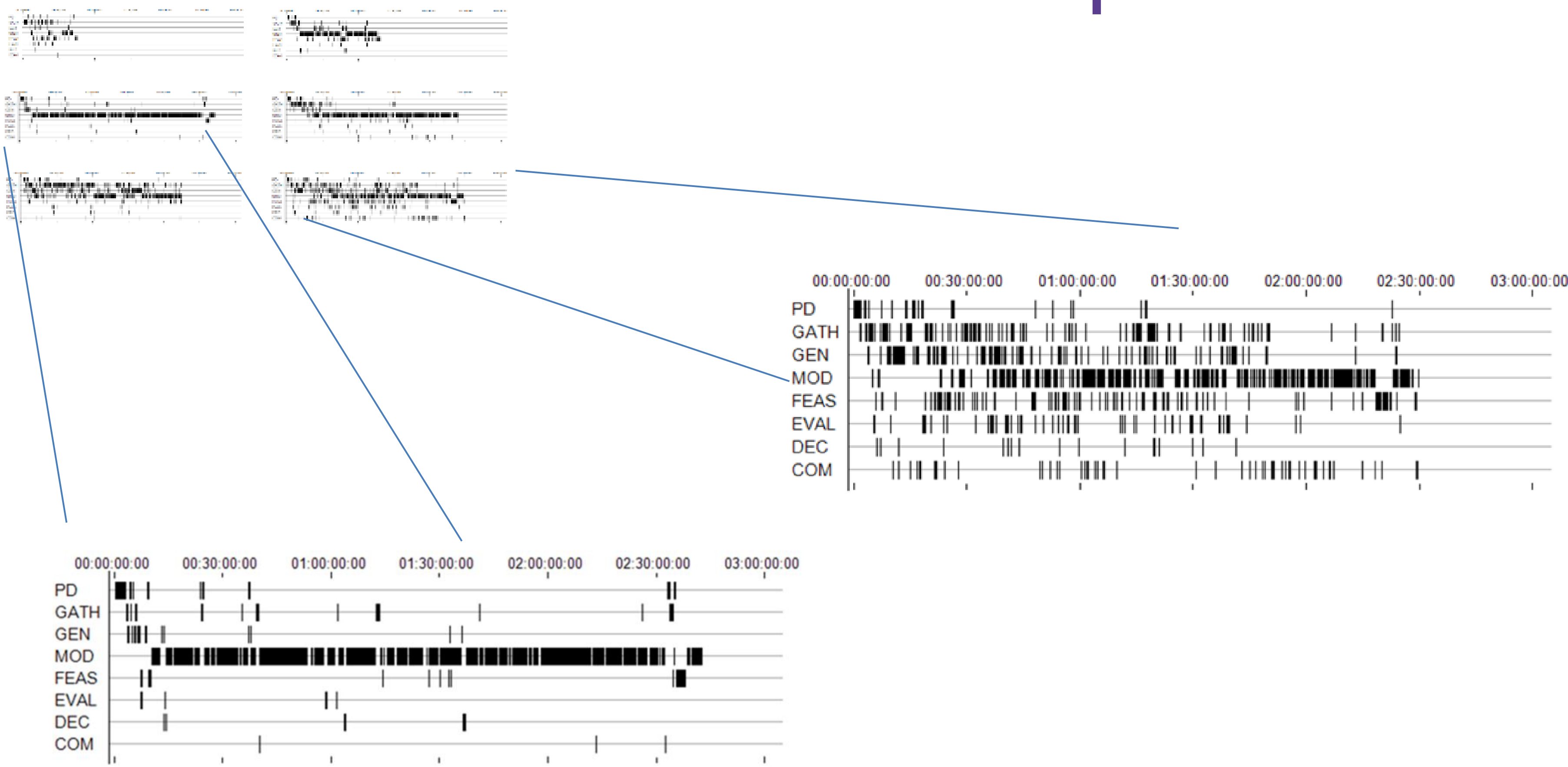
- Empirical research that describes complexity of design processes
- Timeline representations as *design signatures*
  - Concrete & sticky for students
- Warning, once you are captivated by timelines….



. . . you see them everywhere!



Timelines as canvas: An A cappella performance Sound Improv Live!



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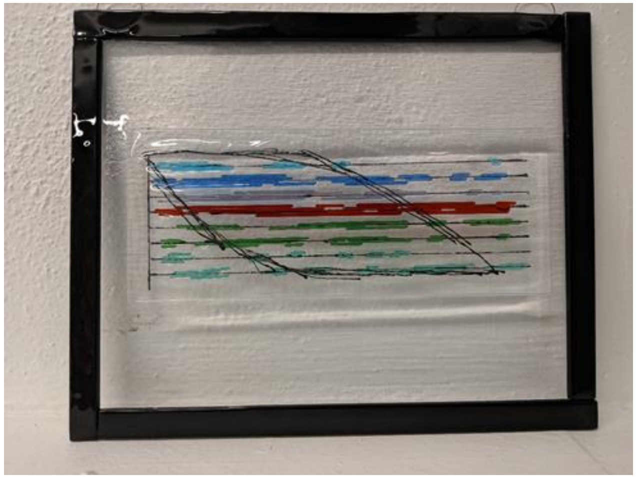
More information about this work - draft

- **Design Teaching/Learning**
  - Atman, C.J., Arif, A., Shroyer, K.E., Turns, J.A., & Borgford-Parnell, J. (2016) “Spend another day in our class talking about this research please”: Student insights from a research-based design thinking exercise. Design Research Society, 2016 Design Research Society 50th Anniversary Conference (DRS), Brighton, UK. June 27-30, 2016.
  - Atman, C.J., McDonnell, J., Campbell, R., Borgford-Parnell, J., & Turns, J. A. (2015). *Using design process timelines to teach design: Implementing research results*. American Society of Engineering Education Annual Conference (ASEE). Seattle, WA. June 14-17, 2015.
  - McDonnell, J. & Atman, C.J. (2015). *Paying attention to the design process: Critically examining personal design practice.* LearnxDesign Conference. Chicago, IL. June 28-30, 2015.
  - Borgford-Parnell, J., Deibel, K., & Atman, C. J. (2010). From engineering design research to engineering pedagogy: Bringing research results directly to the students. *International Journal of Engineering Education, 26*(4), 748–759.
- **Design Expertise**
  - Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education, 96*(4), 359–379.
  - Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A comparison of freshman and senior engineering design processes. *Design Studies, 20*(2), 131–152.
- **Design Process Representations**
  - Atman, C. J., Borgford-Parnell, J., Goist, Z., Deibel, K., Blair, J., Bodle, C., Kumar, V., Roesler, A., Tanimoto, S., & Zachry, M. (2010). Seeing and hearing design: Exploring how visual representations and sound tracks could be used to teach design. In *Proceedings of Design Thinking and Research Symposium 8* (pp. 25–37), Sydney, Australia, 2010.
  - Atman, C. J., Deibel, K., & Borgford-Parnell, J. (2009). The process of engineering design: A comparison of three representations. In *Proceedings of the International Conference on Engineering Design, Stanford University, 2009.*
- **Design Awareness**
  - Atman, C.J. (2018). *Design Awareness: Patterns, Pivots and Persistence.* Invited Talk to the International Conference on Transformations in Engineering Education – Imparting the Futuristic Skills (ICTIEE AP’ 18), July 15, 2018. SRM University - AP, Amaravati, India

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…

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Design awareness

Design awareness

Connection with intention

Reflection throughout.

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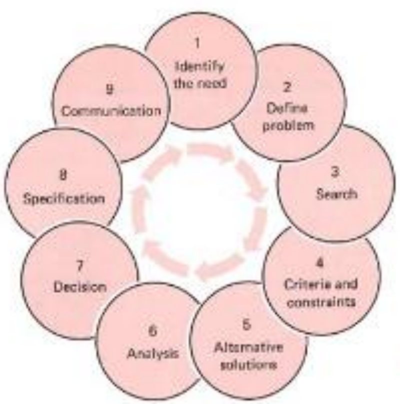
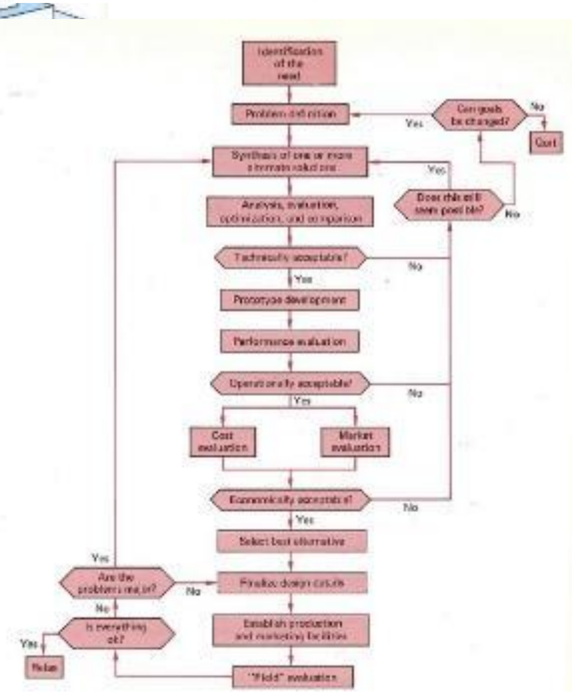
Why are timelines effective teaching tools?

Comparing design process representations

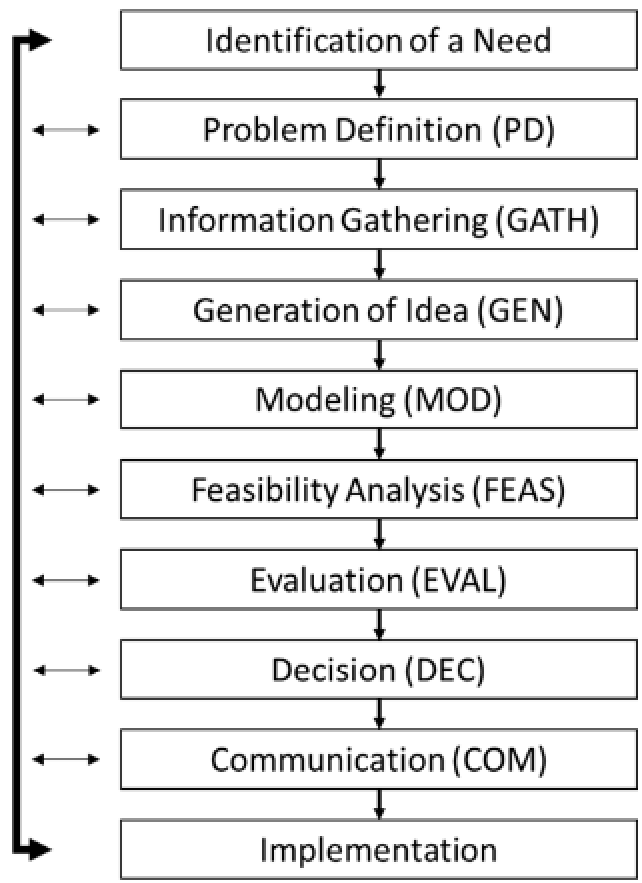
Sample representations from the engineering texts

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



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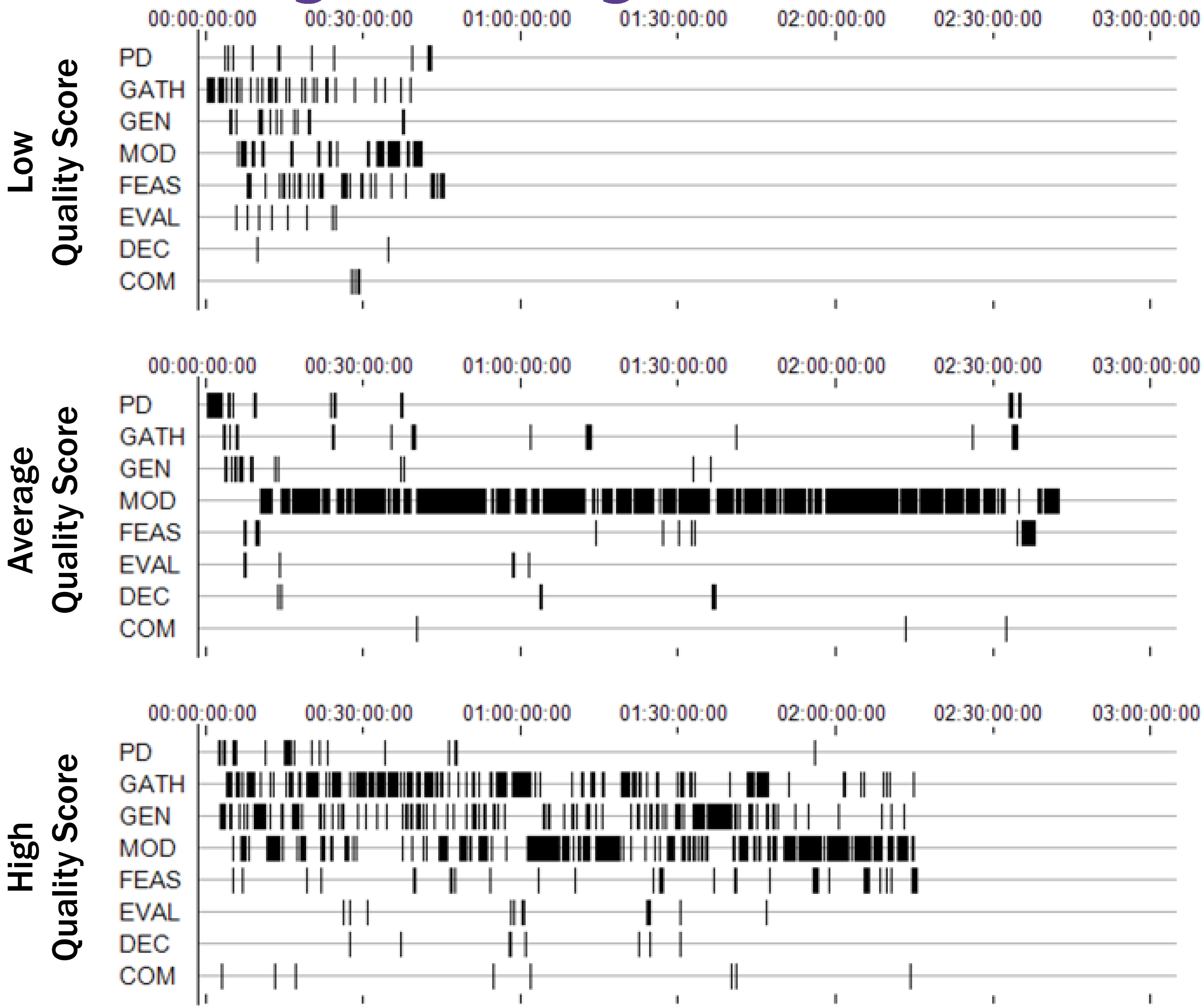
Atman, 2016 June

See *More Informatiom* at the end of this deck for citations

First-Year engineering students



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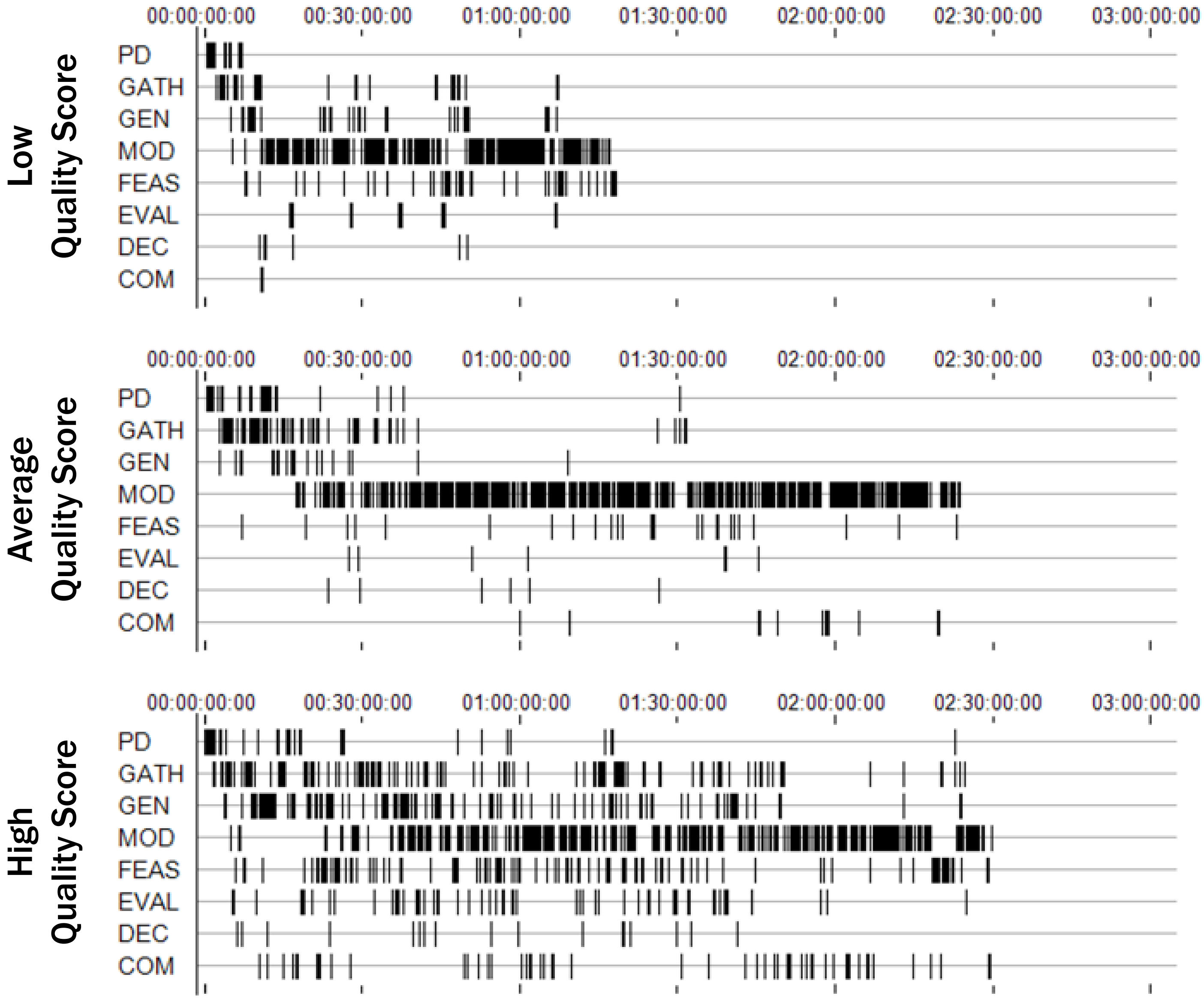
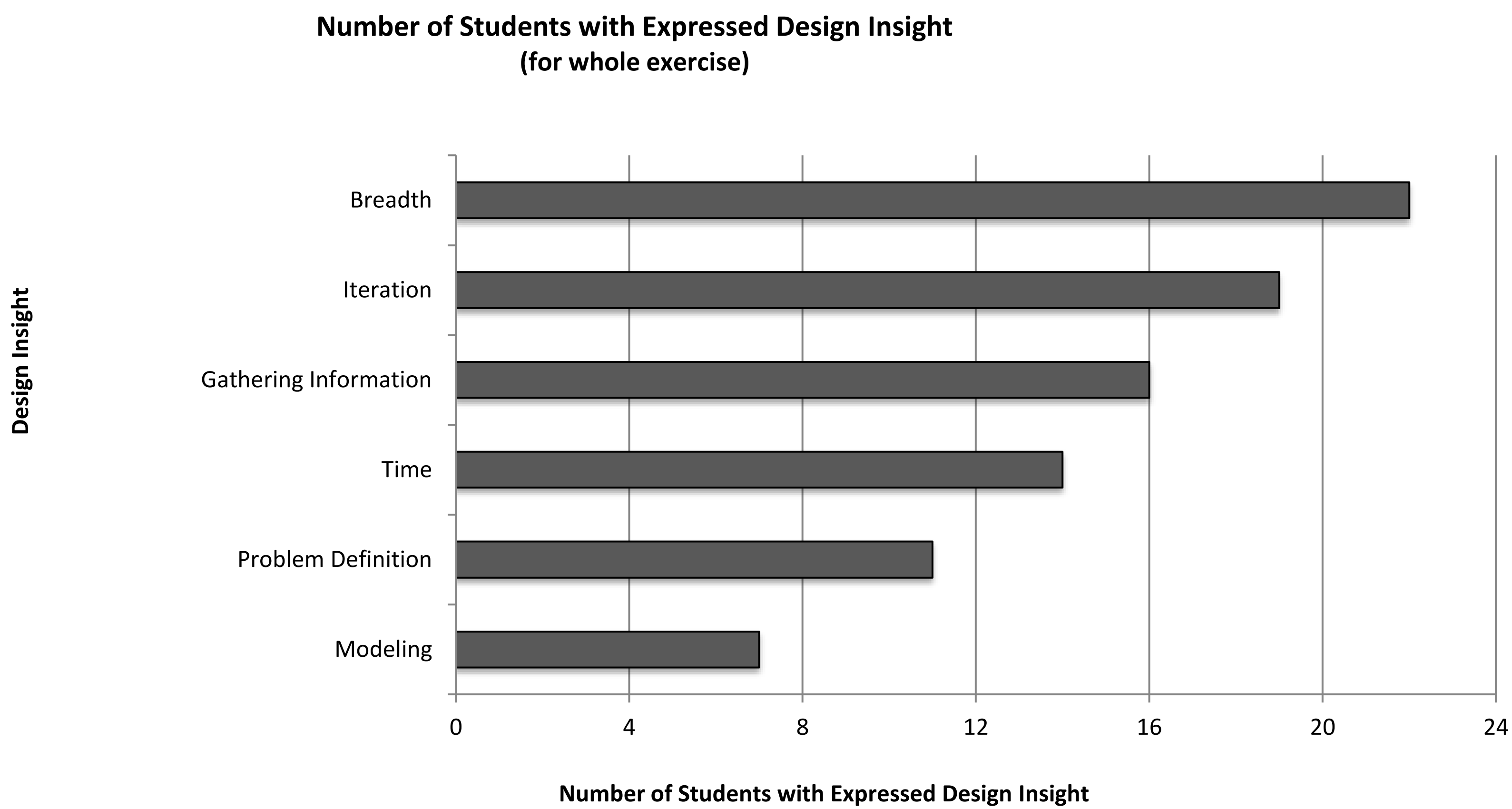
Graduating engineering students



Student insights (n= 24)



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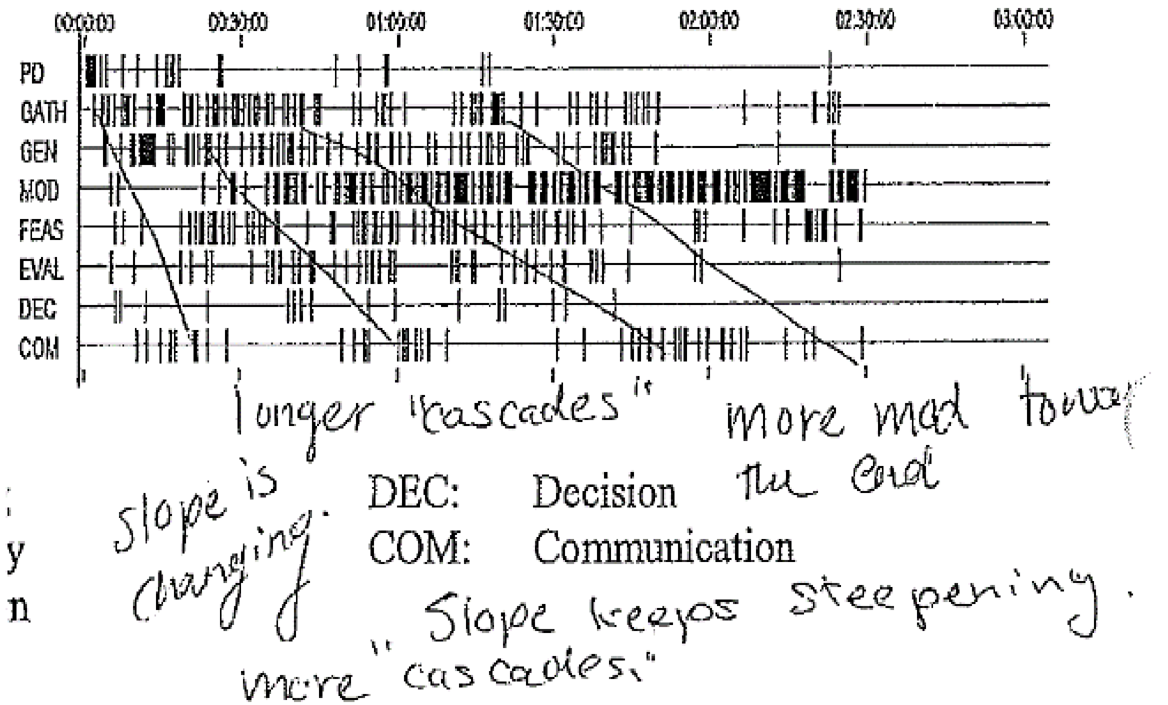
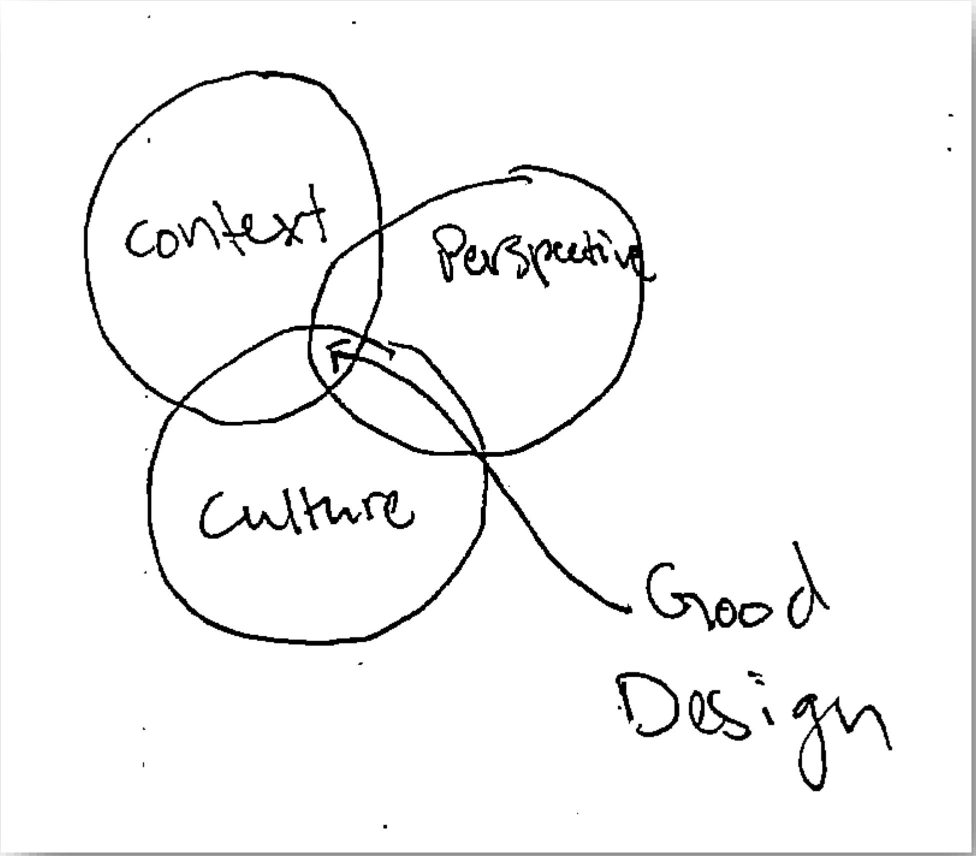
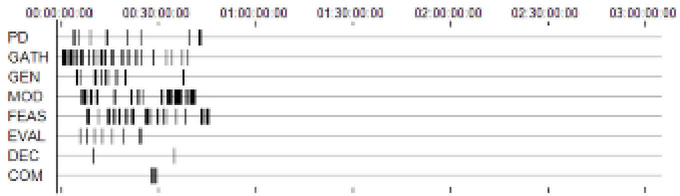
Selected student insights

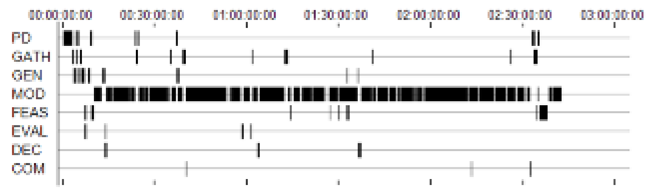


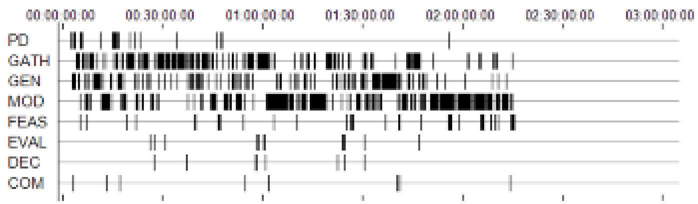
Good design

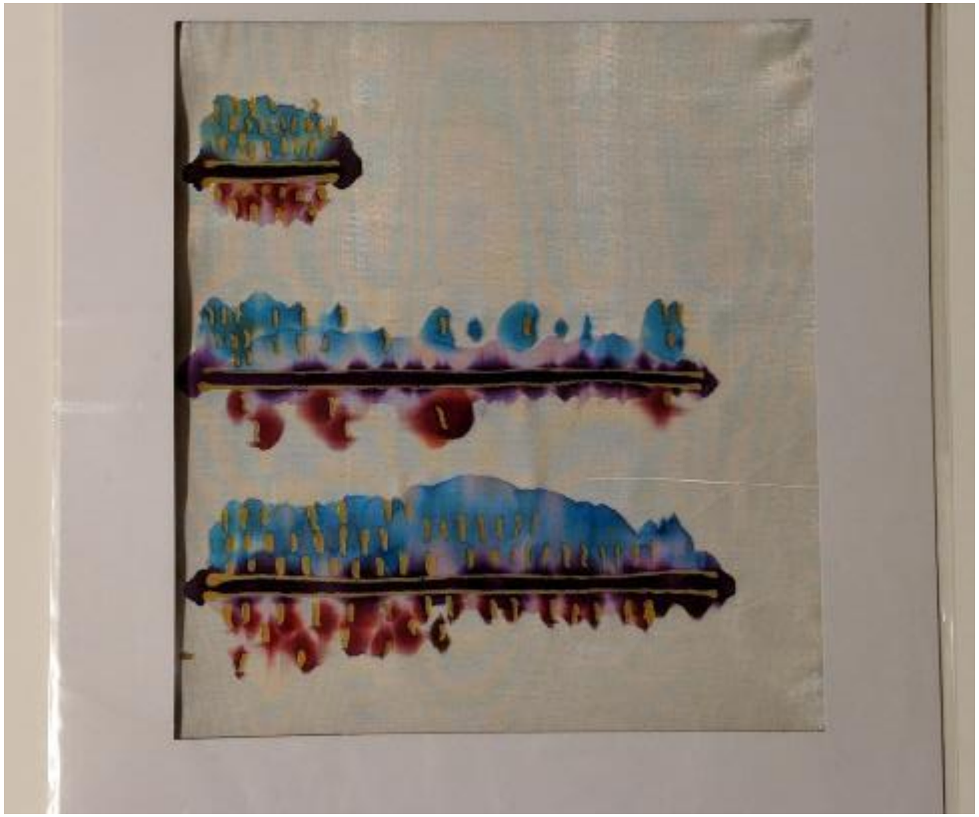


Design is messy!









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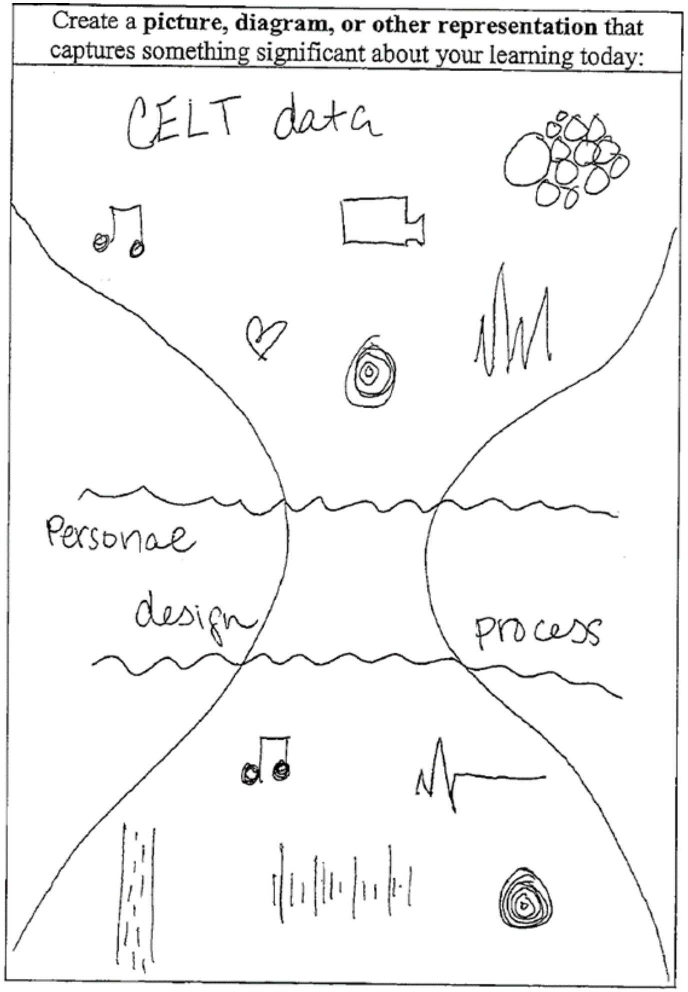
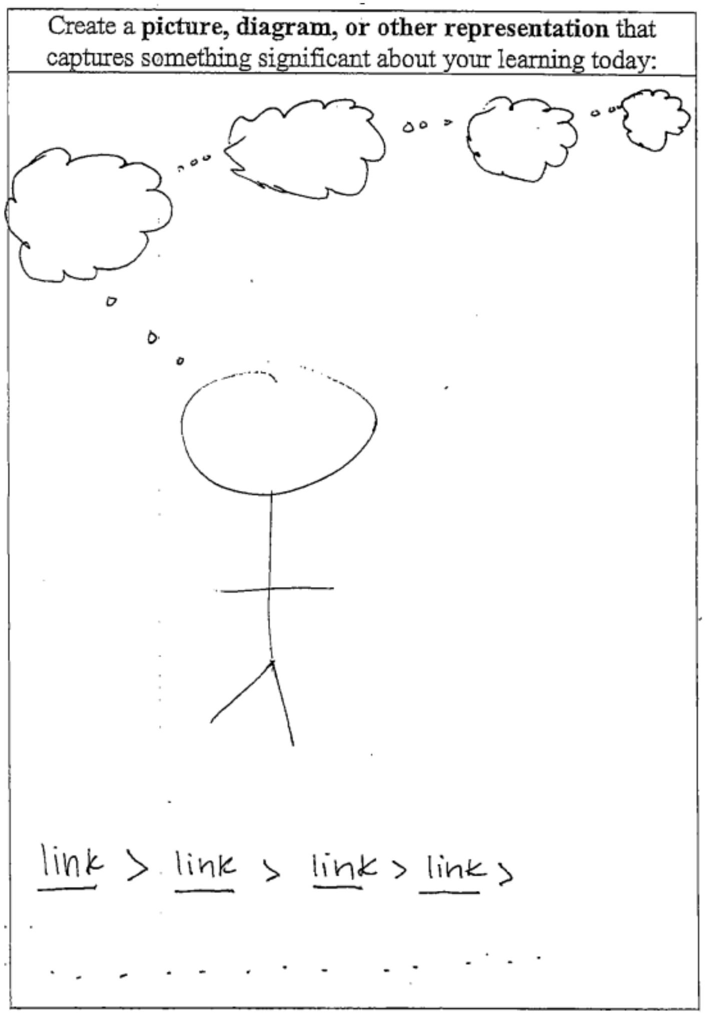
Student Reflections





Breadcrumbs

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)

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