Lecture 2, Sep 13, 2021

- Two foundational models: modelling Engineering Design and Argument

Models

1. No model is perfect; they're all simplifications that are intended to be **useful**
    - Models are interpretations and simplifications of a broader system and are inherently limited
2. Models are **lenses**; they allow you to see the same situation differently
3. **Some** models are predictive, others are explanatory
    - Not all models are predictive

Model of Engineering

- At its core, engineering happens in reality: 1. The world as it is, 2. The world as I/we create it
    - This is the "trial-and-error" space: e.g. if you want to test a building, you would build it and load it until it breaks
    - Early research and impractical in today's world
    - "Technology"
- In the "theory" space: 1. The world as I/we perceive it, 2. The world as I/we dream it
    - Using science and math, we model the world as it is to form the world as we perceive it
    - When we build the world as we dream it, we turn it into the world we create
    - "Science and math"
- The goal of this course is to iterate between perception and dream, so when we finally build it, we have a tried-and-true solution
- The process starts with the world as it is, models it, produces the design, and the build it
    - There is a back and forth between the model and the design that Praxis focuses on

Arguments

- At our core, engineers **make decisions** and **recommend designs**; to push our designs and decisions, we need arguments
- Toulmin's Structure of Argument
    - Any argument starts with a ground: the reason why we make the argument
    - From the ground, a claim is made; in an ideal world, this directly leads to acceptance
    - Any nontrivial claim requires support: bring in justification and evidence to support the claim, qualifiers to limit the claim
    - Example:
        * Ground: technology exists
        * Claim: technology is not applied science
        * Justification: sometimes technology precedes the science that explains it, so science is not necessary prior to technology (claim could be **challenged and questioned**)
        * Evidence: the Wright brothers were flying before aerodynamics; stream engines came before thermodynamics (argument based on historical example; can be **fact-checked**)
        * Qualifier: the "sometimes"; even though our faculty is "Applied Science and Engineering"
    - The order is not set; e.g. an argument can start with a justification, evidence, etc; but the pieces must exist
    - Next lecture: counterclaims
        * Argument by example is vulnerable to counterexamples
- Spectrum of claims: Ground →Analytical Claim →Interpretive Claim →Speculative Claim →Crazy Idea
    - The further a claim is from the ground, the more evidence and justification it requires to be acceptable
    - Analytical →"what?", interpretive →"so what?", speculative →"what could be?"
- Ways to support claims:

1. Research for facts, for previous designs, codes, standards and guidelines, for approaches and processes, for cognate (similar) concepts and theories
2. Testing, calculating, modelling
3. Sketching, low-fidelity prototyping, proofs of concept

Lecture 3, Sep 14, 2021

Arguments, Continued

- To make an argument an engineering argument, the key change will be in the evidence; the nature of the claim might also change
- Evidence should be testing and not example; testing through standard procedures as set out previously and determined through research
- Claims are made engineering claims when we realize that **opinions are not enough**

Defining Requirements

- Frame $\iff$ Diverge $\iff$ Converge
  - Framing: Understanding the situation (what do we want to do?)
  - Divergence: Come up with ideas, respond to the situation as framed
  - Convergence: Throw away the bad ideas and develop and argument for recommending a specific idea
  - Representations: sketch, model, prototype, report, argument, build, photograph, present, ...
  - There is no starting point or ending point; you start at any point and continue until you have the idea that you want
- How do we select a design?
  - Is this alternative **viable** (what the design should or must not be)? (informed by *constraints*)
  - How does this alternative **measure**? (i.e. how do we measure whether this idea is good or not?) (based on *metrics*)
  - How do these alternatives **compare** (what the design should have more or less)? (informed by *criteria*)
    * Criteria should specify what is better, while metrics specify how to measure quantitatively
    * e.g. a metric might be cost, and a criterion might be lower cost is better
  - All are developed based on **objectives** (what the design should do or be; its function), which are interpreted from **stakeholders** (who impact or are impacted by the design)
    * Is the designer or design team a stakeholder? We are **always** stakeholders, with our own voices, values and biases
    * There needs to be a balance between bringing in what we think and meeting the requirements of the clients
- To codify requirements:
  1. Clarify your intention; e.g. if the client wants the device to be repairable, what does that mean?
  2. Create objectives based on the clarified intentions, through common themes; e.g. repairable →openable without special tools, with few tools, without too much effort and in a reasonable amount of time
  3. Identify metrics: Metrics have two core components: characteristic and unit, and a measurement process
     - e.g. if the driving objective is "I want a backpack that's big enough to carry my school stuff", the characteristic would be volume, and unit could be litres; but in this context just volume is not enough, convenience also matters
     - In selection-style design, alternatives come from pre-existing off-the-shelf designs

Lecture 4, Sep 17, 2021

Requirements Continued

- Problem with constraints: hard to justify (e.g. price under $15 – what happens when the price is $15.25?)
  - Possibly justified by the stakeholder (e.g. the person only has $15), but most often hard to justify because it's somewhat arbitrary
  - In this case, we want a *criterion* instead (e.g. cheaper is better)
- Binary metrics are either yes/no (e.g. above zero/below zero); could also be hard to justify
- When objectives are too complex, it is hard to create metrics and criteria
- Requirements should be continuously refined as the project continues and we get more information
- Engineers need to balance the theoretical ideal and practical reality so that it works for you and is **accepted by your peers**
- Criterion define the relationship between a metric and utility ("goodness"), because for some metrics this relationship can be complicated (a utility curve: linear, parabolic, stepwise, etc)
  - A cut-off in the utility-characteristic graph is basically a constraint
  - Should: Cut-off with tolerance; requires justification
  - Must: Hard cut-off

Logic of Converging

1. Metrics: Need a way to differentiate between things before anything
2. Constraints: If the option is to be thrown away, no need to evaluate it any further
3. Criteria: Compare the remaining option to choose the best one

In the end, the conclusion may be that the constraints are too tight and ruled out all the good options, in which case the constraints may be problematic.

Lecture 5, Sep 20, 2021

- Stakeholder Statement →Objective →Metrics (characteristic, units, how to measure) →Criterion
  - Units need not be overly precise
- Stakeholder statement: "The backpack should have pockets to separate out different things and ensure that your lunch does not make contact with your laptop and so that you can find your pen or power cord easily"
  - Objective: have a range of useful pockets
  - Metric #1: Simple count of pockets, corresponding to a utility curve that looks like a parabola (too few pockets is bad, but too many is also bad)
    - The cut off is fuzzy and requires judgement
    - How do we distinguish between things in the acceptable range?
  - Metric #2: Specific attributes for "useful", e.g. a laptop sleeve, phone holder, pen pocket, etc, maybe with different weights on different things
    - Gets further than the previous metric because it focuses on specific characteristics and allows for differentiating between things more finely

The Role of Research

- What is research?
  1. **Secondary research**: Finding sources for proof, information, processes, "reference designs", and related concepts
     - "Reference design": The design of the same or a similar product that we can refer to and learn from (what worked? what didn't work?)
     - Don't reinvent the wheel
  2. **Primary research**: Testing through experimentation, modelling, surveying or prototyping

3. Discovering something new

Lecture 6, Sep 21, 2021

The Role of Research

- Standards from secondary research allows you to find a process and refine an objective, so primary research such as tests make sense
  - e.g. research pen standards so we know how to test a pen
- The research process:
  1. Start with a useful database, e.g. Google Scholar (not just Google!), and a rough search term
  2. Use findings to learn more
  3. Use more refined (specific or general) terms to find better things and learn even more
  4. Use the library for articles behind paywalls
- Evaluating sources: CRAAP test
  - Currency: The timeliness of the information
    * When was it published? Has it been revised?
  - Relevance: The importance of the information for you needs
  - Authority: Where does the information come from?
    * How credible is the source itself and the people who produced the source? Is it peer reviewed?
  - Accuracy: The reliability, truthfulness, and correctness of the information
    * Look at how often it's been cited, etc
  - Purpose: Why does this information exist?

Lecture 7, Sep 24, 2021

- Engineering vocabulary looks like everyday vocabulary, but some words are used in very specific and precise ways (e.g. usability)
- Three types of appeal: logos (pure reason), pathos (emotional connection), and ethos (trust in persona)
  - Logos is used in requirements through the basic facts
  - Ethos is used in requirements through research (trust in research); our ethos is built through trusting the right authority

Lecture 8, Sep 27, 2021

Studying for the Midterm

- Concept map? Read provided materials
- Important concepts:
  - Frame Diverge Converge Represent model
  - Toulmin argument model
  - Requirements model

Framing

- Framing takes us from the situation and stakeholders to opportunity expressed in requirements (the world as it is to the world as we represent it)
- The processing of framing:
  1. Stakeholder Analysis
     - *Stakeholder*: An individual, group of people, organization or other entity that has a direct or indirect interest (or stake) in a system (could be advantaged or disadvantaged)
     - Stakeholders are major sources for requirements
     - Engaging with stakeholders:

        * Asking them questions and interviewing them, or simply observing how they behave
        * Codes/standards that you incorporate used to engage them
        * By engaging with stakeholders, we can validate our understanding of their interests
    - There are many ways to explore and clarify intentions, and handbooks are a good way to do this
    - Some stakeholders cannot directly express their interest, e.g. pets or the environment, and they're often disadvantaged; we have to interpret their interest through research and engagement
    - Model:
        * Perceive $\rightarrow$Interpret $\rightarrow$Assess $\rightarrow$Act
        * Interpret: Apply models and possible meanings
        * Assess: Determine the most appropriate interpretation
        * Need to check our interpretations to make sure they accurately reflect the interests of the stakeholder
    - Scoping defines the boundaries of what is and what is not in consideration
        * The bigger the scope, the more complex your requirements, so getting the right scope is important
2. Perspective Taking
    - Design for X
    - Understanding our Values
    - Integrating Perspectives
3. Defining an Opportunity
    - Entrepreneurship!
4. Developing Requirements

Lecture 9, Sep 28, 2021

Scoping

- Scoping fits into framing as a whole
- Framing is the orientation, perspective, lens/filter
- Scoping is the boundary, size and level of abstraction
- Framing asks the question of "How am I perceiving this?"
- Scoping asks the question of "What am I considering?"

Designing for X

- Designing for X (DfX) is one "lens" to narrow the scope
- Create a scoping diagram:
    - Will be included/considered:
        * These are absolutely critical
    - Should be included/considered:
    - Won't be included/considered (unless forced):
        * These do not matter
- Key things to consider/design for: SUMA: Safety, Usability, Manufacturing & Assembly, Accessibility
    - Designing for Safety:
        * Eliminate: "Design out" the hazard
        * Mitigate: Design in safety devices: things that allow the device to be safe even when things are going wrong
        * Warn: Design in warning devices: things that make it evident when things are going wrong
        * Train: Design special procedures and training
    - Designing for Usability:
        * Usability involves testing using a consistent methodology; without testing we can't say that something is usable

        * The people tested on should be a sample of representative users
        * Sample representative users, sample representative tasks, follow standard procedures
        * Use handbook resources to find the appropriate things to test for
        * Usability generally does not require a large number of test subjects
    - Designing for Accessibility
        1. Physical accessibility is easy to measure
        2. Cognitive accessibility has metrics that can also be measured (e.g. usability)
        3. Accessibility is becoming more important and even mandatory

Lecture 10, Oct 1, 2021

What is Culture?

- An ensemble of structures, practices, and convention which individuals reproduce or transform but would not exist unless they did so (Bhashar, 1998: p. 36)
- Humility: To have an accurate opinion of yourself, to keep your accomplishments and abilities in perspective; to be free from arrogance **and** low self-esteem
- Culture Humility: the process of accepting that we do not know what it's like to be someone else and live as them, but at the same time be willing to engage in conversations that allow us to learn
- Engage with stakeholders and understand the way they see the problem

Test Prep: Kolb's Experimental Learning Cycle

- The cycle consists of 4 stages and can start at any stage
    1. Experiencing: Concrete experience
        - Learn from doing
    2. Watching: Reflection and observation
        - Step back and reflect on what you did
        - Compare and contrast different ways of doing a thing
    3. Thinking: Abstraction and Generalization
        - From observations create models and generalize
    4. Trying: Hypothesizing and Testing
        - Experimentation and trying something new
- Different people have different preferences:
    1. Diverger: Experiencing to watching
    2. Assimilator: Watching to thinking
    3. Converger: Thinking to trying
    4. Accomodator: Trying to experiencing

Lecture 13, Oct 8, 2021

Types of Design

1. Conceptual Design: Rough initial ideas
    - e.g. What type of bridge do we want? Suspension, truss, etc
2. Embodiment Design: Specify details, prototypes
    - Hit the reference designs, guidelines, handbooks, etc
3. Detailed Design: Specific details
    - e.g. What specific fastener should we use?
    - Figure out every single little component, and step right into production
4. (Sometimes) Production (Re)design
    - "Make it work in *our context* with our materials, peoples, etc"

Possible Ways to Frame

- There are many ways to frame the same problem:
  1. Design for the behaviour
  2. Design out of the behaviour
  3. Change the interaction between user and object
  4. Question the concept of the object
- Reference designs help you decide which way of framing is more opportunistic

Design Briefs

- The design brief answers:
  - Am I able to resolve it? (at what design level)
  - What is the need for it? Is it worth my time?
  - Has it already been solved? (reference designs)
  - What does success look like? (requirements)
  - How can I approach it? (which framing is in scope)
- What is the opportunity? (Purpose)
  - What is the observed behaviour? (Background)
  - Why is it interesting or worth pursuing? (Justification)
  - What do we have to go on? (Background)
  - What has been done before? (Reference Designs)
  - Who cares? (Stakeholders)

Lecture 18, Oct 22, 2021

Prototyping

- Prototyping: A model whose purpose is to generate or communicate information about **a design concept**
- Types of prototype:
  1. Functional prototype: Communicate specifically how one or more of its elements **accomplishes a task**
     - Does not have to have everything, can simply show one feature
  2. Scale prototype: Will this fit? Communicate specifically the size, orientation, organization, etc
  3. Graphical prototype: Communicate through the medium of drawings, sketches, renderings, etc
  4. Mathematical prototype: Ensure designs are feasible using math
  5. Simulation prototype: How does it behave over time?
- Questions to ask:
  - What information is it intended to communicate?
  - What information is it intended to generate?
  - What aspects of the design concept is it focusing on?
  - How does it integrate with all of the other prototypes?
- Prototype the stuff that's the most unbelievable/does not already exist
  - Consider your audience but don't give them too much credit for prior knowledge
- Prototypes are for others *and* yourself (**build to think**); answer your own questions
- Prototypes don't have to be perfect or look good or be complete; focus on the critical parts
- Prototypes crystallize your thinking and express ideas effectively, even if the prototype is very crude
  - Use representations to enable progress

Lecture 20, Oct 26, 2021

SCAMPER

- SCAMPER works best from a Morph Chart, or at least a deconstructed reference design; instead of aspects think of actions that a design needs to do
- SCAMPER is for building on existing designs
- SCAM:
  - Substitute: Are there approaches that should be substituted for others in this design? What if we changed ?
    - Acknowledge that an existing approach can do two things
  - Combine: Are there actions/aspects that should be combined into one approach?
    - Collapses multiple rows of the morph chart into one
  - Adapt: Are there approaches that could be adapted to address other aspects/actions?
    - Same but opposite direction as combine
    - Change one approach to make it work for two actions
  - Modify/Magnify/Minimize: If you select a specific approach and emphasize it (change the focus), what effect will it have on the other aspects/actions?
- PER:
  - Put to other uses: What else can these approaches do that's unrelated to what we're trying to do? How might that change what is created?
  - Eliminate: What if an action/aspect wasn't necessary? What if a constraint wasn't present?
    - If the problem is overconstrained, this can be helpful in opening it up
    - Can also be used to shave redundant features
    - Removes a row of the morph chart entirely
  - Reverse/Rearrange: What if aspects/actions were completed in a different order?

Lecture 24, Nov 5, 2021

Feedback Stages

1. Framing feedback – start to understand the purpose
   - AID model to structure feedback:
     1. Action: What did they do? Not your judgement or thoughts, but specific examples of the behaviour.
     2. Impact: How did this impact the team or yourself?
     3. Development/Desired outcome: What do you want them to do to improve their actions?
2. Delivering feedback for review
3. Receiving feedback
4. Acting on feedback to improve performance

Giving Useful Negative Feedback

- Critique, unlike criticism, needs to be reasoned, systematic, and consist of argument and discussion
- Focus on growth

Lecture 26, Nov 16, 2021

Convergence

- The result of convergence is a single recommendation of the best design
- Key concepts:
  - Verification: How have you verified that your design is the best? Does the recommended design meet the requirements?

        * Show multiple concepts and show that you've gone through a rigorous process of comparison
        * Must meet the requirements
        * Validation: Taking a recommendation back to the stakeholders and asking does it meet their needs?
            - This verifies that your requirements are good in the first place
    - Prototyping and Research
    - Measuring and Comparing
    - Proxy Testing
    - Recommending a Design
- The design critique is a 5 minute presentation followed by 7 minutes of question and answer
    - Every member must speak for the presentation
    - Must demonstrate that you've compared the recommended design against at least 3 other credible candidate design concepts (things that could work but not as good)
        * Not necessarily the same as ones in alpha
        * Every concept must have a prototype
- Critical metrics should have consistent measuring processes
- Converging to a recommended design:
    1. Acknowledge that your preconceived idea of "best" may not be actually the best
        - Look at designs critically and don't be biased in your measurement process
    2. Figure out why exactly you think those ideas are "best", so you can codify these implicit criteria to better understand the requirements
    3. Gather data (measurement or research) to enable verification
        - What can I prototype? What do I need research for?
    4. Systematically compare the designs to determine whether they should remain candidates
        - Especially when the candidates are best in different aspects
    5. Eliminate some designs, refine some designs, refine the requirements and return to step 2
        - The outcome of convergence may be that there is no appropriate design that meets the requirements
        - Use your own judgement!

Pairwise Comparison Matrices

- Codifying your biases and turning them into requirements
- Compare two candidates at a time, determine which is better, and do this across all candidate pairs to make a matrix of comparisons
- Two ways:
    1. Pick a specific requirement and compare based on just this alone
        - Approximate the utility curve, and use it and the metric measurements to compare two designs
        - In the end in each cell is either a 1 or a 0 – the design is either better or worse
    2. Compare holistically as a design
        - Think about things as a whole
        - Talk out loud or take notes so you're concious about what you're thinking
        - Designate two champions that argue for each design and a recorder and run a pairwise comparison of the alternatives
            * The things that come out during this argument are noted and checked
            * The recorder marks down the characteristics that are being mentioned
- After marking down all the cells, sum up the "wins" for each design and pick out the ones with more wins
    - Review the ones that have very little wins and think about why: Did we consider all the requirements? Why was this idea included in the first place?

Measurement Matrices

- Compute measurements according to metrics for each candidate

- Think about the precision needed to enable comparison – don't spend time measuring them too precisely if that's not useful
- Measurements can be absolute or relative; if it's too hard to measure absolutely just figure out which design measures better
- The points of these is to enable comparison for selection, not to actually evaluate them in the real world

Lecture 27, Nov 19, 2021

Gathering Data

1. Conduct research:
   - Selection-style embodiment design decisions (reference designs, key features)
   - Determining the feasibility and whether the technology exists already
   - Critical metrics from research:
     - Material properties (mechanical, chemical, etc)
     - Production cost
2. Perform calculations:
   - Decisions that you can answer with your civ or physics knowledge
   - Deformation, bending, loading, response
   - These things cannot be tested because we do not have access to the variables
3. Develop and test prototypes using protocols
   - Proxy testing!

Proxy Testing

- Make sure you have a consistent and repeatable test protocol
- Prototypes are the input to a measurement process that produces a measurement that can be used for comparison
- Conducting tests:
  1. Determine the characteristic you wan to assess
  2. Look up standards about how to run these tests
  3. Develop a proxy test protocol that works for what you have
  4. Conduct your tests and gather comparable data
     - You don't need standard units, as long as the measurements enable comparison it's good enough

Lecture 28, Nov 22, 2021

Comparison Matrices/Pugh Charts

- Pairwise comparisons across all different metrics, relative to a single reference alternative/benchmark
  - Change reference if it doesn't tell you much, e.g. if for a particular critical metric, one alternative is worse than all others, then using that alternative is a bad benchmark
- Columns are alternatives and rows are metrics
- Each entry is whether the alternative is better than the benchmark or worse for that specific metric
- At the end of it, argue for the recommended alternative in words; the matrix does not tell you what the best alternative is
  - Think about "what do I do next"?
    * Change reference design
    * Reconsider whether metrics are useful
    * Re-divergence
    * Analyze patterns for linked metrics
    * Look at metrics that are weighted more and figure out if they can be broken down
    * Look at metrics that are weighted less and figure out why they're there

- Don't sum up the table
- Decision making tools are representations of your candidates that enable comparison

Lecture 29, Nov 23, 2021

Requirements for Design Critique

1. Justify "best" concept
    - Should evoke the reaction of "I believe in this design", or "I know why I should not believe in this design"
    - If the final design doesn't satisfy the objectives, it's still a legitimate conclusion to have, you just have to say why, and still identify the one that sucks least
    - Needs sufficient embodiment work (critical components have been developed enough to demonstrate that the concept is workable)
    - Needs detailed design in some areas so critical decisions can be made because the details are known
2. Demonstrate sufficient verification
    - Detailed objectives:
        1. Prototypes for all 4
            1. Prototypes need to all have specific purposes
        2. Measurements for every metric
        3. Need comparison matrices (use as base)
        4. Everyone needs to be on the same page
        5. Simple reasons why we did what we did
    - Required:
        - Need concepts to test, need measurements to take
        - If we have very diverse ideas, some designs might not have measurements for some metrics

Problem Solution Structure

1. Describe the situation from which the problem emerges
2. Isolate the problem (design brief)
    - This part is already done, so keep it short
3. Explain the solutions
4. Evaluate the solution
    - Research
    - Testing
        - For each, identify what you have learned and what you hope to learn from it
    - Prototypes
        - For each, identify what you have learned and what you hope to learn from it
    - "Candidate A is better than Candidate B
        - … in part because of *this criterion* that allows us to compare *these measurements* we made
        - … by using *these prototypes* as inputs to *this measurement process*
        - … which has *this unit* and focuses on *this characteristic*
        - … which relates to *these objectives*
        - … which we elicited from *these stakeholders*"
            * Confidence is limited to the confidence level of the prototypes

Presentation Storyboard

1. Find your highlight point
    - What does your audience care about?
    - This could be the best design or why the designs don't work
        - The final design
        - A critical test that gives you confidence

    - A key relationship to a reference design or research
    - An aspect of your process or decision making
    - The most unbelievable point
  - Don't make it a mystery
  - Focus on your degree of confidence
  - Watch teammates for things that make you say "we have to talk about that next week"
  - Record all your activities!
2. Create a rough outline
3. Remove anything weak
   - Don't need too much story or detail on things that don't matter
4. Create the learning arc/refined outline
   - How will the audience get to the highlight?
5. Sketch slides
6. Build slides
7. Practice and refine

Presentation Tips

1. Be ruthless about time control
2. Start with a substantive overview
   - Talk about what you're going to talk about
3. Make meaningful hand-offs
   - Introduce the next person that's speaking and say what they'll be speaking
4. Focus, even when you're not speaking
5. Support the speaker