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Prototyping for Capstone Design

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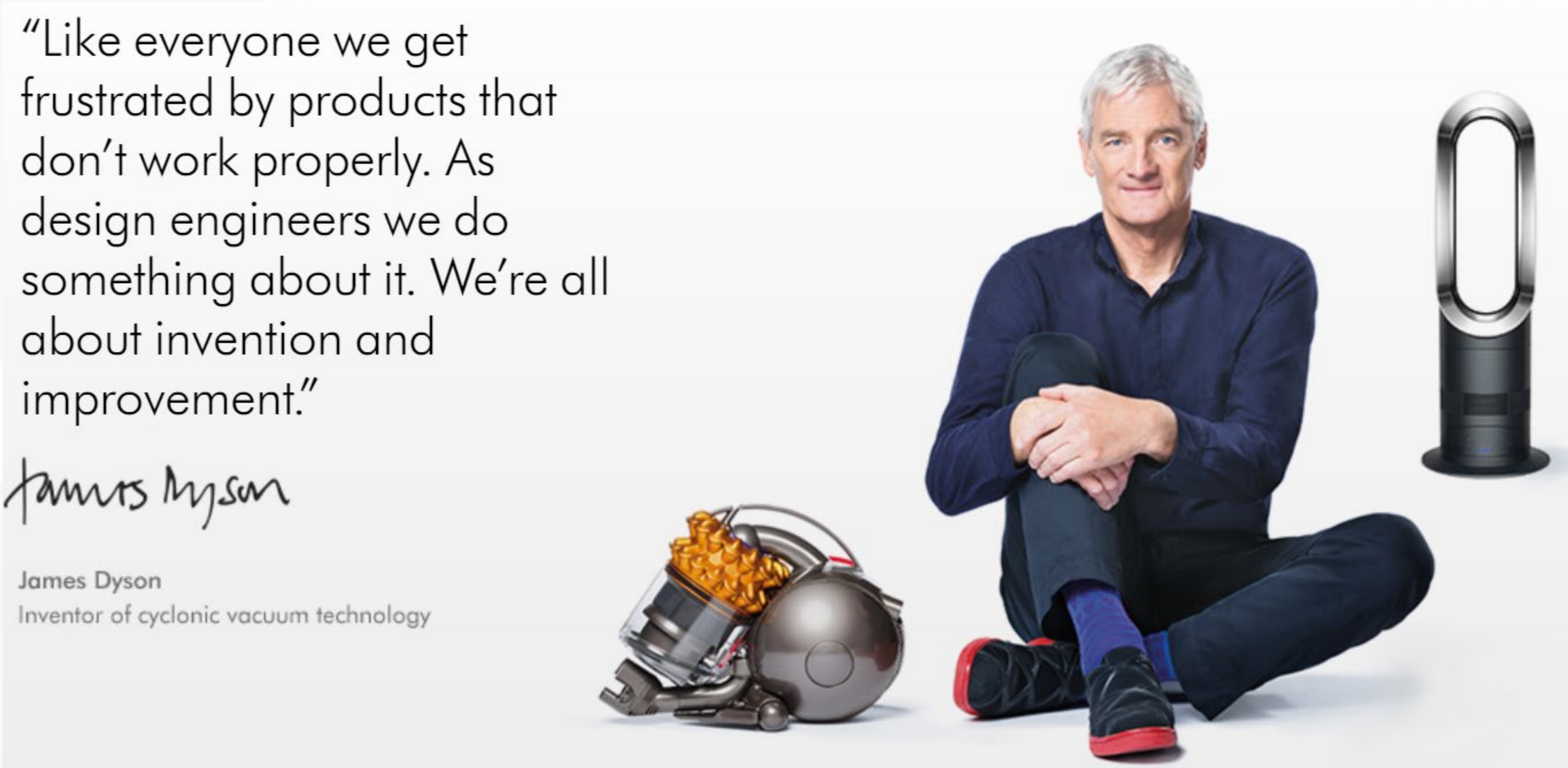
Date: 06/01/2020

http://popin.it/**vbf6wp**

Acknowledgements to Veronica Spencer (BSME, MSID 2019)

Story of an Inventor



http://Dyson.com/

Story of an Inventor

Passion + Inspiration

“I made 5,127 prototypes of my vacuum (over 15 years) before I got it right. There were 5,126 failures. But I learned from each one. That’s how I came up with a solution. So I don’t mind failure.”

“By 2,627, my wife and I were really counting our pennies,… By 3,727, my wife was giving art lessons for some extra cash.”

- James Dyson

http://www.dennyyou.com/2018/06/04/james-dysons-5217-prototypes-before-he-invent-first-cyclone-vacuum-cleaner-dc01/

Story of an Inventor

Dyson Automotive update 10th October 2019

"The Dyson Automotive team have developed a fantastic car; they have been ingenious in their approach while remaining faithful to our philosophies. However, though we have tried very hard throughout the development process, we simply cannot make it commercially viable. We have been through a serious process to find a buyer for the project which has, unfortunately, been unsuccessful so far. I wanted you to hear directly from me that the Dyson Board has therefore taken the very difficult decision to propose the closure of our automotive project.

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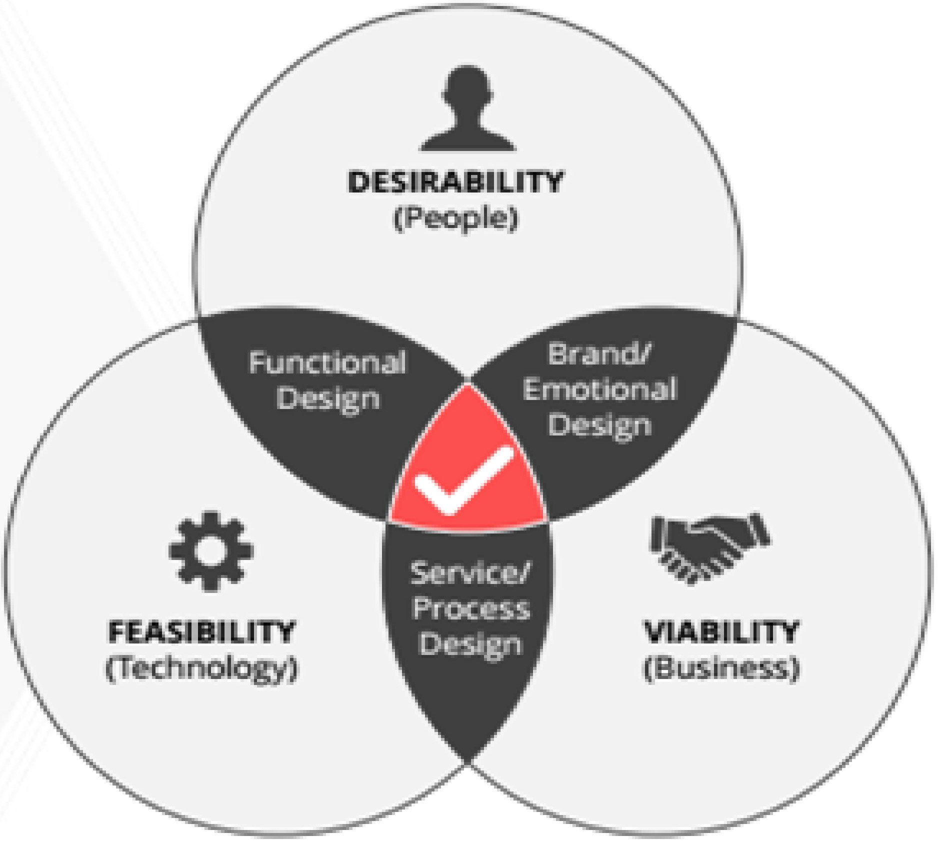
http://Dyson.com/
https://www.engadget.com/dysons-electric-car-n526-085341772.html

Invention v/s Innovation

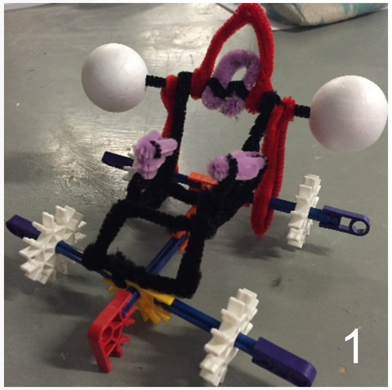


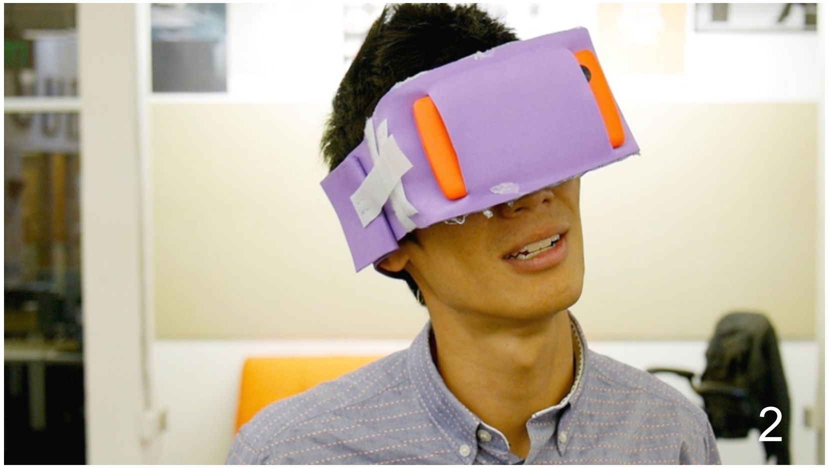
https://gomedici.com/design-thinking-global-business-landscape-research-report-by-medici/

Learning Outcomes

- What is a Prototype?
- Prototyping in Design
- Why to prototype?
- How to prototype?
- When not to prototype?
- Difference between prototype and product

Are these Prototypes?





Yes, they can be simple!

Are these Prototypes?

Yes, they can be sophisticated

Discussion

?

1. Are the items shown on the left considered a prototype for the Excavator shown on the right?

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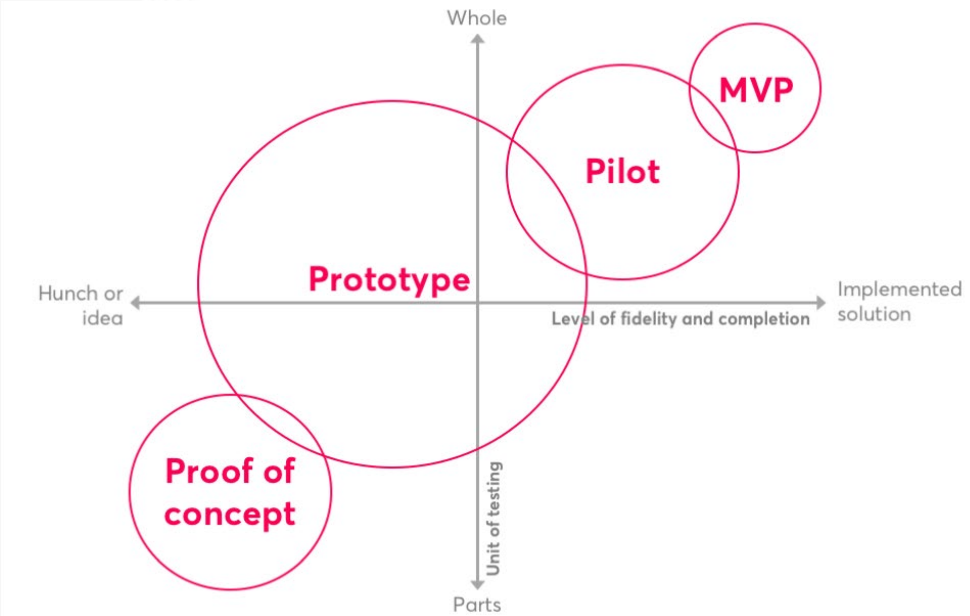
What is a Prototype?

A design representation of some aspect such as form/fit or function of a design

Prototypes can be classified as a stage of the design process; they can also be described as a tool to further product development.

Demystifying Terms (*from Wikipedia*)

- **P**roof **O**f **C**oncept – A realization of a certain method or idea in order to demonstrate its feasibility or a demonstration in principle with the aim of verifying that some concept or theory has practical potential
- **P**rototype - An early sample, model, or release of a product built to test a concept or process
- **M**inimum **V**iable **P**roduct – A product with just enough features to satisfy early customers and to provide feedback for future product development



https://www.nesta.org.uk/blog/proof-of-concept-prototype-pilot-mvp-whats-in-a-name/

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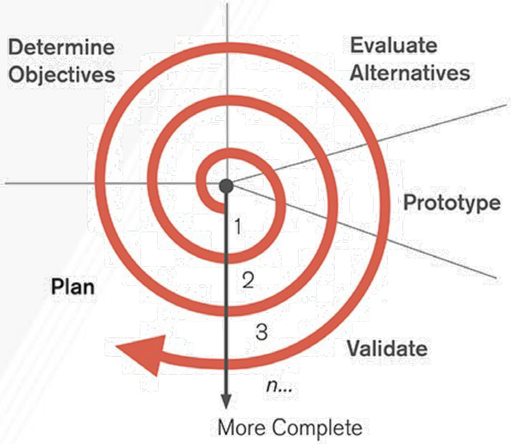
What causes design failures?

- Failure to understand user needs (NO Desirability)
  - “Discover” the customer
  - Identify Functional Requirements (FR)
  - Develop Design Specifications
- Failure to perform (NO Feasibility)
  - Solution fails in service
  - Not enough analysis or testing
- Failure to realize (NO Viability)
  - High cost
  - Not practical to manufacture

Segue into project processes

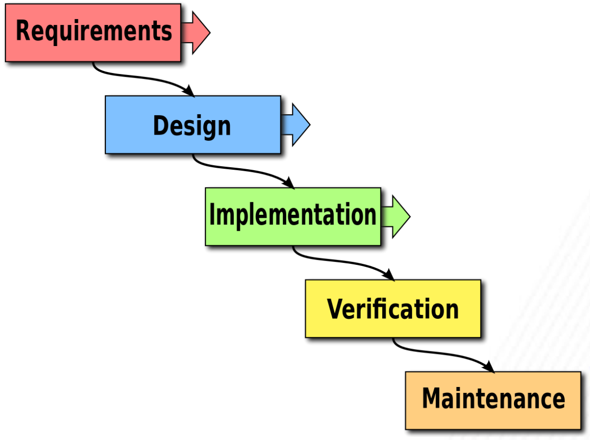
- Agile
  - Focused on refinement through iteration
  - More qualitative
  - Classically associated with Industrial Design
  - Find WHAT to build

  - Typically for Consumer Product



- Waterfall
  - Focused on risk evaluation
  - More quantitative
  - Classically associated with Engineering
  - Know what to build

  - Typically for defense/B2B products



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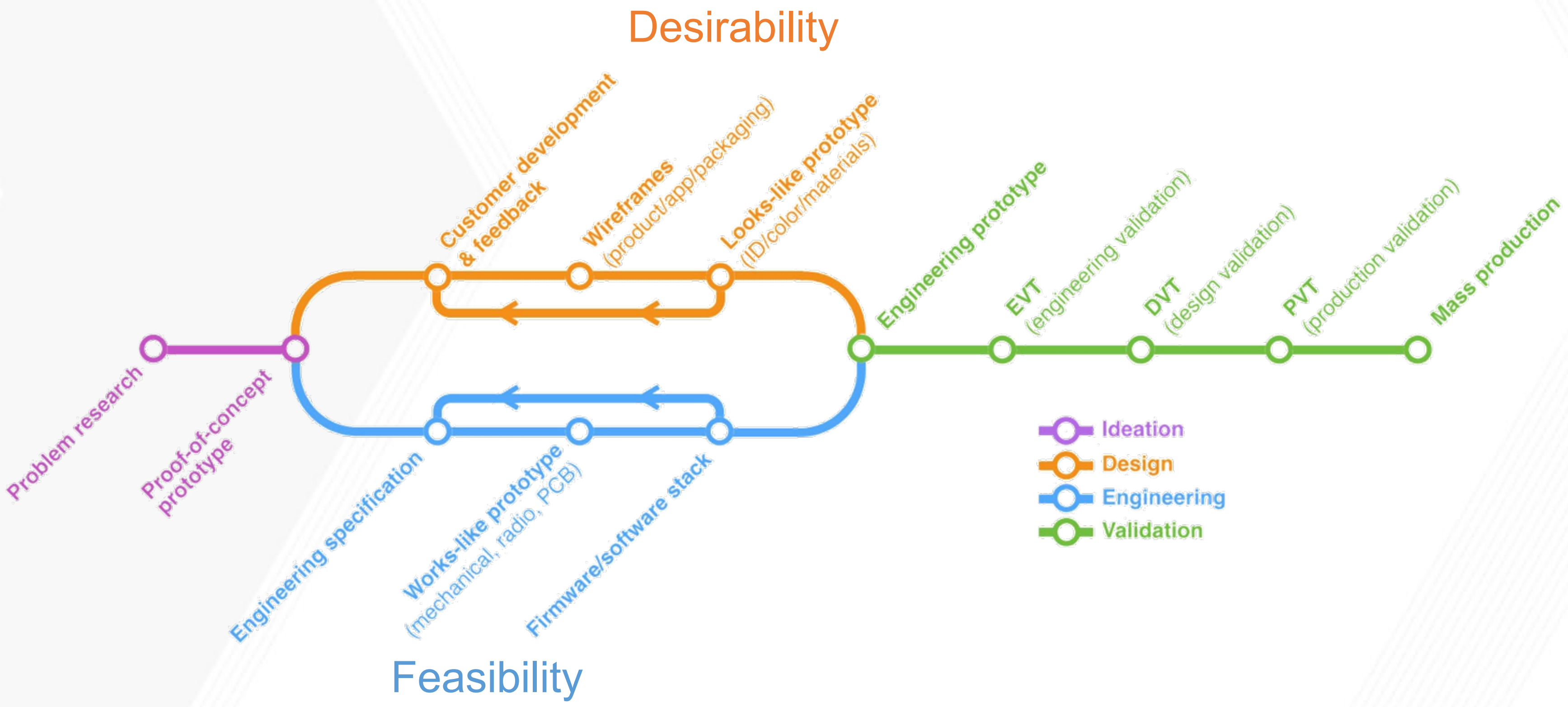
Typical hardware product design process

- Combination of several iterations within a waterfall framework



https://blog.bolt.io/ideation/

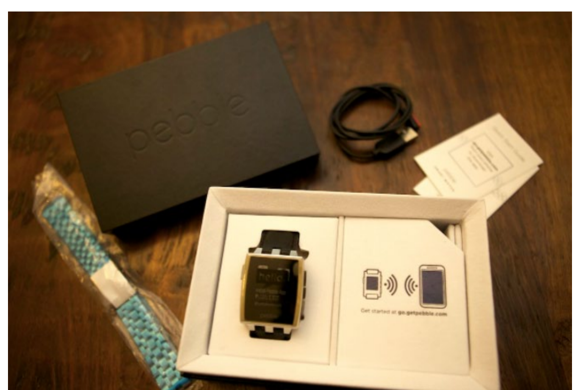
Functional types of Prototype - Example

- ***Looks-like*** *(Desirability)*

  Focuses on the look, feel, form, and aesthetics of the product.

- ***Works-like*** *(Feasibility)*

  Demonstrates functionality and ensures technical challenges are resolved



Courtesy: Scott Miller

Discussion

2. What type of prototype should you have for your Capstone Design project?

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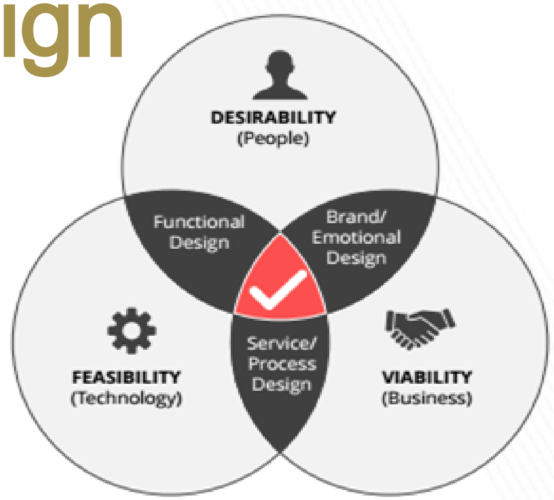
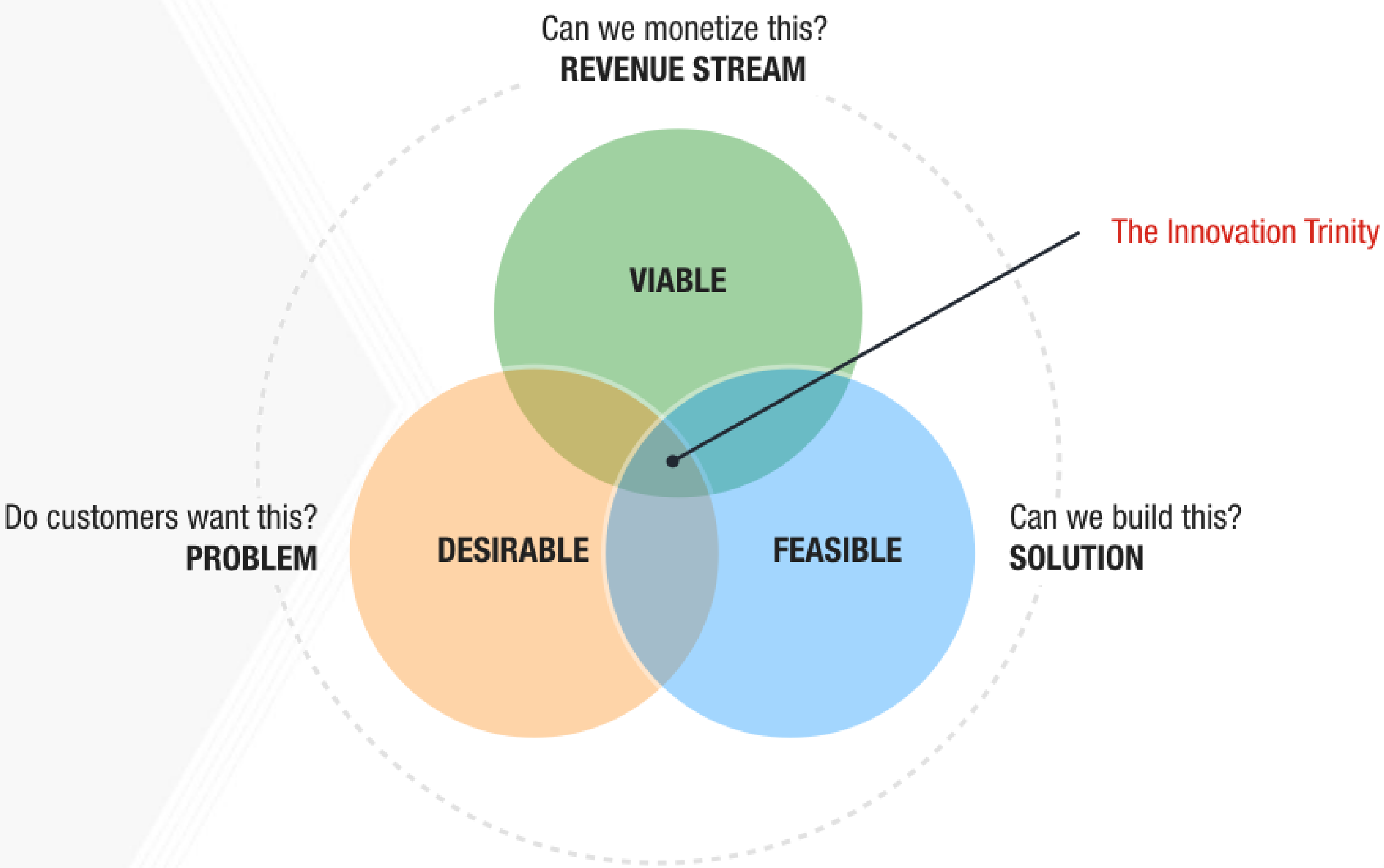
Prototypes reduce risk in Design



- A risk is a possibility that could significantly impact the success of the project if it occurs
- Desirability
  - Missing key requirements and preferences that impact end-user
- Feasibility
  - Solution fails to meet desired functionality, performance
- Viability
  - End product is too expensive or difficult to manufacture
  - Misses overall timeline

Quick reminder about Innovation



Modification from IDEO's Innovation Framework

https://blog.leanstack.com/lean-startup-or-business-model-design-or-design-thinking-is-the-wrong-question-f84216fad869

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Prototyping through Innovation Framework

- **Context**: ACME Tool company has a product family of 18V cordless drills, saws and sanders that have been very successful in the consumer market. Their marketing department recommends expanding the product line to include cordless handheld vacuum.

Desirability	Feasibility	Viability
Need: Design and build a prototype of a handheld vacuum. ***Your prototype should focus on solving a customer need and you should work to create a positive customer experience.***	**Need:** Design and build a prototype of a handheld vacuum. ***Your prototype should focus on solving a key issue in functionality or technical feasibility.***	**Need:** Design and build a prototype of a handheld vacuum. ***Your prototype should focus on creating an economically viable solution that is ready for mass manufacture.***
Goal: A jury consisting of corporate executives, typical customers and investors will judge your design based on ***its aesthetics, ergonomics, and general appeal to consumers.***	**Goal:** A jury consisting of corporate executives, typical customers and investors will judge your design based on ***its performance, functions, and features.***	**Goal:** A jury consisting of corporate executives, typical customers and investors will judge your design based on economic potential, predicted assembly cost, and ***its ability to be successfully mass manufactured.***

Menold, Jessica, Kathryn Jablokow, and Timothy Simpson. "Prototype for X (PFX): A holistic framework for structuring prototyping methods to support engineering design." *Design Studies* 50 (2017): 70-112.

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Discussion

3. How many prototypes would you have to build for your Capstone Design project?

4. Why do designers prototype?

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Why Prototype? Prototyping Outcomes

1. Refine ideas
   - Clarify requirements
   - Identify potential performance increases
   - Identify mistakes and failure modes
   - Reduce risks early

2. Communicate
   - Observe or experience use and user needs
   - Discuss with stakeholders

3. Explore ideas
   - Test multiple concepts
   - Gather information about the design space
   - Ideation tool

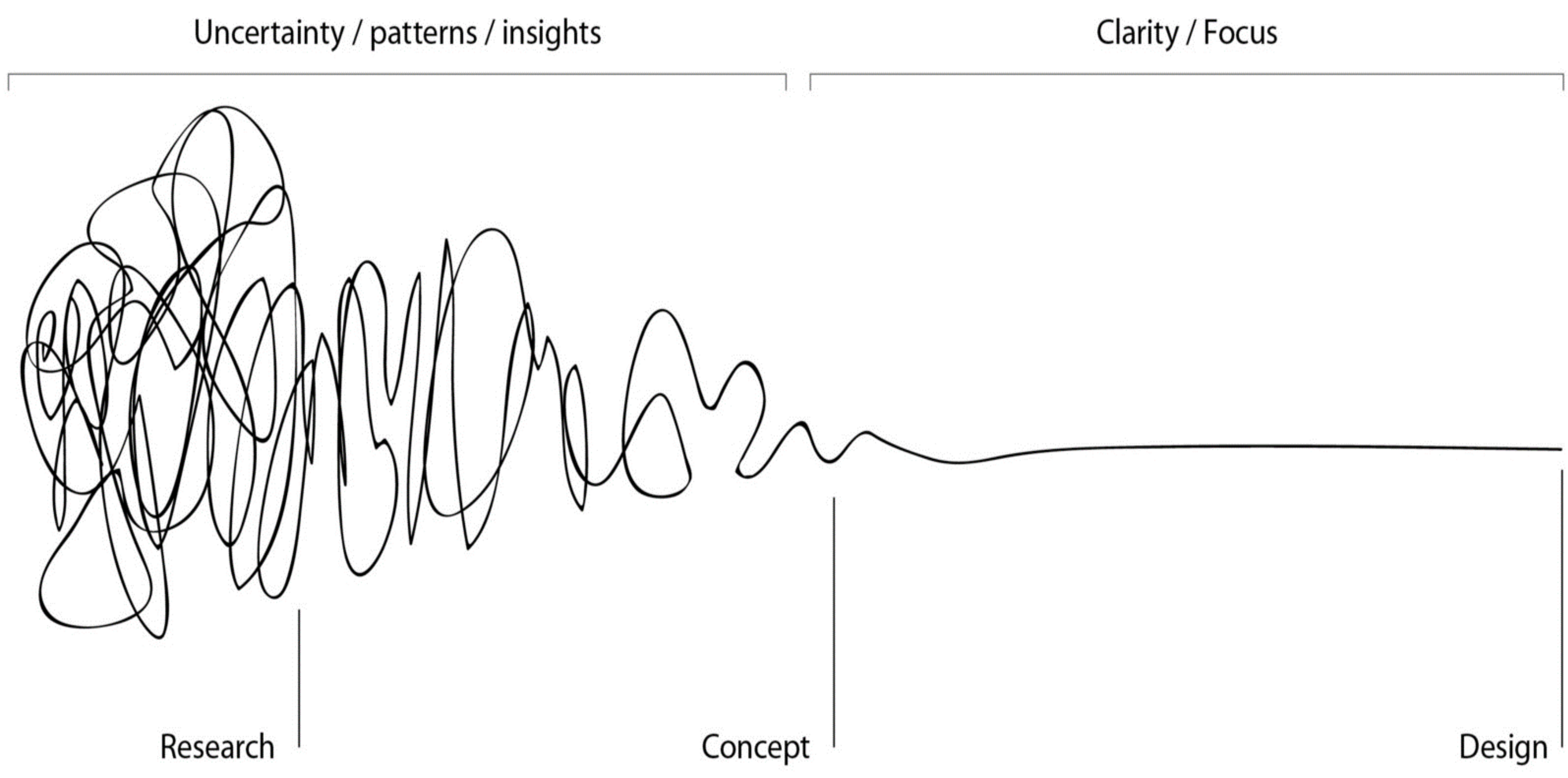
4. Learn
   - Test phenomena
   - Verify mental or computational models
   - Increase confidence

There is ALWAYS a specific purpose for prototyping…

how to decide the correct purpose?

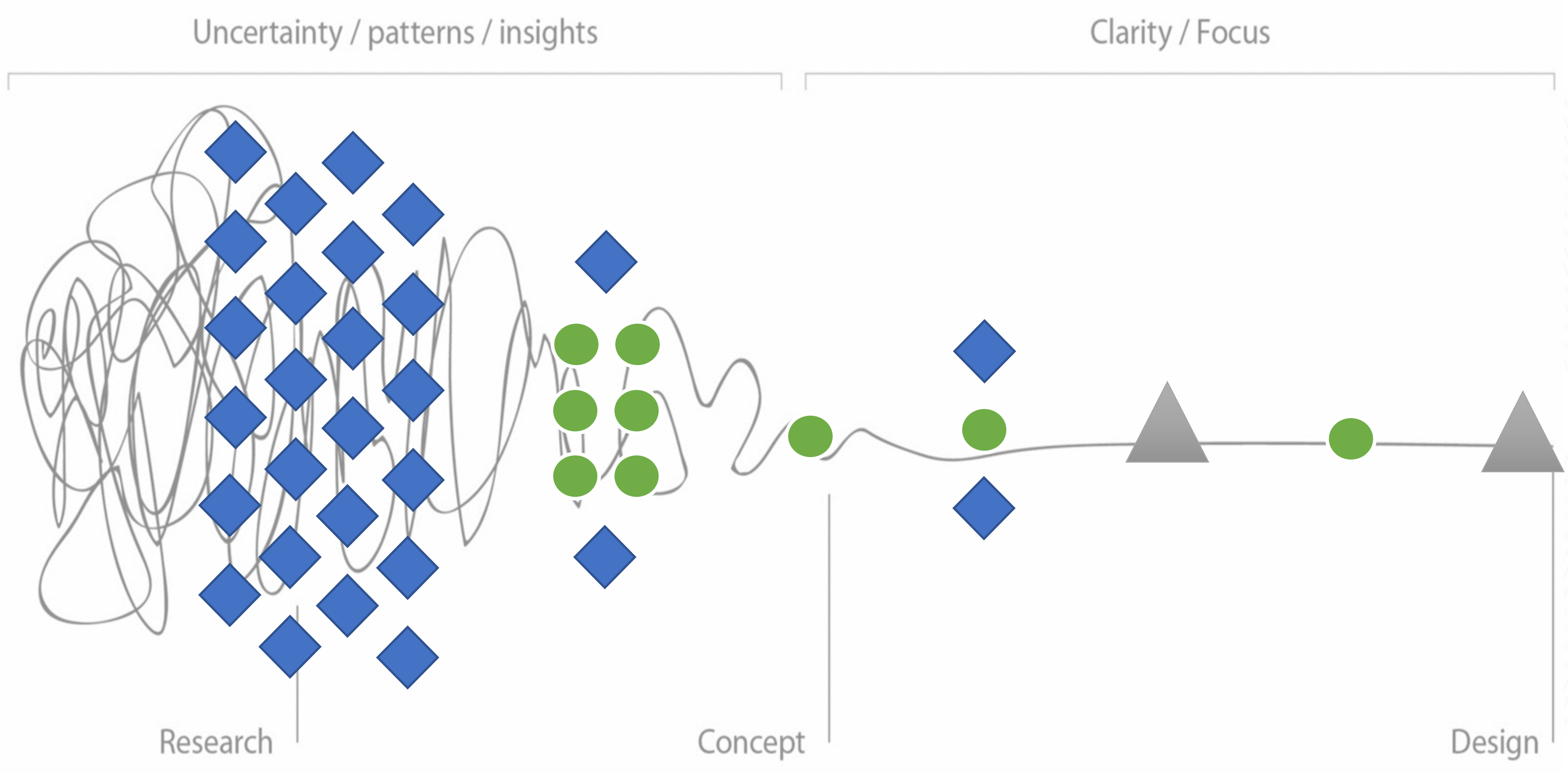
Camburn, B. A., 2015, "Design Prototyping Methods," Dissertation, The University of Texas at Austin.

Capstone Design Process



Design thinking squiggle from IDEO

Capstone Design Process



KEY
- Low Fidelity Prototype
- Medium Fidelity Prototype
- High Fidelity Prototype

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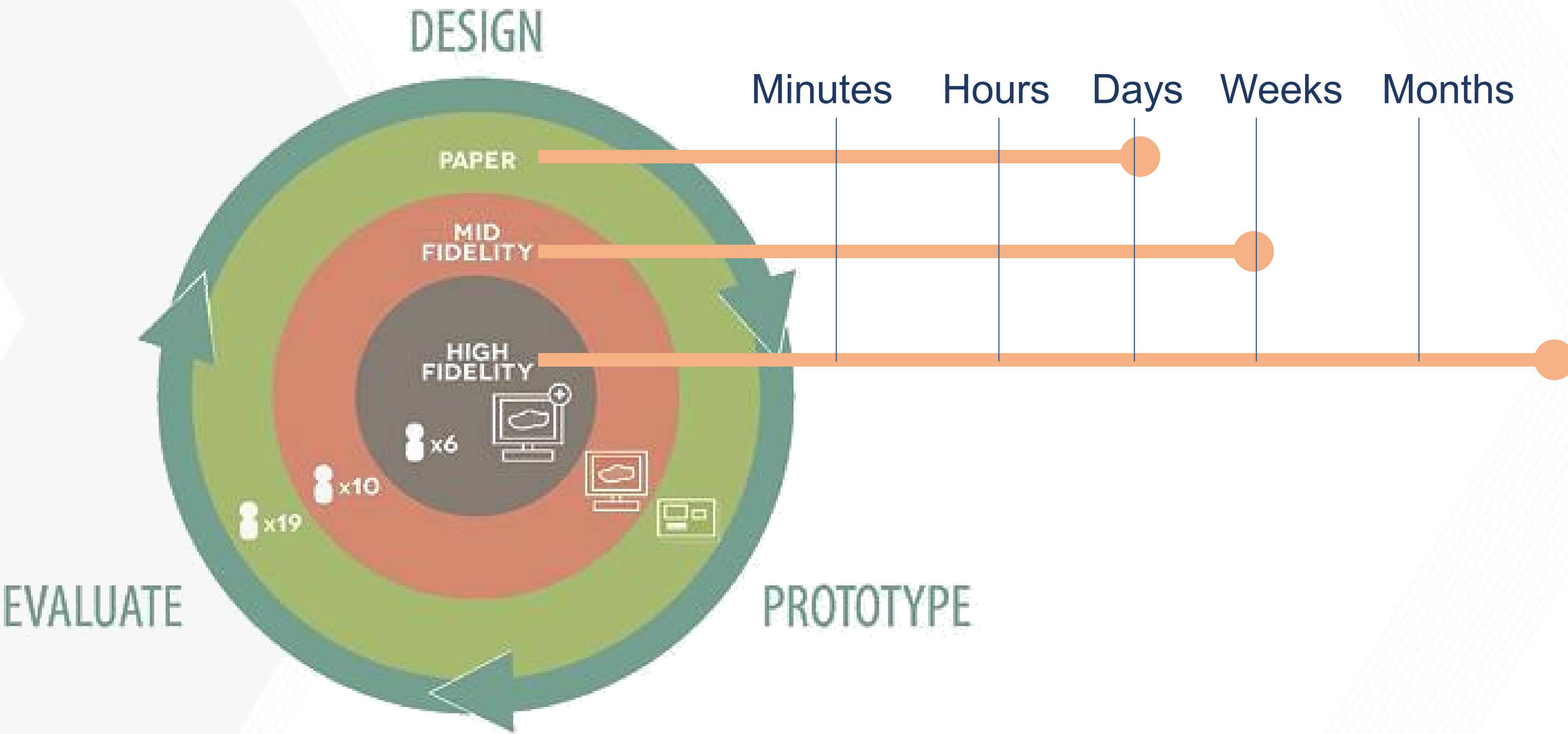
Evaluation is a necessary task after each Prototype



http://cargocollective.com/ivytsai/Data-Visualization

Questions to consider when prototyping

1. How many concepts to test in parallel?
2. How many iterations of each concept?
3. Virtual or physical?
4. Breakdown into isolated subsystems?
5. Scale down the size?
6. Relax design requirements?

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T. Gurjar, D. Jensen, R. Crawford, "Effects of a Structured Prototyping Strategy on Capstone Design Projects", 122nd ASEE Annual Conference Proceedings

Prototyping Strategies – *Number of Iterations*

- Prototype numerous iterations if …
  - Difficult to meet the requirements with lesser iterations
  - Team has less experience with prototyping

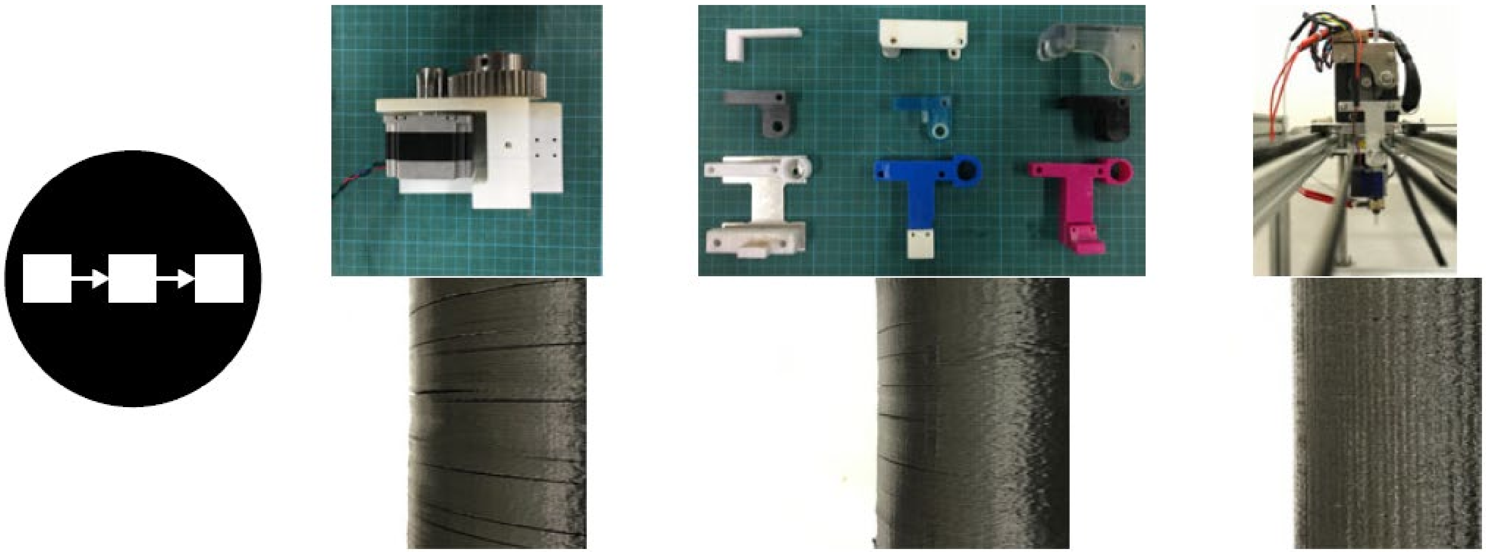


Figure 6. An example of iterative design. (Left) Initial design; (centre) a series of three iterative refinements; (right) the final design for a large-scale 3D printer extrusion head. The reliability of the print process gradually increased with each iteration (test prints shown below each design). The final design required nearly 40 iterations to achieve reliable printing. Courtesy of Gilmour Space Technologies.

Camburn et. al "*Design prototyping methods: state of the art in strategies, techniques, and guidelines*", Design Science vol. 3, e13

Prototyping Strategies – *Number of Concepts*

- Prototype several concepts in parallel if…
  - Evaluation ranks of multiple concepts are close enough
  - Sufficient time and materials are available

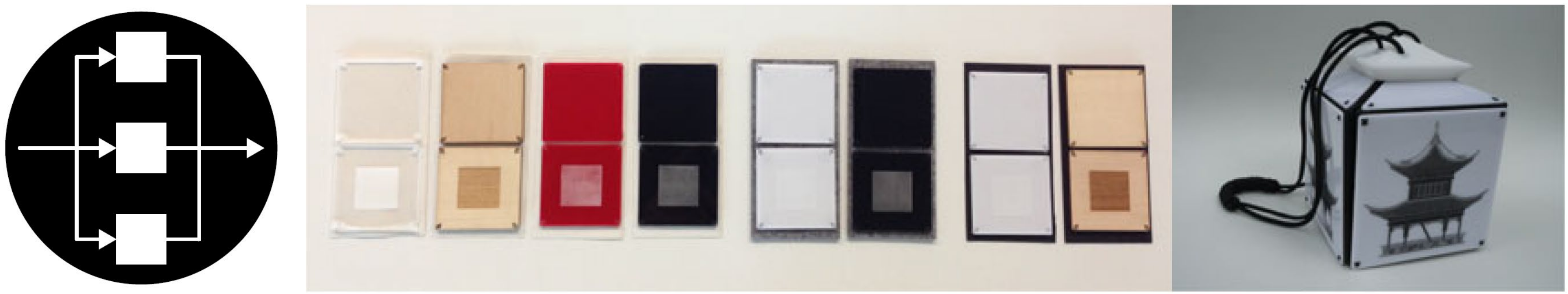


Figure 8. An example of parallel prototyping. (Left) Eight alternative textile prototypes for the casing of a collapsible carrier; (right) prototype of the selected materials in the final concept (right).

Camburn et. al "*Design prototyping methods: state of the art in strategies, techniques, and guidelines*", Design Science vol. 3, e13

Prototyping Strategies – *Virtual* or *Physical*?

- If virtual models are sufficiently accurate
- If CAD models necessary for advanced engineering analysis like FEA, CFD, etc.
- If virtual prototyping will take less time

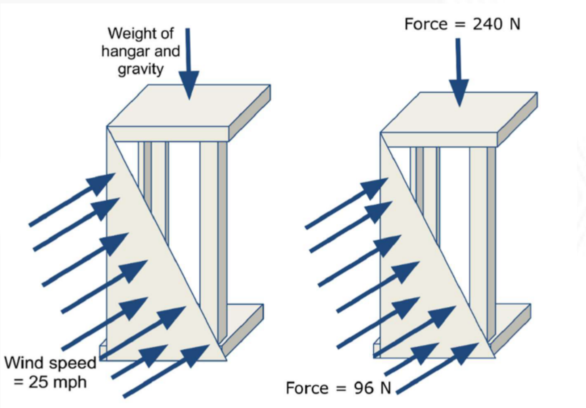


Figure 28: FEA Load conditions on the Base

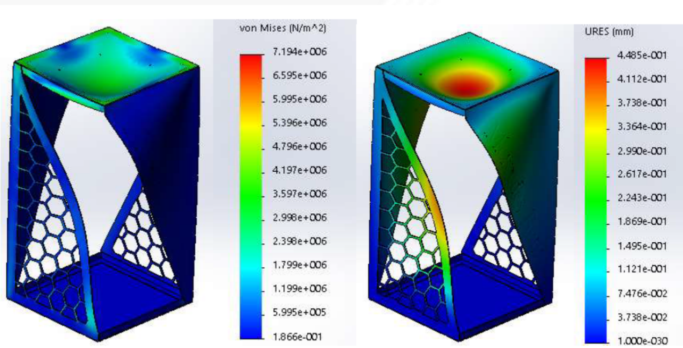


Figure 29: FEA results for von Mises stress (left) and displacement (right)

Benzie Box

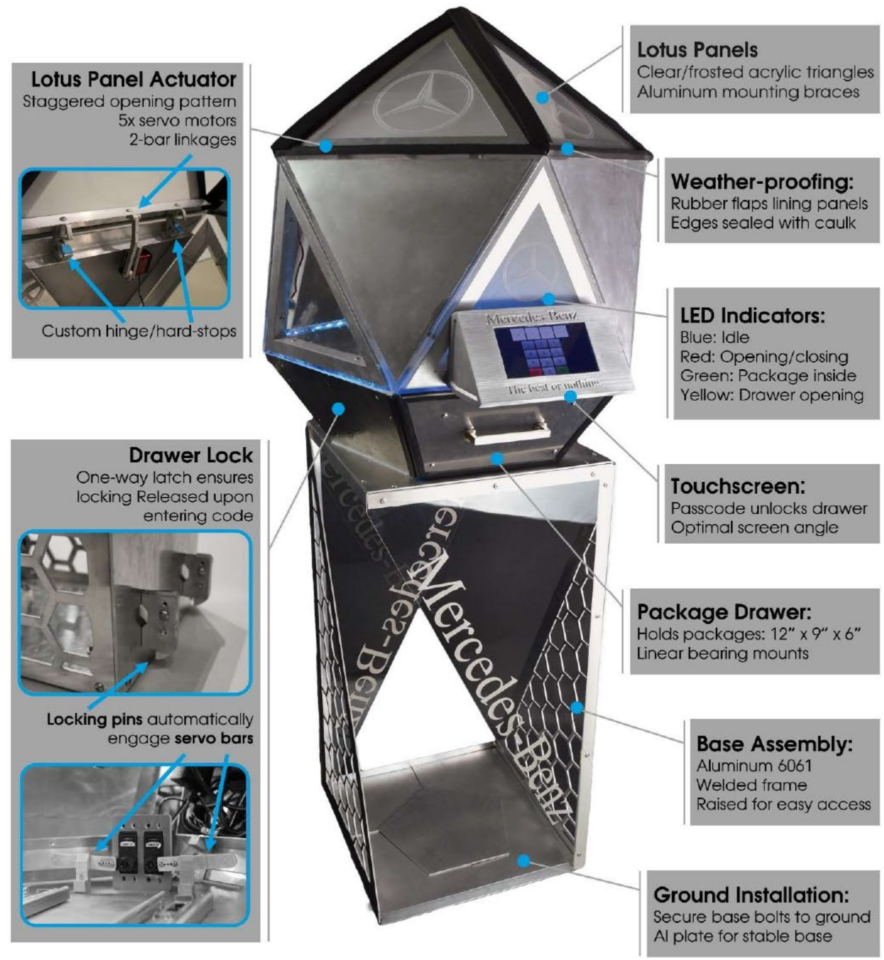


Figure 36: Final Working Model

Prototyping Strategies – *Subsystem Isolation*

- If interfaces between subsystems are predictable
- An isolated subsystem can be properly tested
- Few subsystems embody critical design requirements

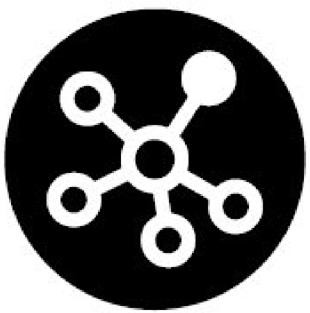
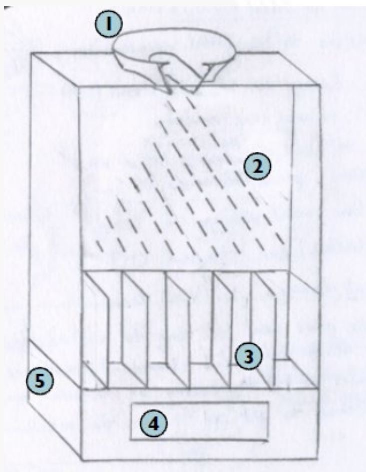


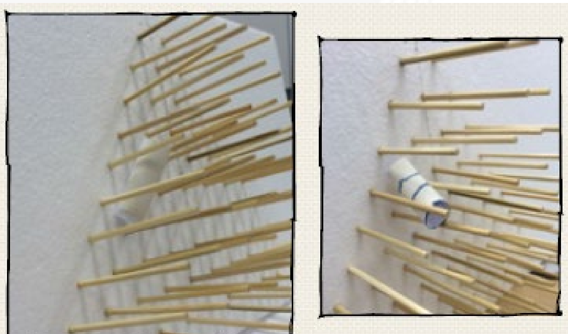
Figure 16. (Left) Isolated subsystem prototype of an electric vehicle drive train; (center) integrated functional design of the same vehicle; (right) final model of the market product, rendering. Courtesy of Gilmour Space Technologies.

Camburn et. al "*Design prototyping methods: state of the art in strategies, techniques, and guidelines*", Design Science vol. 3, e13

Prototyping Strategies – *Scaling*

- If known scaling law will permit accurate knowledge gain
- If scaling will simplify the prototype





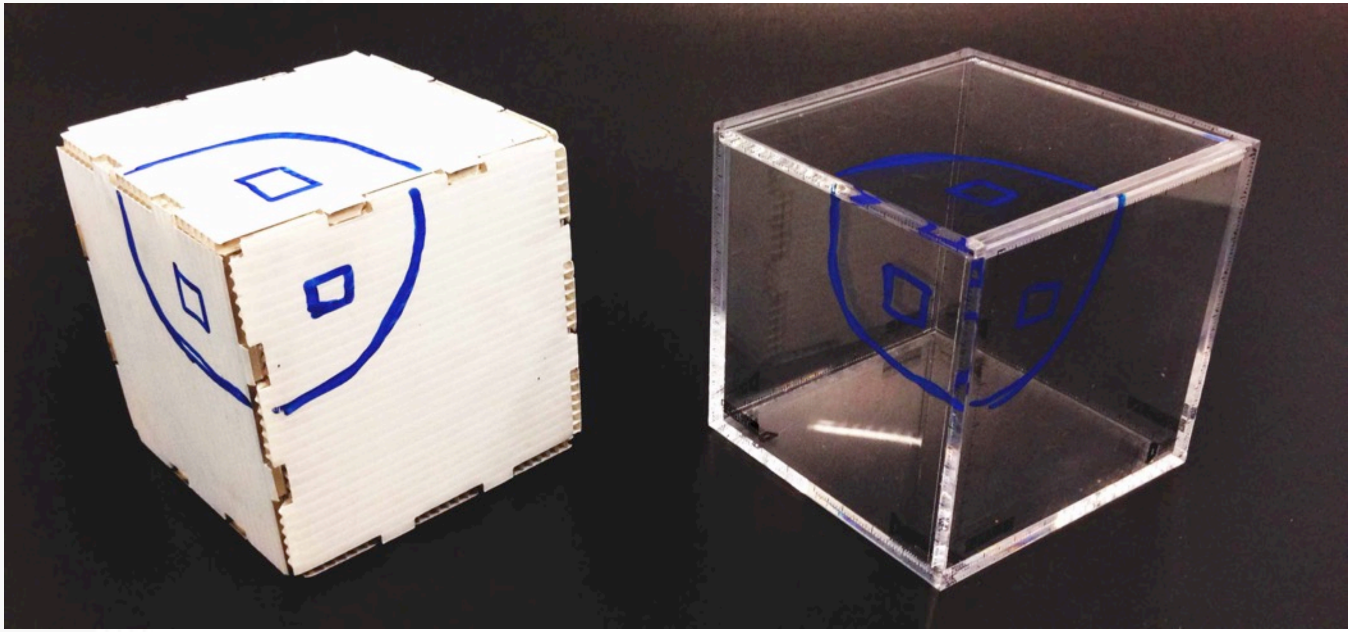
1st prototype using styrofoam for base board, skewers for pins

Quick prototype made from cardboard and push-pins

Courtesy: Students in SUTD 3.007 Fall 2013

Prototyping Strategies – *Relaxing Requirements*

- If design requirements are flexible to allow meaningful results despite relaxing requirements
- If prototype can be simplified



(*left*) Relaxed prototype made from posterboard; (*right*) fully functional prototype for a 3D whiteboard.

Camburn, B. A., 2015, "Design Prototyping Methods," Dissertation, The University of Texas at Austin.

Prototyping occurs in stages

Low Fidelity → High Fidelity

Sketches

Experiments
- Lab testing
- Partial systems

Alpha Prototypes
- Limited user testing
- May have partial systems

Beta Prototypes
- More general user testing
- Tweaks

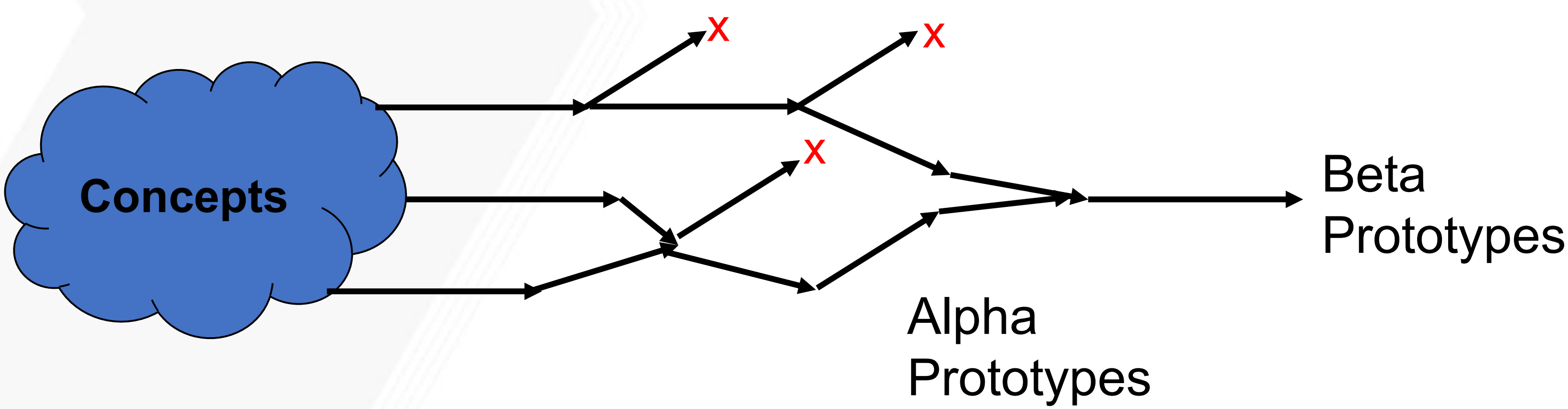
Pre-production Prototypes

But the stages are not a single trail of ideas

Low Fidelity → High Fidelity

Sketches | Experiments | Alpha Prototypes | Beta Prototypes | Pre-production Prototypes

What really happens



Be wary of fixating

Know when to abandon an idea

Discussion

5. What are the various factors to consider when Prototyping?

Example: *Team's experience with prototyping*

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Prototyping Strategies

		Objectives			
		Refinement	Exploration	Communication	Active Learning
Individual Techniques	Iterative Prototyping	●			
	Parallel Prototyping		●		
	Requirement Relaxation			●	●
	Subsystem Isolation				
	Scaled Prototyping				
	Virtual Prototyping			●	

Camburn, B., Viswanathan, V., Linsey, J., Anderson, D., Jensen, D., Crawford, R., ... & Wood, K. (2017). Design prototyping methods: state of the art in strategies, techniques, and guidelines. Design Science, 3.

Mixed Prototyping Example

- Enable prototyping in complex systems where it may be difficult to model the entire system with a single approach. They also enable the integration of various levels of fidelity.
- Typically emerge at later stages of prototyping once subsystem prototypes are integrated.

Figure 22. Application of mixed prototyping for a multi-phase 3D printer. (Left) Software based control software simulation – flow diagram; (center-left) scaled, empirical similitude, physical test of the slurry injection valve; (center-right) full system CAD model; (right) final integrated design prototype. Courtesy of Gilmour Space Technologies.

Camburn et. al "*Design prototyping methods: state of the art in strategies, techniques, and guidelines*", Design Science vol. 3, e13

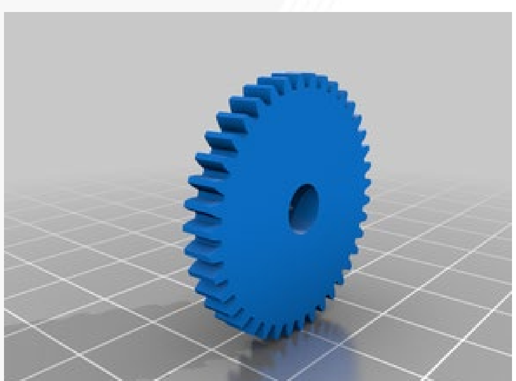
Discussion

http://popin.it/**vbf6wp**

6. Imagine that your final design involves a gear. Which of the following option would you pick?

- Option A:

1. Design gear in CAD
2. Build a 3D printed prototype in the Invention Studio.
3. Test the prototype gears with the rest of the prototype
4. Build the gears for the final prototype in a machine shop



- Option B:

1. Select gears from McMaster Carr based on requirements.
2. Download CAD for your simulation.
3. Order the gears for your final product.

Plastic Gear - 14-1/2 Degree Pressure Angle
Press-Fit Mount, 48 Pitch, 12 Teeth

Each

ADD TO ORDER

In stock
$7.06 Each
57655K11

Pressure Angle	14 1/2°
Pitch	48
Number of Teeth	12
Pitch Diameter	0.25"
OD	0.29"
Face Width	1/8"
Overall Width	0.313"
Fabrication	Molded
Color	White
Material	Nylon
Bore Type	Plain
Mount Type	Press Fit
For Shaft Diameter	3/32"
Hub	
Diameter	0.188"
Width	0.188"

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What is this prototype and what is it testing?

http://www.gamasutra.com/view/news/181321/Sometimes_paper_is_your_best_prototyping_tool__even_if_youre_Nintendo.php

Discussion Prompt #1 Follow-up

!=

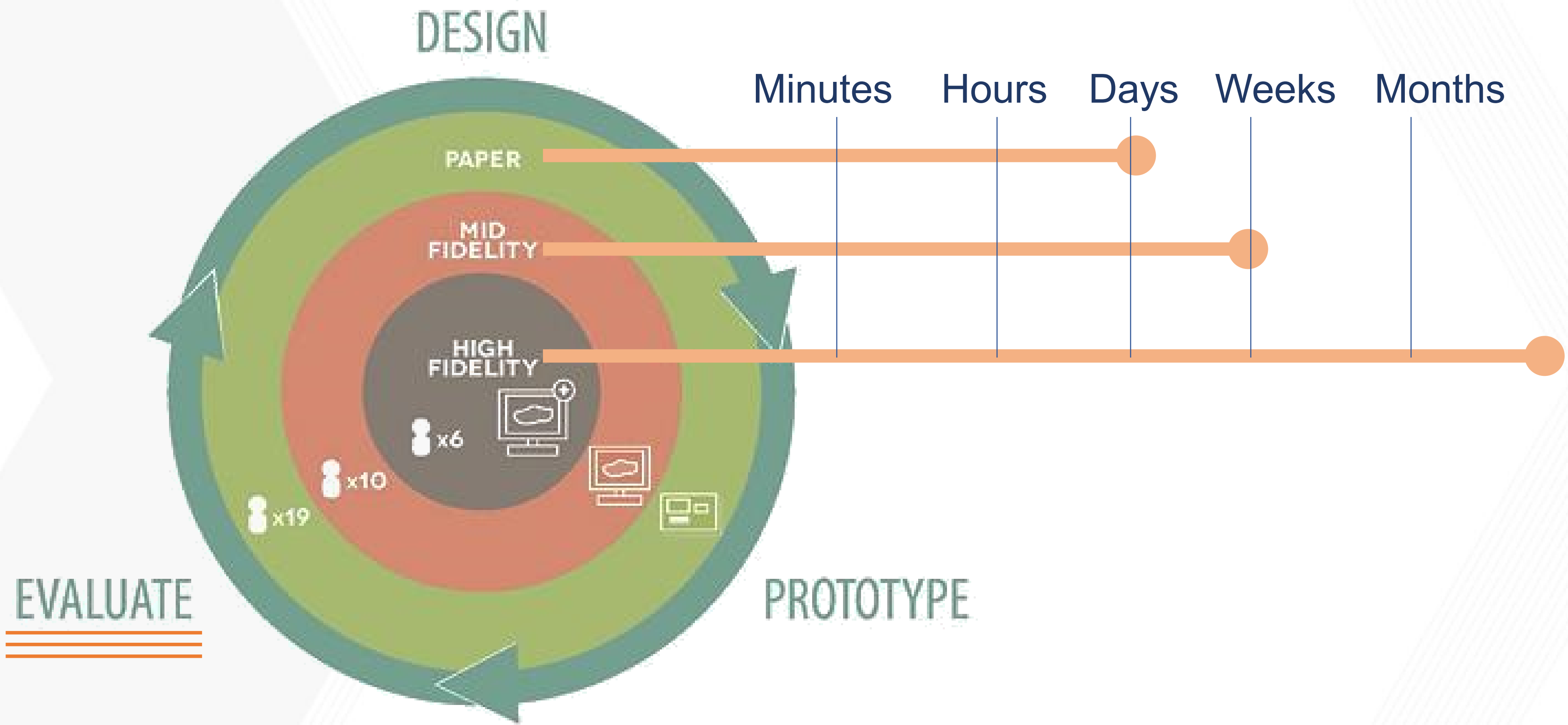
DO NOT: Mistake Your Prototype for Your Final Product

Risks with Prototyping

1. Novice designers may self-impose additional constraints
   - Assume only a certain material or manufacturing process is available
   - Unreasonable/excessive use technology as a driving factor to make design decisions
2. Fixation with “ONE” final prototype
3. Changing prioritization of design constrains during prototyping

Prototype with a clear hypothesis!
Else you are building an art exhibit.

Evaluation is a concurrent task during product development



Your prototype should help evaluate a hypothesis

DO NOT BUILD without a clear purpose

http://cargocollective.com/ivytsai/Data-Visualization

When NOT to prototype?

Antikythera Mechanism, 37 gear astronomical calculator - 87 BC

Do Not: Reinvent the Wheel!

Discussion Prompt #6 Follow -up

- Option A:

1. Design gear in CAD
2. Build a 3D printed prototype in the Invention Studio.
3. Test the prototype gears with the rest of the prototype
4. Build the gears for the final prototype in a machine shop

Cost: 3 weeks of design time, ~$500 of in-house machine time.

- Option B:

1. Select gears from McMaster Carr based on requirements.
2. Download CAD for your simulation.
3. Order the gears for your final product.

Cost: 0.5 weeks of design time, ~$60-150 of ordering cost

Are you designing a prototype or prototyping your design?

Cardboard is your friend

Military tank seat prototype.
Credit image: Courtesy of PageOne for DailyMail

Cardboard iPhone Scanner made by designer Kyle A Koch. Credit Image: Kyle A Koch

http://makingsociety.com/2014/11/how-to-cut-cardboard-prototyping/

Dos:

- Make Prototypes for a Reason
- Watch Out for the Sunk Cost Fallacy
  - Make sure that you budget an appropriate amount of resources towards your prototype

Reimbursement Process

- Confirm your rationale for physical prototyping with your section instructor FIRST!

- Typical Process Overview: (Funding limits TBD) https://mecapstone.gatech.edu/resources/reimbursement-guidelines/

- Fill out Intent for Reimbursement Form: https://forms.gle/DhYTsR21jYSgVXp88 (**TODAY**!)

- Only **ONE** person per team: Finance Manager
- Receipts must show payment: last 4 digits of CC
- Receipt with ANY personal items will be rejected
- Final Reimbursement Package Due: 24th July 2020
- Contact: **TBD**

All The Best!