Researching and Teaching Engineering Design

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Preferred pronouns: she/her

Extraordinary Engineering Impacts on Society Symposium

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CELT
CENTER FOR ENGINEERING LEARNING & TEACHING

Thinking forward to the engineer of 2040

- How might you fill in the following?

In ___2040___ (YEAR) the ___ENGINEERING___ (MAJOR) graduate who wants to ___"X"___ might need to know ___"Y"___ and could learn it by ___"Z"___.

Altman, A., Krauss, G.G., Lande, M., Atman, C.J., & Turns, J. (2018). The Key Ideas of MDW X: A Summary. *International Journal of Engineering Education,* 34 (2B), 549-557.

In 2040, the engineering graduate who wants to "X"

1. Change the world/ help/impact/make a difference/transform
2. Design/build/system
3. Politics/activism
4. Solve/define problems
5. Be happy
6. Know themselves
7. Shift/grow/disrupt
8. Ethics/humility/virtues
9. Be a good citizen
10. Teach/learn/spread STEM literacy

...might need to know "Y"

1. Communication/listen/talk/ handle conflict
2. Empathy/kindness/compassion/ perspective
3. Know themselves/ self-reflective /self-directed learning
4. How to learn/theory
5. Engineering is only part of the solution/policy/politics
6. Design/design thinking/human centered design
7. How to not rely on technology/ take a digital vacation
8. multiple languages
9. Dance with ambiguity
10. Systems-thinking

...and could learn it through "Z"

1. Reflecting
2. Failing
3. Doing
4. Interdisciplinary work
5. Humility/following/ mentoring
6. Listening
7. Laughing
8. Dreaming
9. Emotional learning
10. Neural implants

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My pathway

- My lifetime goal as high school student
  - Change the world/ help/impact/make a difference/transform
- On graduation day with my BS in industrial engineering a mentor took me aside and said

  "You should think about getting a PhD, we need people like you teaching at the university level"

- Life happened
  - Work, masters degree, work, PhD, faculty member
- My refined lifetime goal as engineering faculty member
  - Help teach engineering students to change the world
    - think about impact of engineering on society and globe
    - consider context in their engineering work
    - minimize unintended consequences

Engineering is…

…design under constraint.

(William Wulf, U.S. National Academy of Engineering President,1998)

Engineering is design under constraint

- Constrained by
  - Nature
  - Safety concerns
  - Environmental concerns
  - Cost
  - Reliability
  - Constructability
  - Maintainability
  - Many other such “ibilities”

- Engineering is…
  - Creative
  - Designing what can be

(William Wulf, NAE President,1998 - https://www.nae.edu/7580/TheUrgencyofEngineeringEducationReform

My pathway

- If engineering is “design under constraint”
- How to help teach engineers to change the world?
  - as they engage in design
- My **more** refined lifetime goal:
  - deeply understand the doing of engineering design
  - to inform design teaching

NSF investment enabled my career

- Graduate student funding
  - Engineering & Public Policy, Carnegie Mellon University
- Young Investigator award (precursor to CAREER program)
- Multiple traditional grants
- Center for the Advancement of Engineering Education (CAEE)
  - Director & Principal Investigator
  - $12.2 million, 2003-10
  - Colorado School of Mines, Howard, Stanford, University of Washington
    - Adams, Fleming, Sheppard, Smith, Stevens, Streveler, Turns

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Goal: deeply understand the doing of engineering design

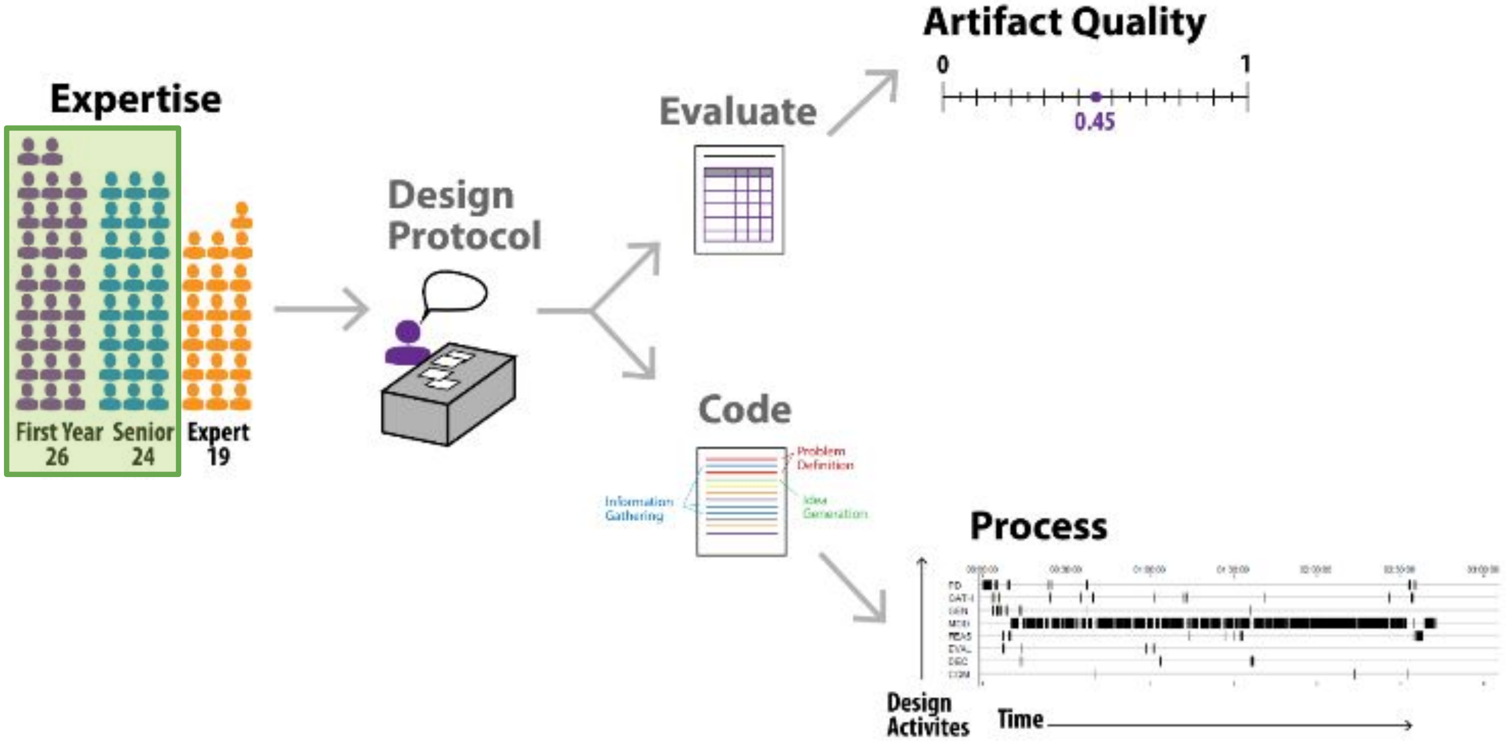
- Questions:
  - How do engineering students and experts engage in design?
  - Are there differences that can inform how to teach design?

Goal: deeply understand the doing of engineering design

- Embarked on quest, funded by NSF
  - Use research methods from cognitive science
  - From 177 engineers with various levels of expertise
  - Solving design problems out loud
  - Create quantitative measures from verbal data
  - Compare processes across levels of expertise
    - E.g., experts and novices

Design a playground for a fictitious neighborhood

Experimental setting



Defining Design: Design activity codes

7 Engineering
Design Textbooks

→ Content Analysis →

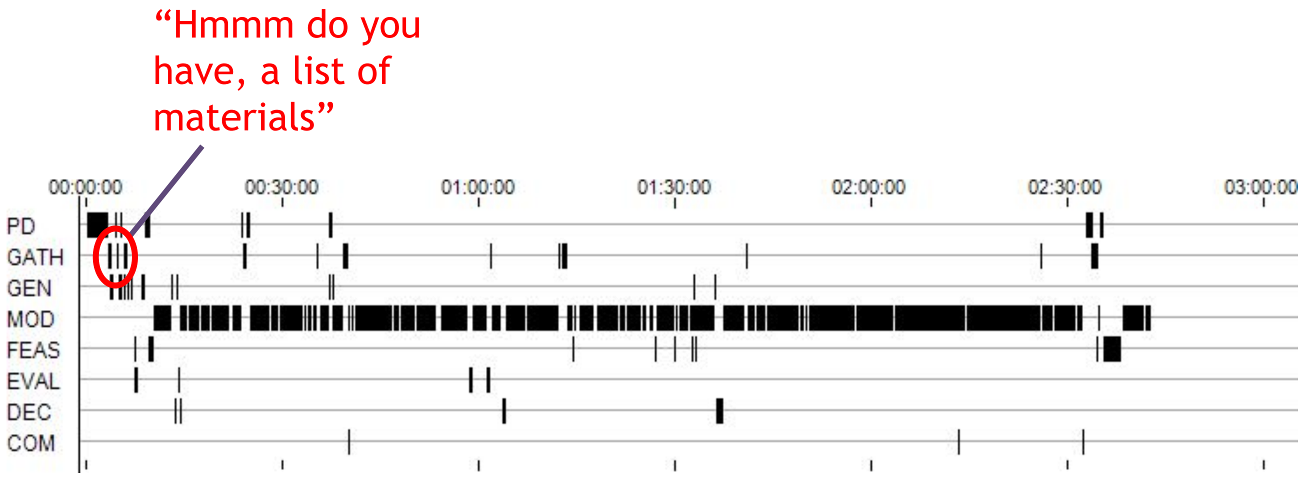
- (Identification of a Need)
- Problem Definition
- Information Gathering
- Generation of Ideas
- Modeling (prototyping)
- Feasibility analysis
- Evaluation
- Decision
- Communication
- (Implementation)

Experimental results

- Graduating seniors were significantly more likely than first-year students to...
  - have higher-quality designs
  - make more transitions among design activities
  - scope the problem more effectively by considering more categories of information
  - progress further in the design process

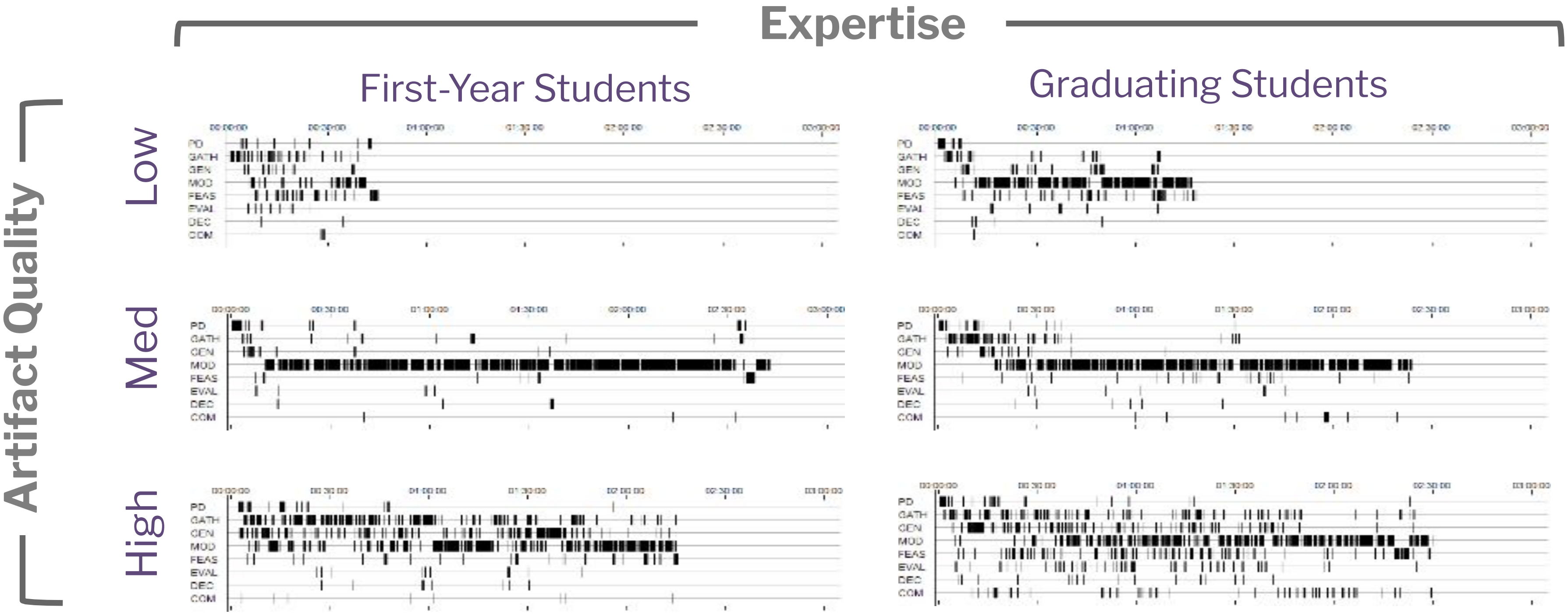
Atman, C.J., Chimka, J. R., Bursic, K.M., and Nachtmann, H.L. (1999). "A comparison of Freshman and Senior Engineering Design Processes." *Design Studies*, 20(2), 131-152.
Atman, C. J. (2019). Design timelines: Concrete & sticky representations of design process expertise. *Design Studies*, *65*, 125-151.

Design timeline representations



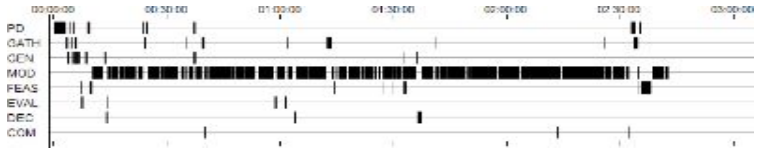
PD:	Problem Definition	FEAS:	Feasibility Analysis
GATH:	**Gathering Information**	EVAL:	Evaluation
GEN:	Generating Ideas	DEC:	Decision Making
MOD:	Modeling	COM:	Communication

Looking across the student groups

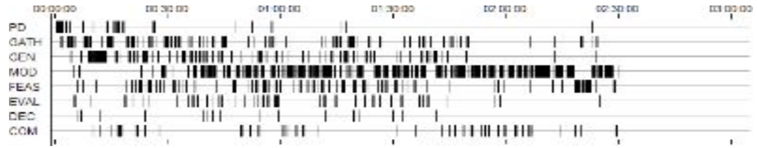


A focus on these two

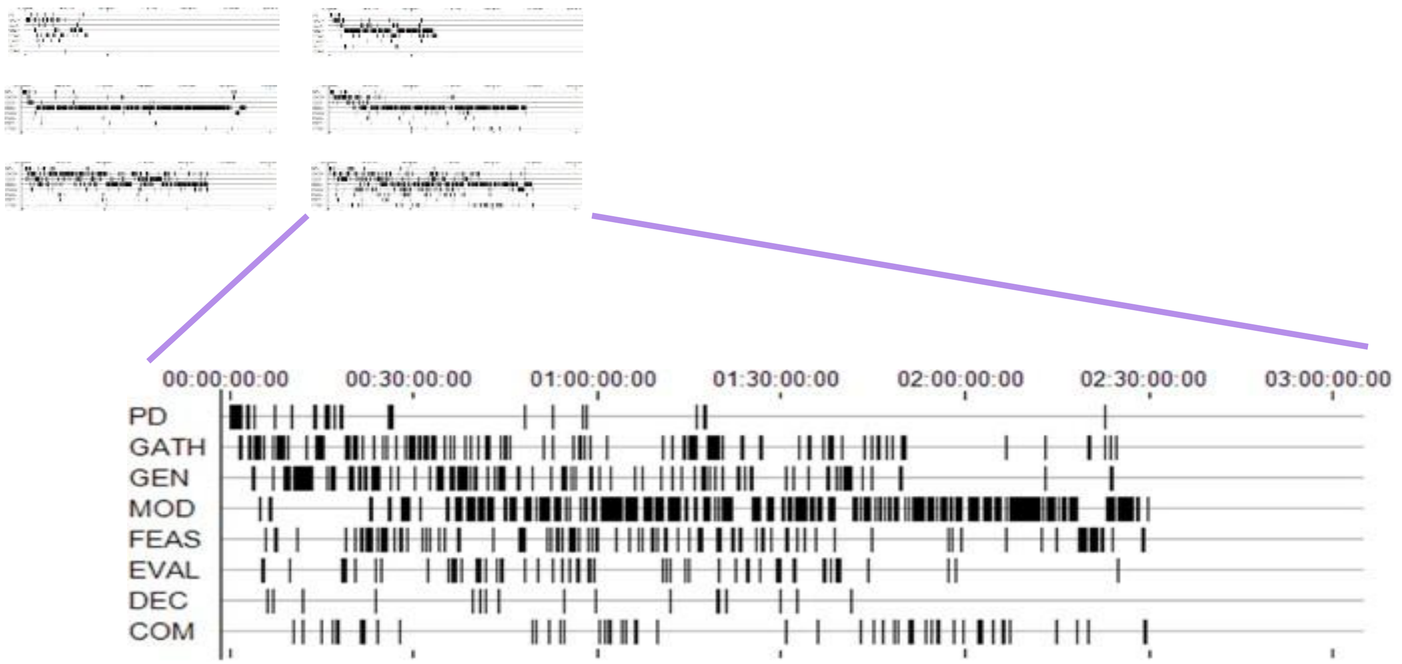
- First year student,
  medium quality design



- Graduating senior,
  high quality design

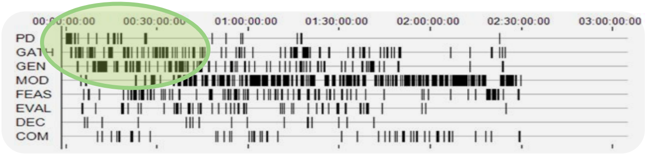


Timelines as canvas for research results



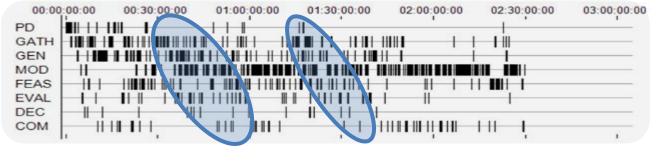
Moving towards more experienced design behaviors (also, where to consider context in design)

- Thorough problem scoping at the start of the process before turning towards modeling

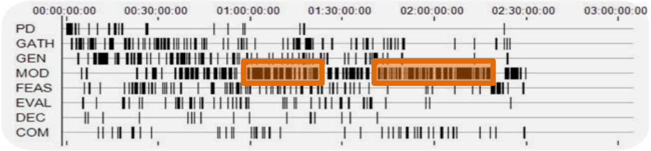


- Gather information throughout the process

- Transition and iterate throughout the process

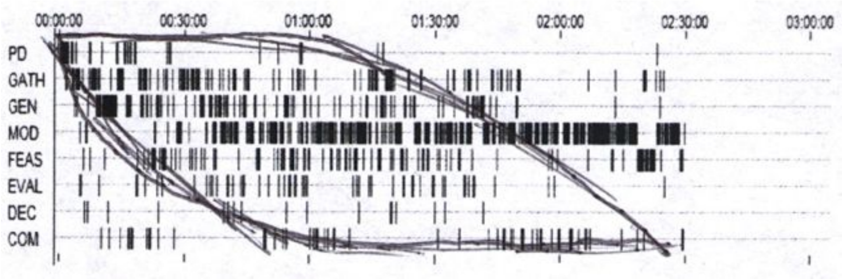


- Stay the course at certain times



Moving towards more experienced design behaviors (also, where to consider context in design)

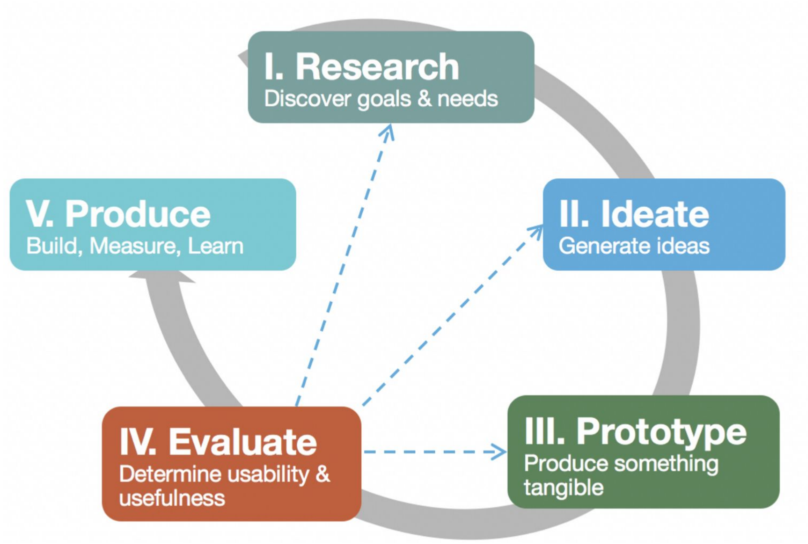
- Cascade shape
  (ideal project envelope)



So now what?

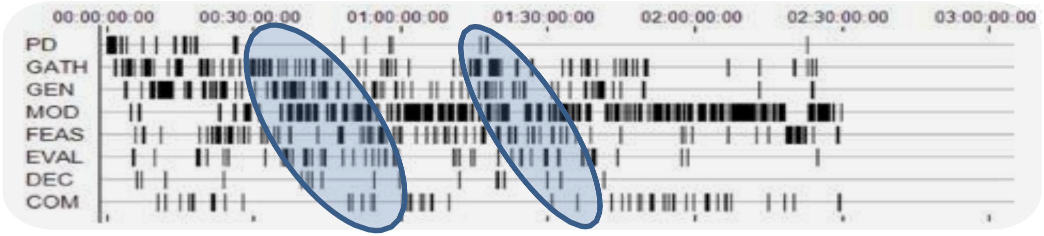
- Recalling my more refined lifetime goal:
  - deeply understand the doing of engineering design
  - to inform design teaching

How design is typically taught

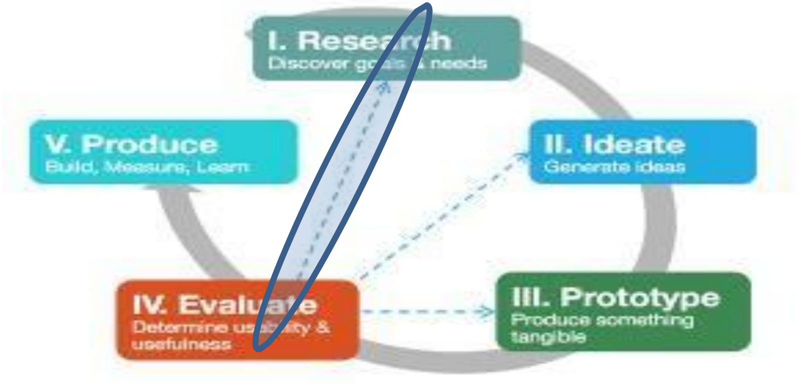


Model from Brock Craft and Tyler Fox, Human Centered Design & Engineering, University of Washington

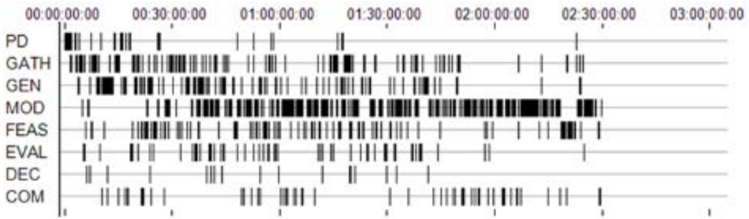
Affordances of timelines: Abstract concepts made visible

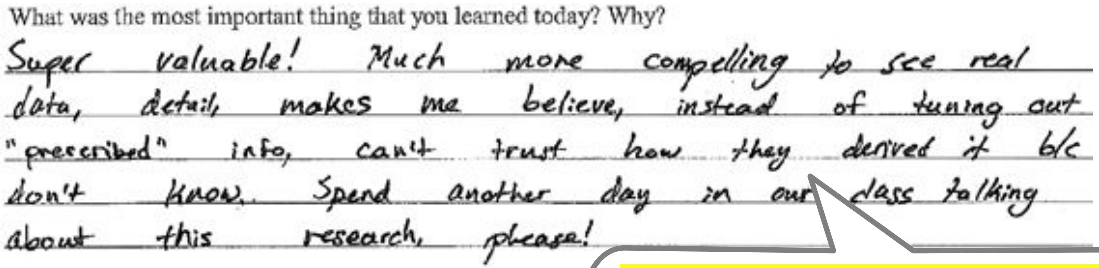


Representing transitions/iterations in timeline and traditional design models



Teaching with timelines: Student reactions





"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!"
(Mechanical engineering student)

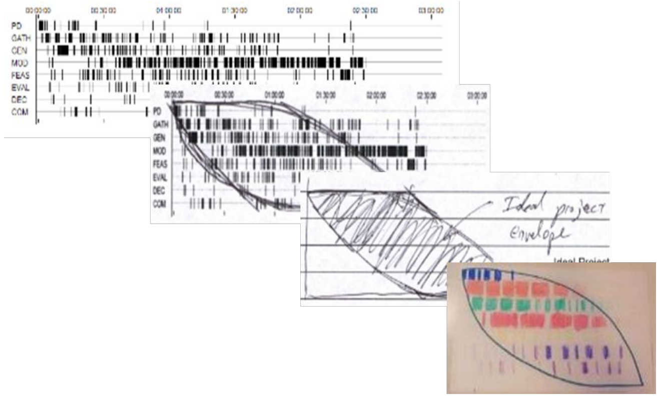
As a practicing engineer

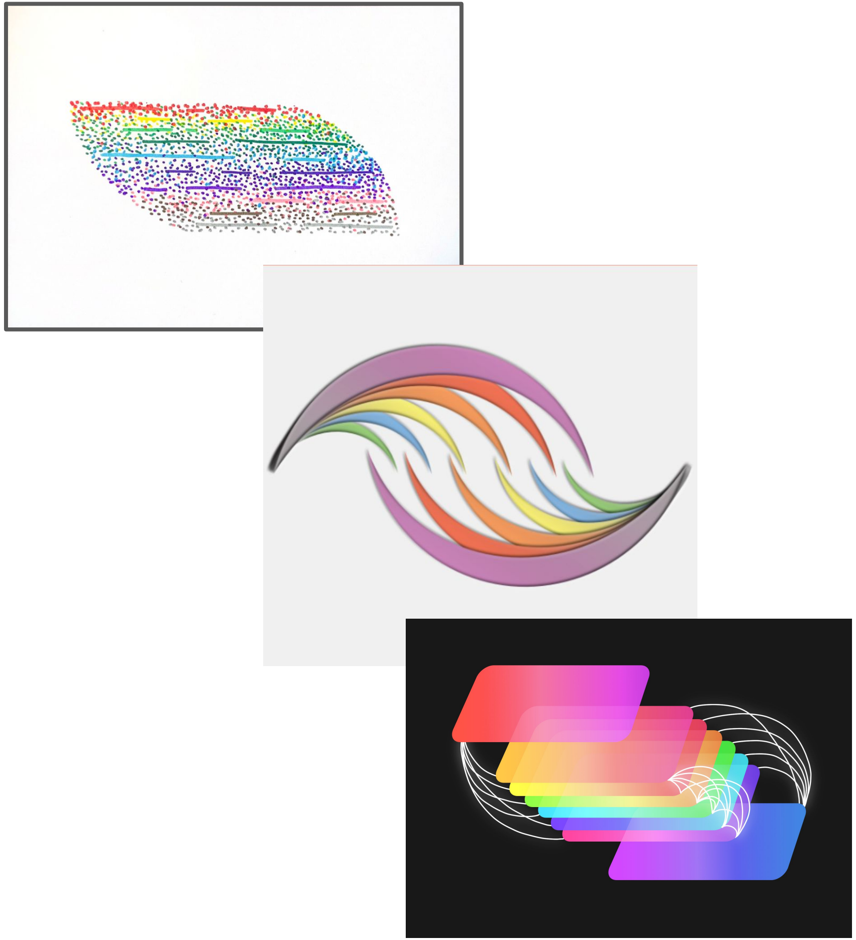
"...if I ever find myself getting stuck in one mode/stage, I remind myself that the iterative cascade is where the magic happens."

Zach Goist
Human Centered Design & Engineering graduate

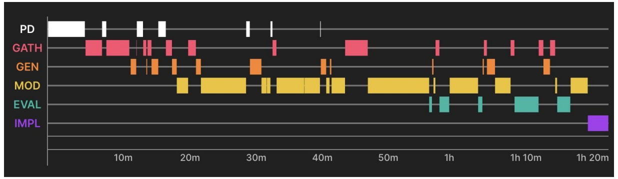
Current work

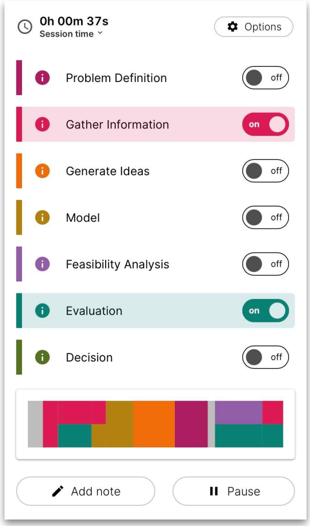
- Make this work accessible to a larger audience
  - An app
  - A seminar

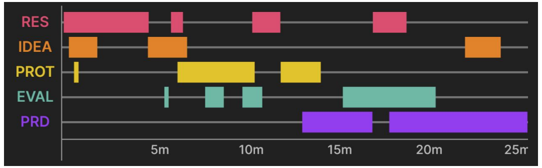


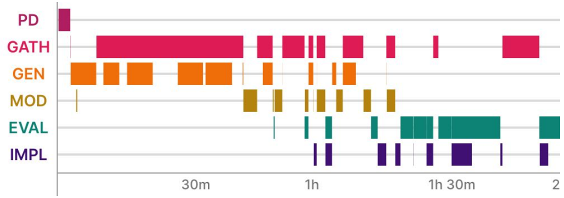


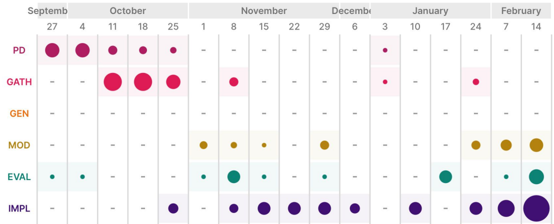
Current work: Design Signatures App



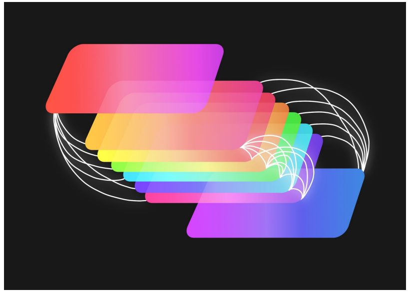


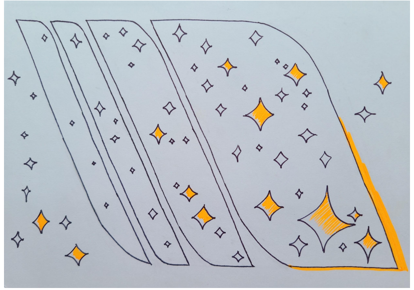


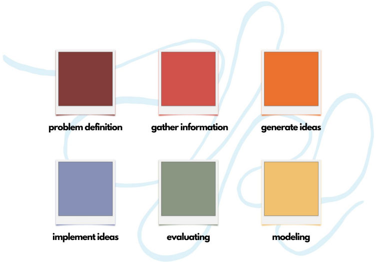


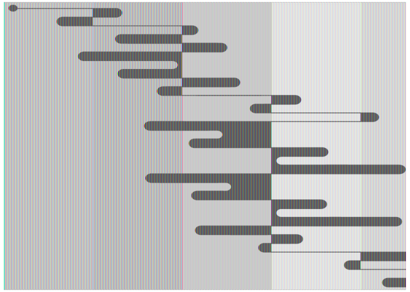


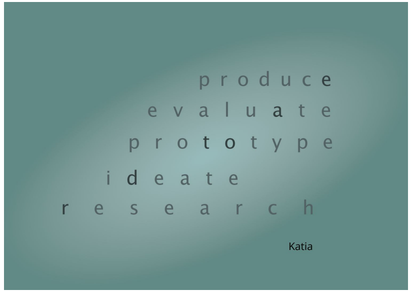
Current work:
Dear Design
Ideal Design Signatures

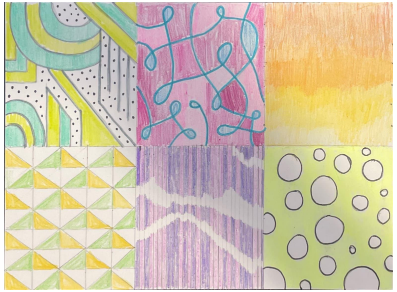


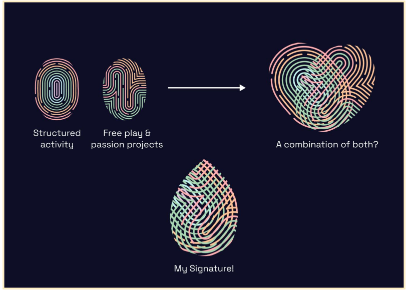


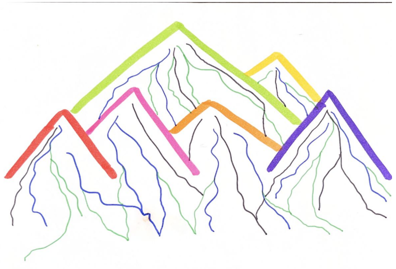






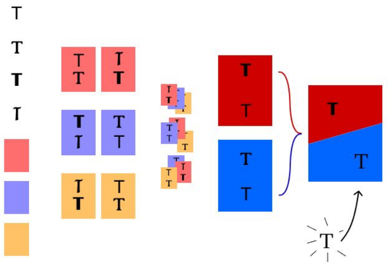


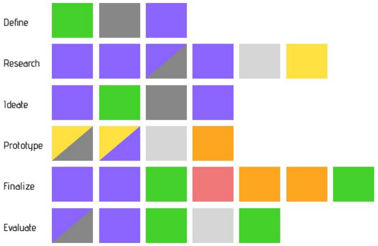


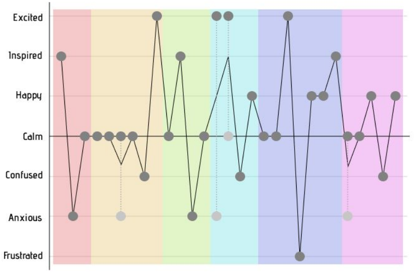


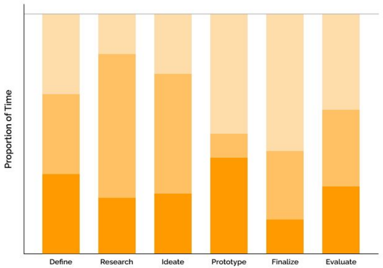
Inspired by "Dear Data" project: Lupi, G., & Posavec, S. (2016). *Dear data*. Chronicle books.

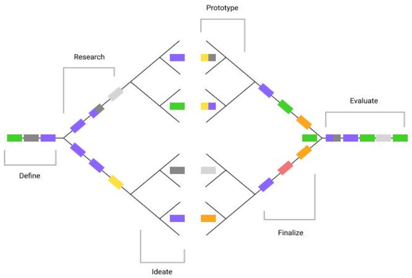
Current work: Dear Data across the 9 weeks
Eileen Zhang

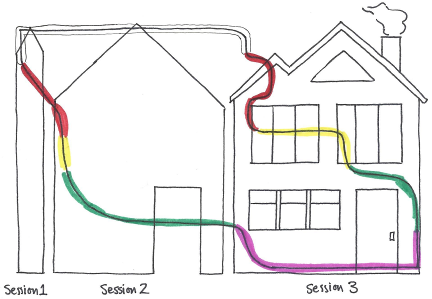


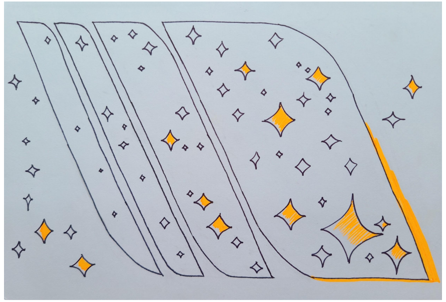










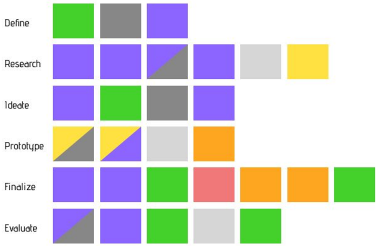


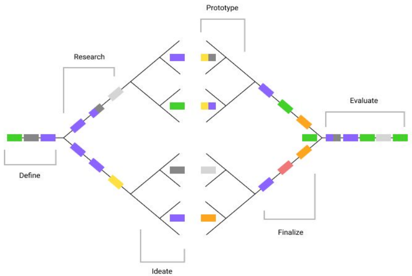
Reflection on the Dear Design seminar

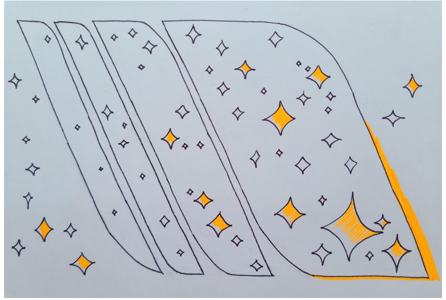
"The Dear Design seminar taught me how to conceptualize design processes and how to conceptualize my own design work. I was struck by the fact that there are multiple ways to “get to” design…this realization powerfully shapes how I collaborate with people…

My ideal design signature is a core part of the work that I want to do as an engineer, and it also strengthens my belief that I am a designer…"

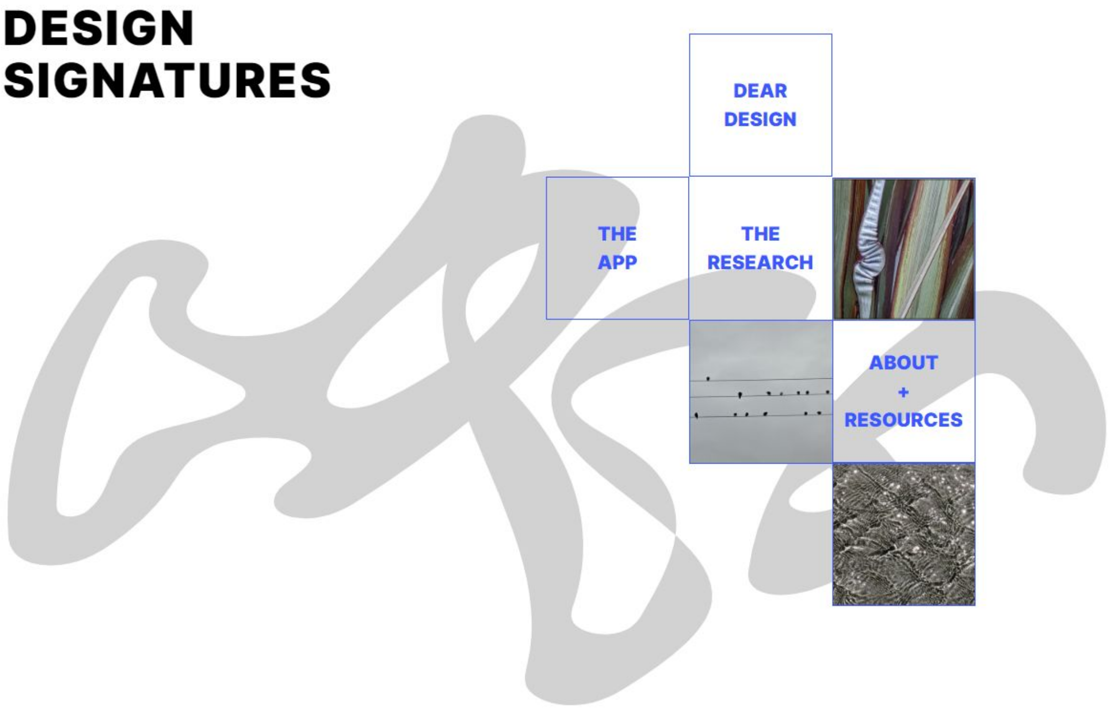
Eileen Zhang, Winter quarter, 2022





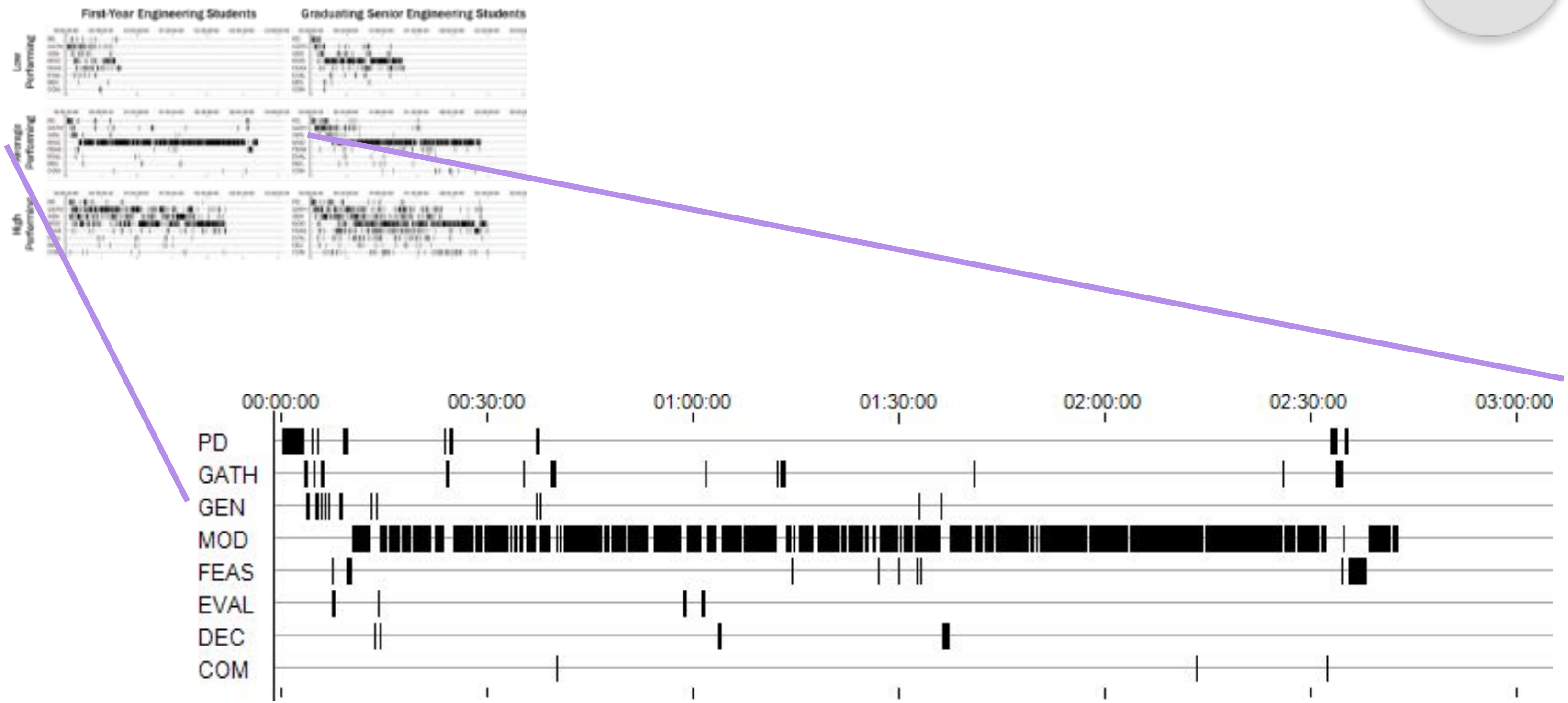


For more information

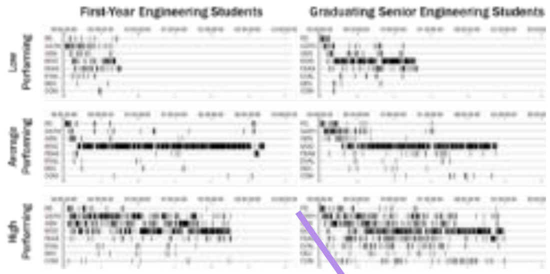


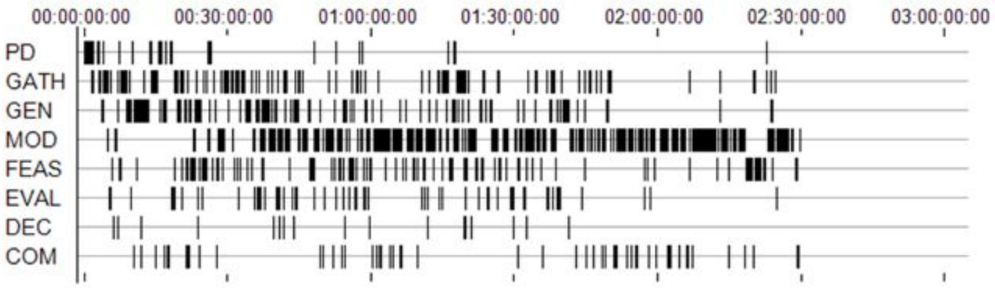
Design Signatures website with Dear Design materials available fall, 2022
Summary of research: Atman, C. J. (2019). Design timelines: Concrete & sticky representations of design process expertise. *Design Studies*, *65*, 125-151.
Cindy Atman: atman@uw.edu

Listening to design



Listening to design





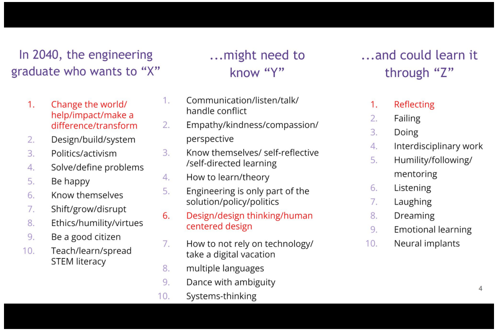
Collaborators

- 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, Mark Zachry, Eileen Zhang.
- …and many, many undergraduate students

Interested in engineering education research?

- Many areas besides design
  - Engineering pathways
  - Diversity, equity and inclusion
  - Engineering identity
  - Engineering ethics
  - Threshold concepts (key concepts for learning a topic)
  - Teaching methodologies
  - The list can go on...
- For inspiration for more research topics check out
  - Journal of Engineering Education
  - Advances in Engineering Education

Thank you, NSF



In 2040, the engineering graduate who wants to “X”	…might need to know “Y”	…and could learn it through “Z”
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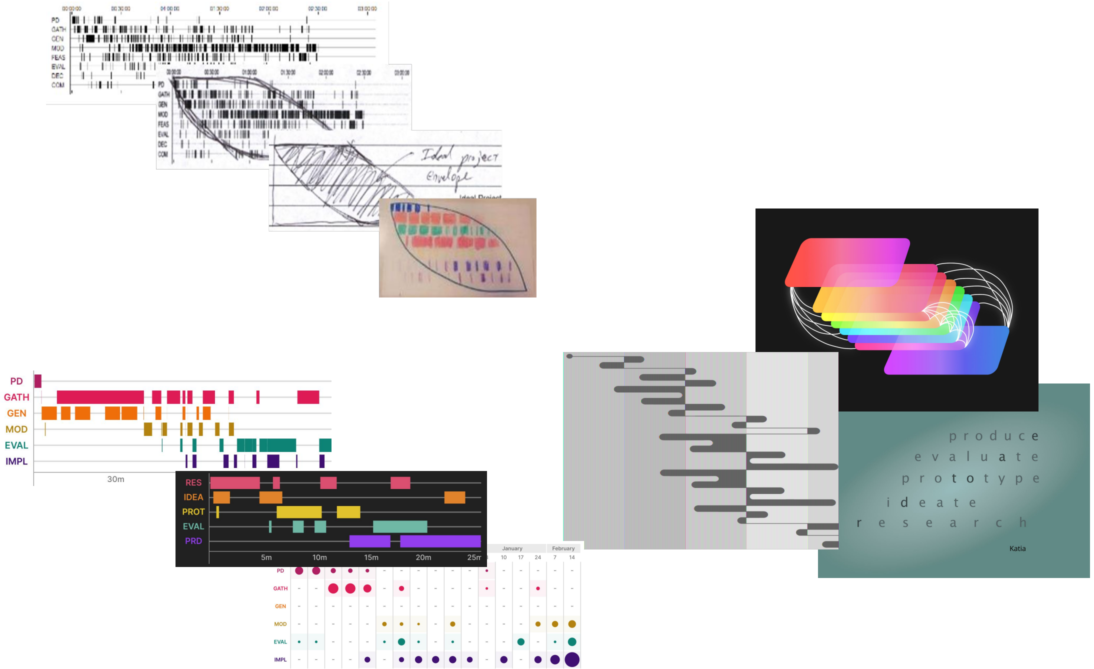
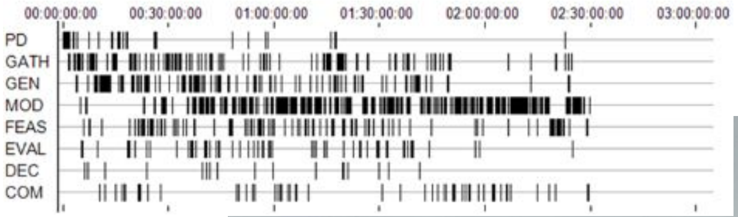
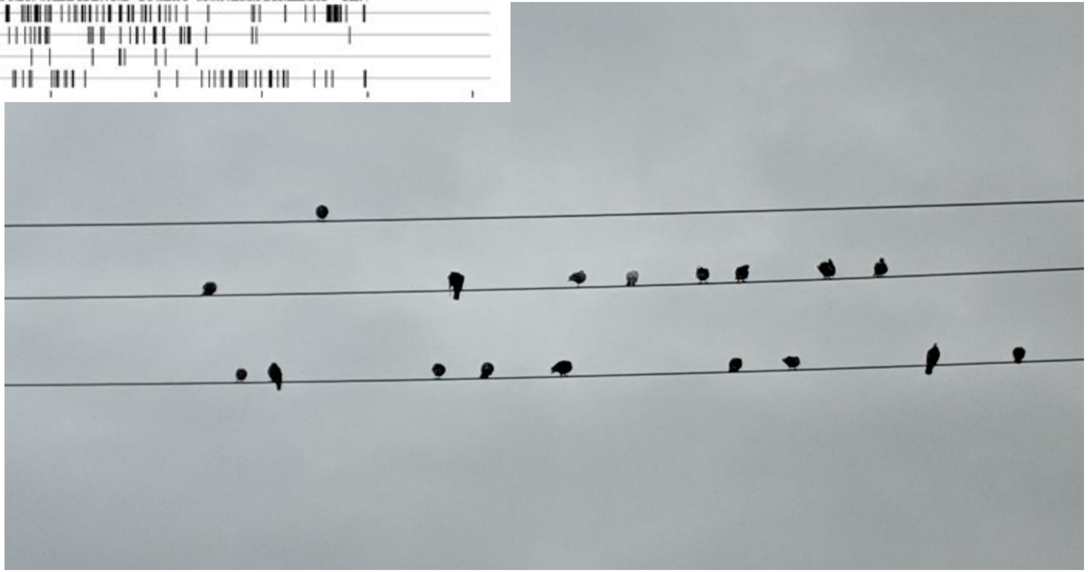


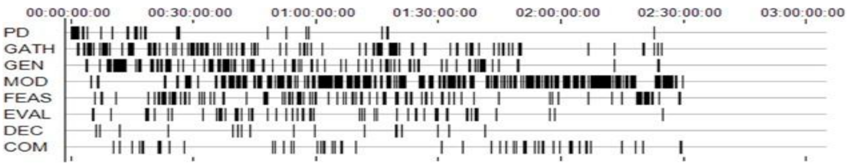
”... the iterative cascade is where the magic happens.”





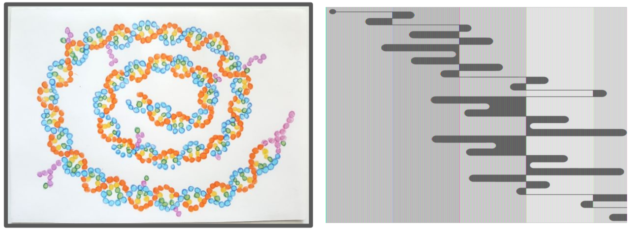
Questions?

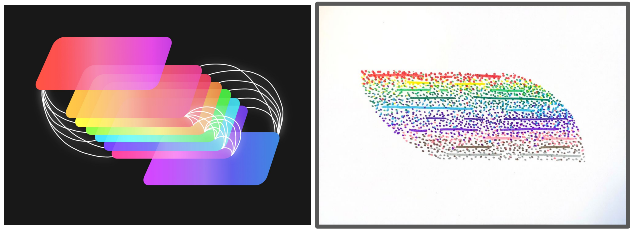
- ▶ Research on design process expertise



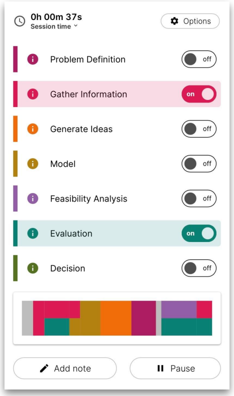
- ▶ Current research on using representations to teach design

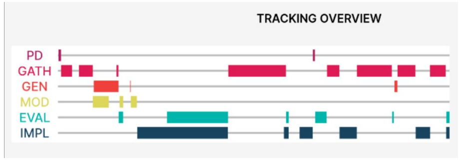
Dear Design Seminar

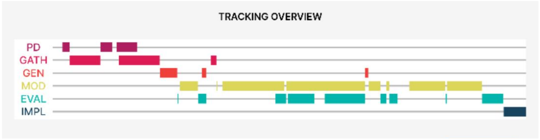


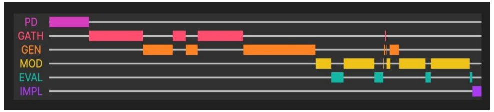


Design Signatures App





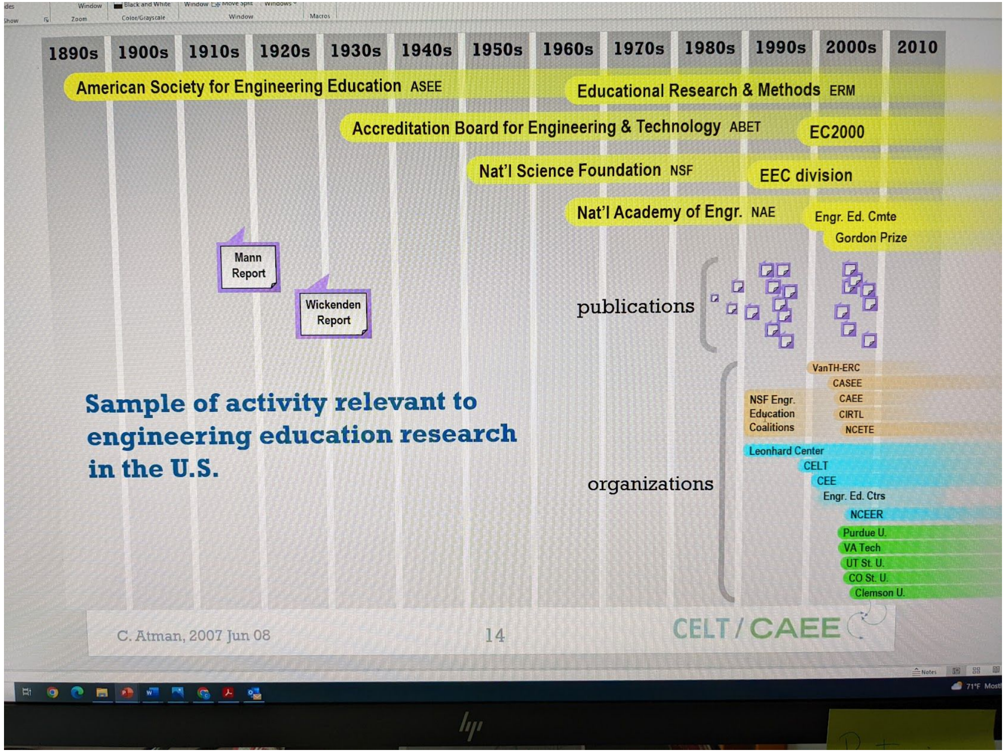




Back-up slides after here

Engineering education & engineering education research

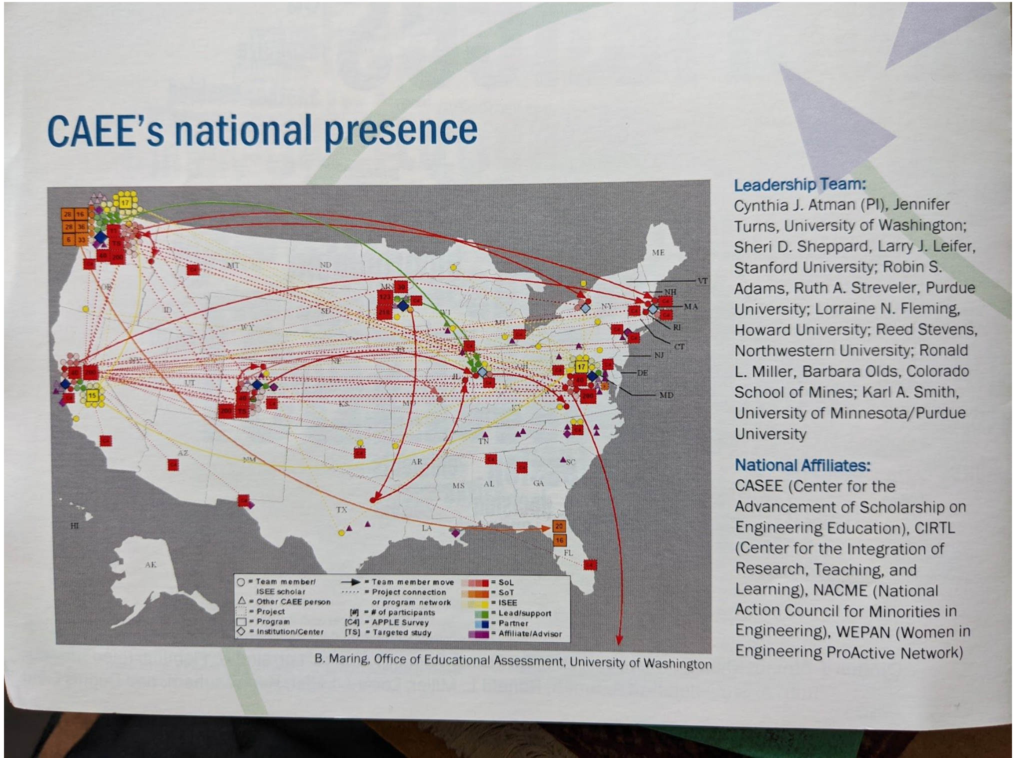
- Snapshot of history



- Resources
  - [Engineering education community resource]
  - [Engineering education pioneers]

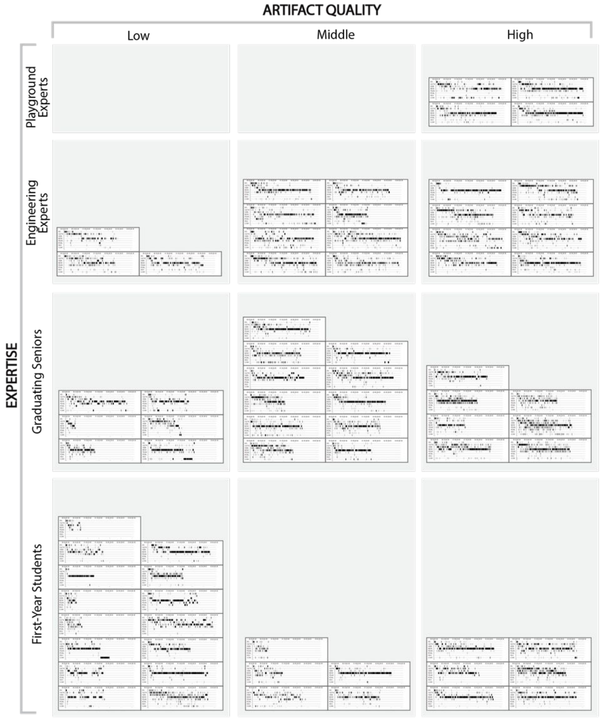
Center for the Advancement of Engineering Education (CAEE)

- Colorado School of Mines, Howard, Stanford, University of Washington
  - Adams, Fleming, Sheppard, Smith, Stevens, Streveler, Turns
- 104 faculty, research staff, graduate students
- $12.2 million, 2003-10



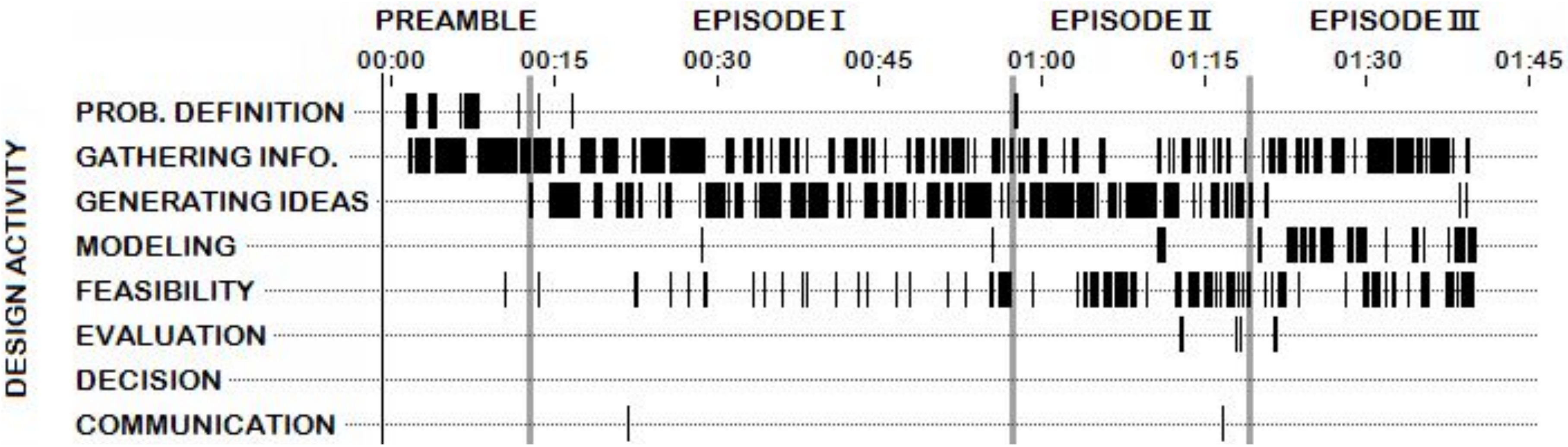
Adding engineering experts

More experience, more complex processes



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

Teams, Design a digital pen (n=1)

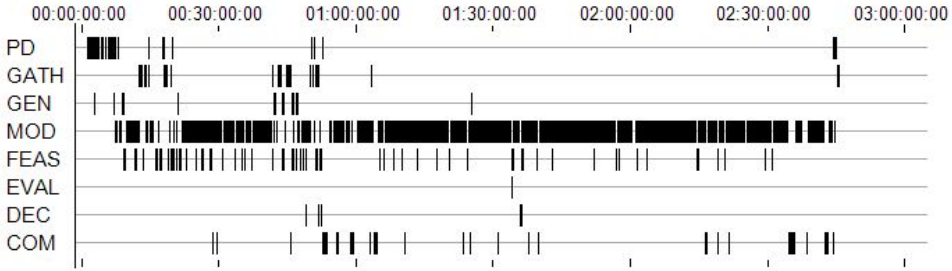


(Atman, Borgford-Parnell, Deibel, Kang, Ng, Kilgore, & Turns, 2009)

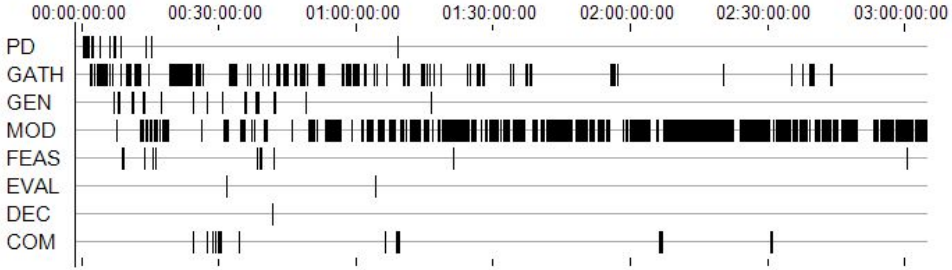
Individuals, Design a playground

- Undergraduate engineering students from a different institution

First-Year
(n=6)



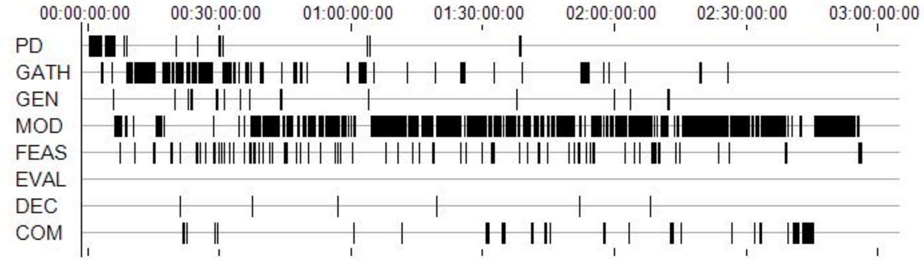
Graduating
Senior
(n=8)



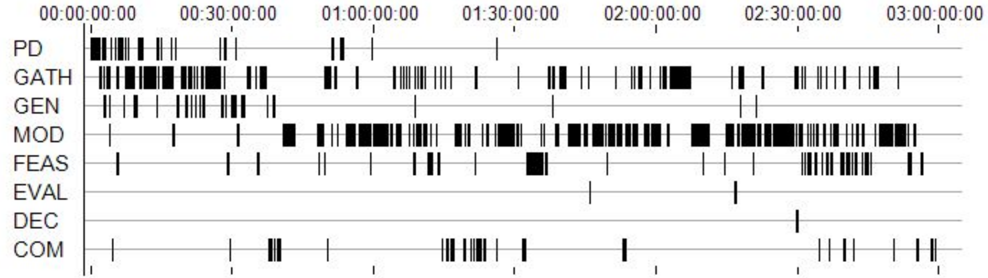
(Deibel, Atman, Saleem, Kang, & Ng, 2007)

Individuals, Design a playground

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



- Engineering faculty (n=4)



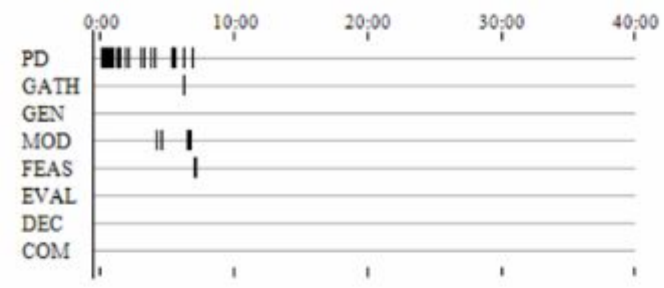
(Atman, Turns, Cardella, & Adams, 2003; Krause, Atman, Borgford-Parnell, & Yasuhara, 2013)

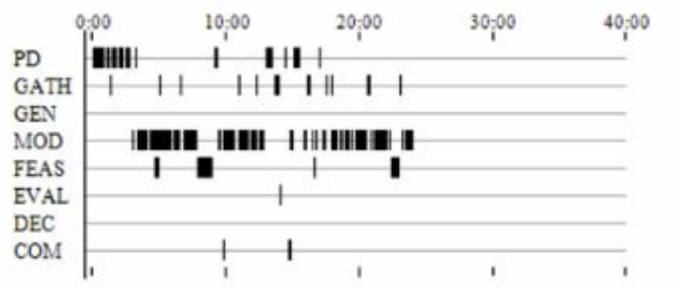
Individuals, Within-subject longitudinal

(n:32 First Year, 61 Graduating; 18 w/in subject)

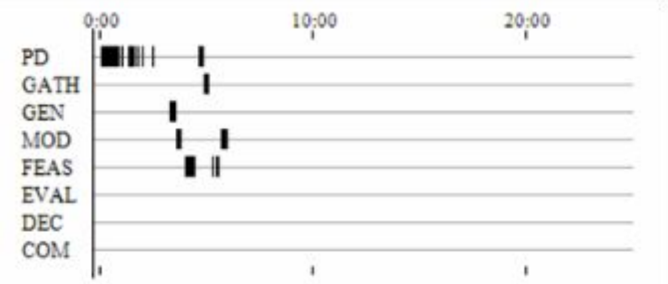
First-Year | **Graduating Senior**

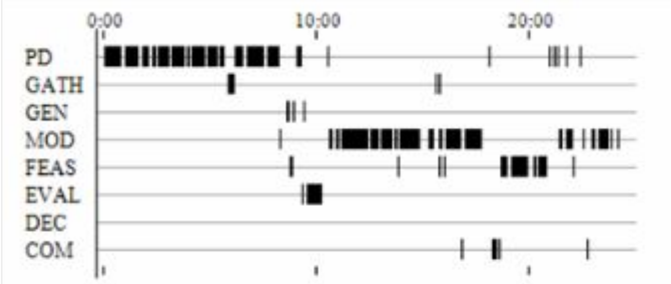
Design a Ping-pong Ball Launcher





Design a Street Crossing System

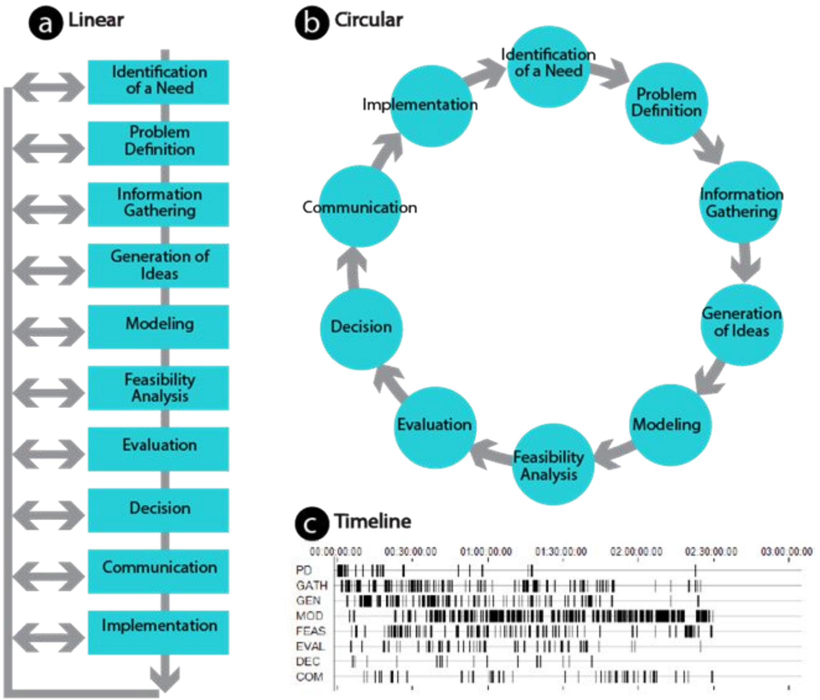




(Cardella, Atman, Turns, & Adams, 2008)

Affordances of timelines - concrete & sticky

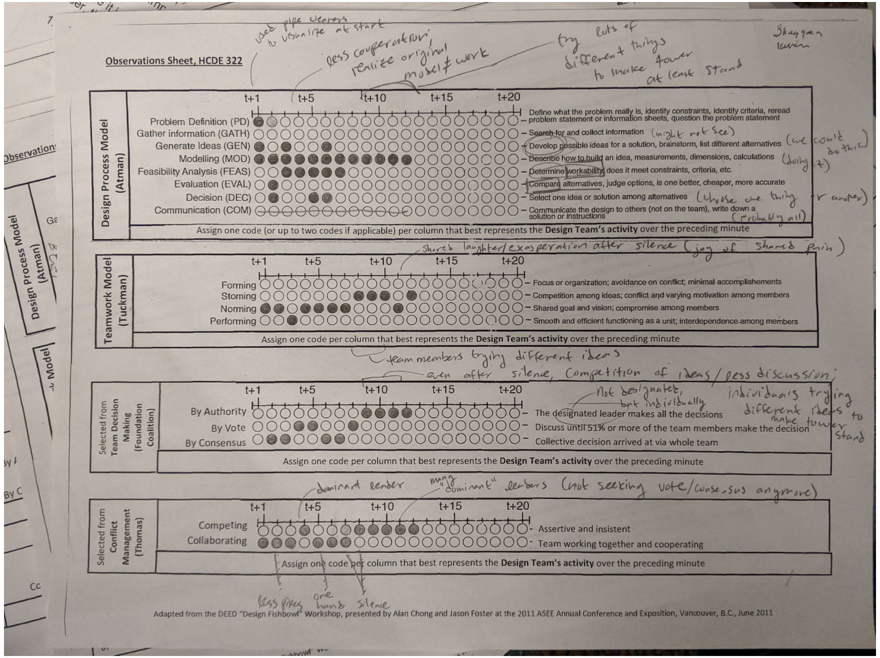
- Specific instance
- Time is explicit
- Abstract concepts made visible
- Grounded in data
- Can personally identify with
- This makes them both
  - concrete
  - sticky

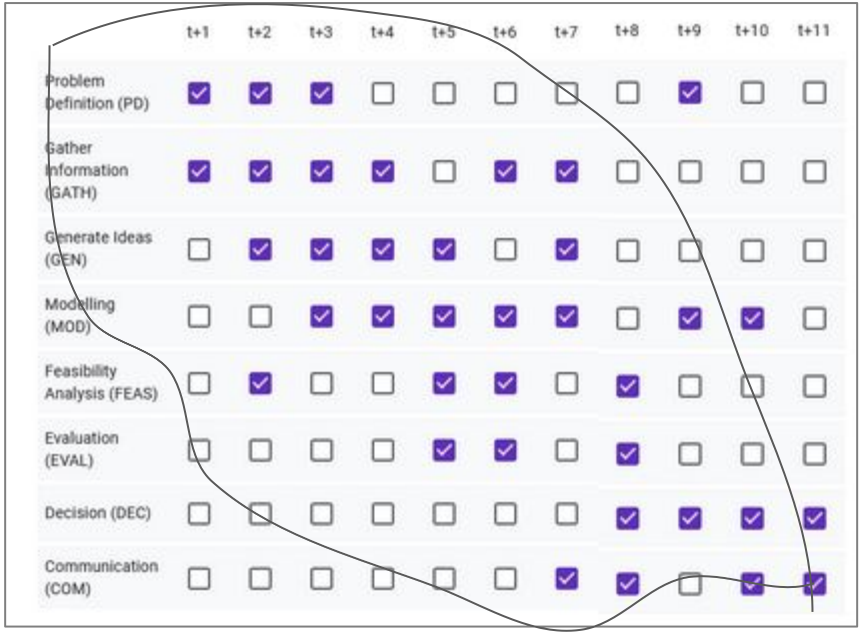


Timelines as teaching tools: Some examples

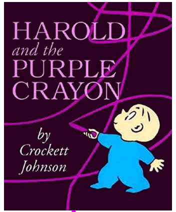
- Classroom exercises
  - Presentations
  - Timeline activities
  - Coding sheet for “fishbowl” design challenge
  - Card sorting task
- Two design briefs (McDonnell & Molhave)
- Dear Design seminars
- Design Signatures App

Classroom activity: coding design challenges





Built on workshop by Chong, Foster & Irish 2011



Teaching with timelines: links to research on learning

- **Make learning personal for learners - motivation matters** [motivation, learning happens in the learner]
  - Time on task is most important predictor for learning (John Anderson)
  - own your own learning [agency]
  - "And he set off on his walk, taking his big purple crayon with him" (Crockett Johnson)

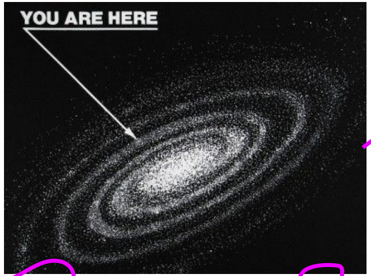
- **Learners come to a situation with a full life already** - honor this and value everyone [prior conceptions]
  - **perspective matters**
    - "Until the lions have their own historians, the history of the hunt belongs to the hunter" (Chinua Achebe)
    - "A bird doesn't sing because it has an answer, it sings because it has a song" (Maya Angelou)
  - context matters
    - "What the hell is water?" (David Foster Wallace)

- **Knowledge organization matters** [mental maps]
  - facts matter, but links are just as important - and links disappear without reinforcement [goal-directed practice]
  - tell people what's coming - advanced organizers
  - [learners make the maps - learning happens in the learner not the teacher]

- Neurons that fire together wire together [goal directed practice]
  - make learning **active**
  - make learning **collaborative**

- Thinking about thinking [self directed learners, metacognition]
  - remember **reflection**
  - synthesize/make meaningful [links back to make learning personal]
  - can lead you into pretzels, but they can be productive sometimes

- Looking across...
  - "We shape clay into a pot, but it is the emptiness inside that holds whatever we want" (Lao Tzu, Tao Te Ching, ch. 11)
  - "Chance favors the prepared mind" (Pasteur)



Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). *How learning works: Seven research-based principles for smart teaching*. John Wiley & Sons.