ME4182: Prototyping for Capstone Design

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Date: 02/10/2020

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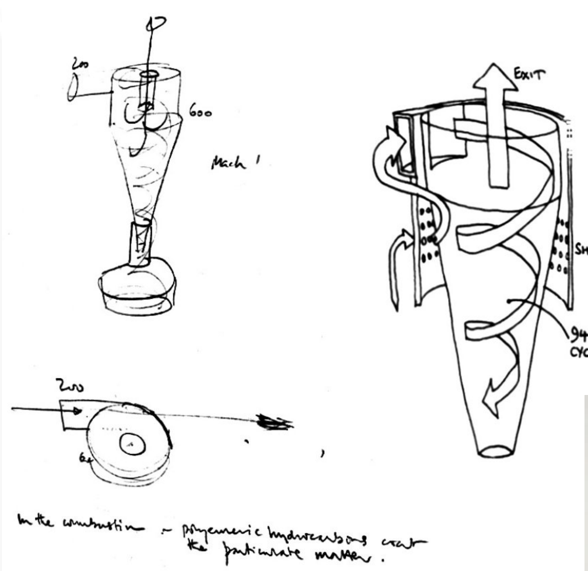
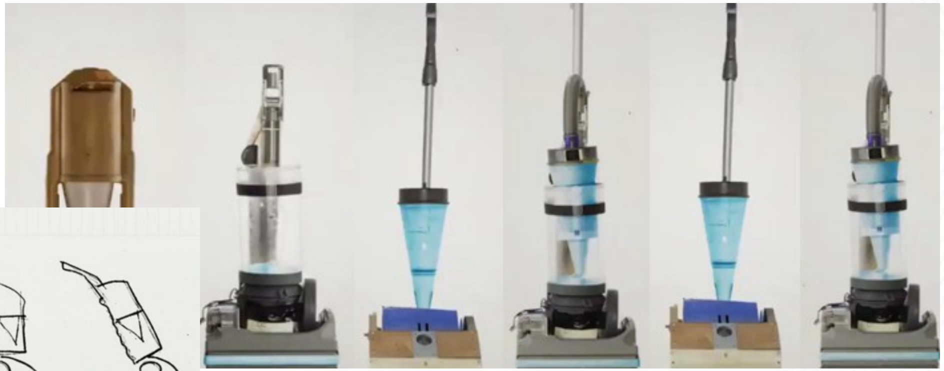
Acknowledgements to Veronica Spencer (BSME, MSID 2019)

Learning Outcomes

- What is a Prototype, types of prototypes and prototyping process
- When and what to prototype
  - When NOT to prototype
- How to use Prototyping strategies

A Prototyping Story





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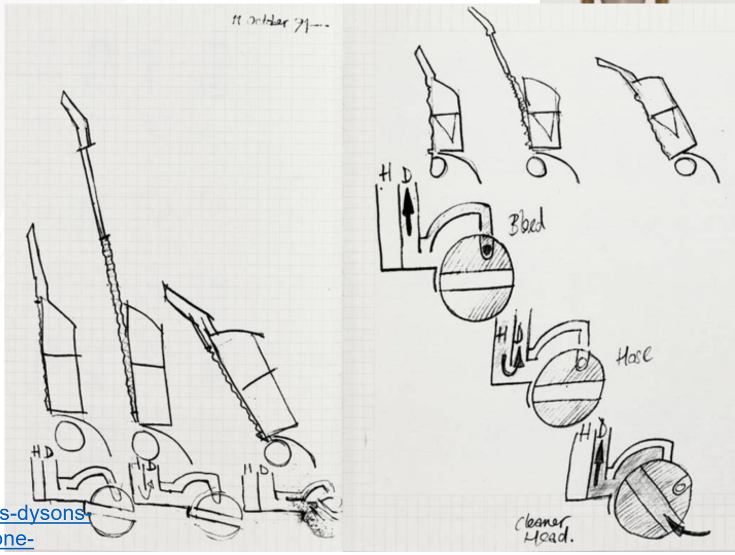
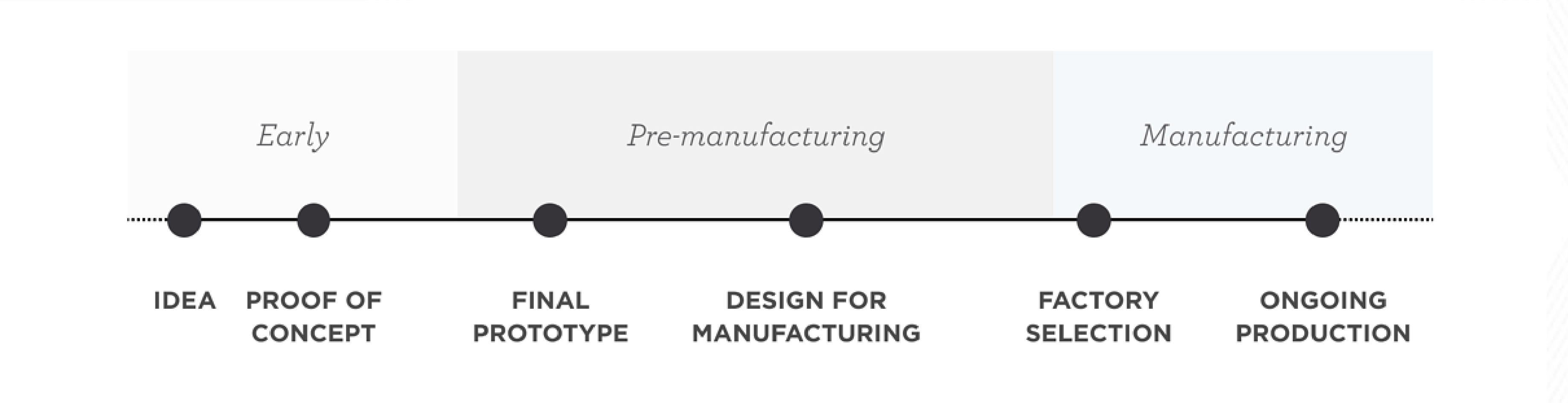


http://www.dennyyou.com/2018/06/04/james-dysons-5217-prototypes-before-he-invent-first-cyclone-vacuum-cleaner-dc01/

Product Design Process



https://blog.dragoninnovation.com/blog

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

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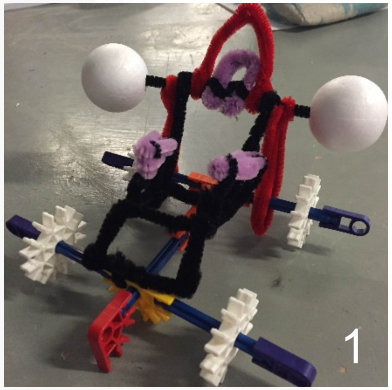
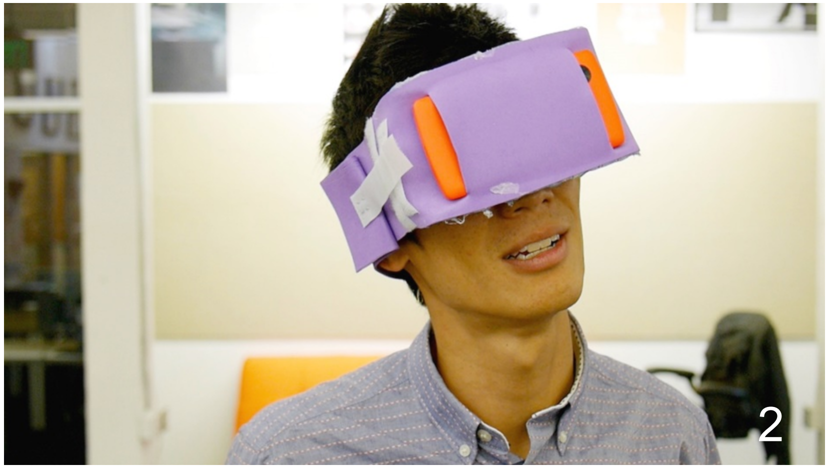
Are these Prototypes?





Yes, they can be simple!

Are these Prototypes?

Yes, they can be sophisticated

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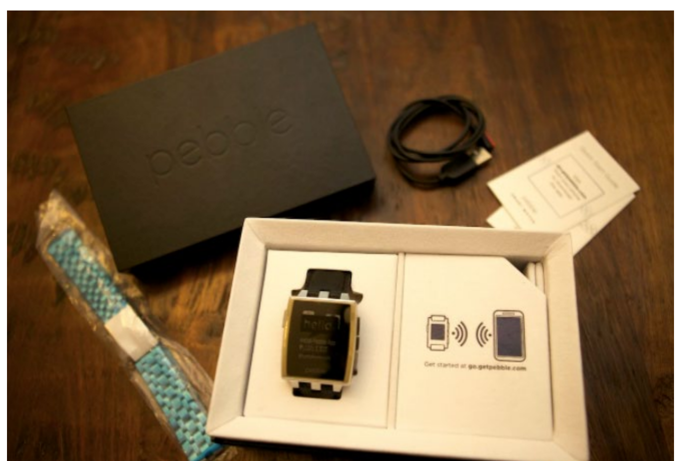
Types of Prototype

- *Looks-like*

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

- *Works-like*

  Focuses on the functionality of the product – Ensures technical challenges are resolved



Courtesy: Scott Miller

Why do designers prototype?

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What is a Prototype?

- An artifact that
  - Communicates design intent to internal and external stakeholders
  - Informs and changes the designer's conception of the problem space
- A design representation of some aspect such as form/fit or function of a design.
- Unlocks your ability to experiment, fail, learn and grow – explore, optimize and validate!

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

Why Prototype? Prototyping Outcomes

- Refinement
  - Clarify requirements and risks
  - Identify potential performance increases
  - Identify mistakes and failure modes
- Communication/Usability
  - Observe or experience use and user needs
  - Discuss with stakeholders

- Exploration
  - Test multiple concepts
  - Gather information about the design space
  - Ideation tool
- Active Learning
  - Test phenomena
  - Verify mental or computational models
  - Increase confidence

Reduce risks early – expose key areas of improvements

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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

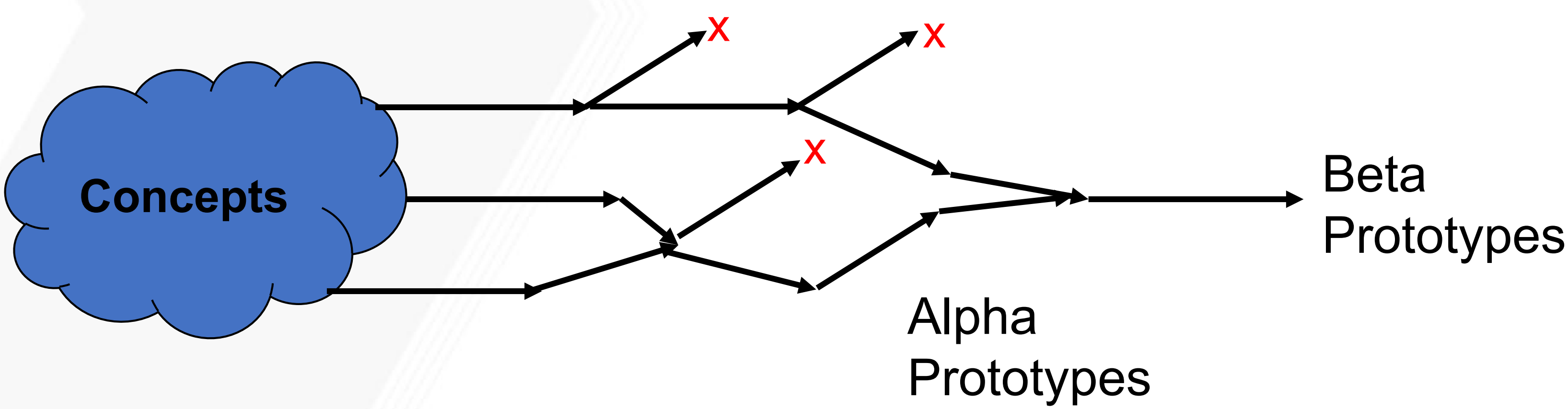
Pre-production Prototypes

But the stages are not a single trail of ideas

What they tell you

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

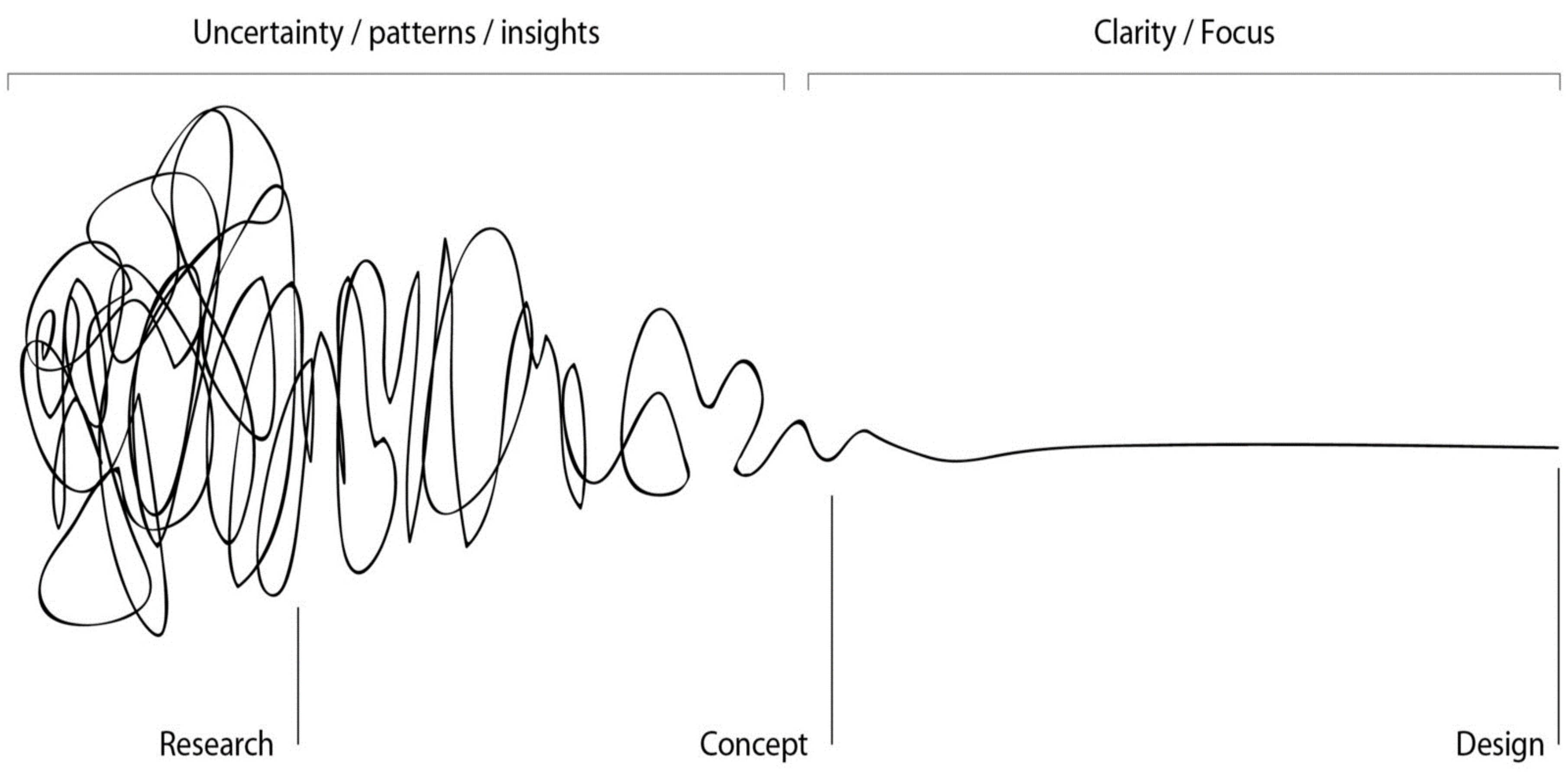
What really happens



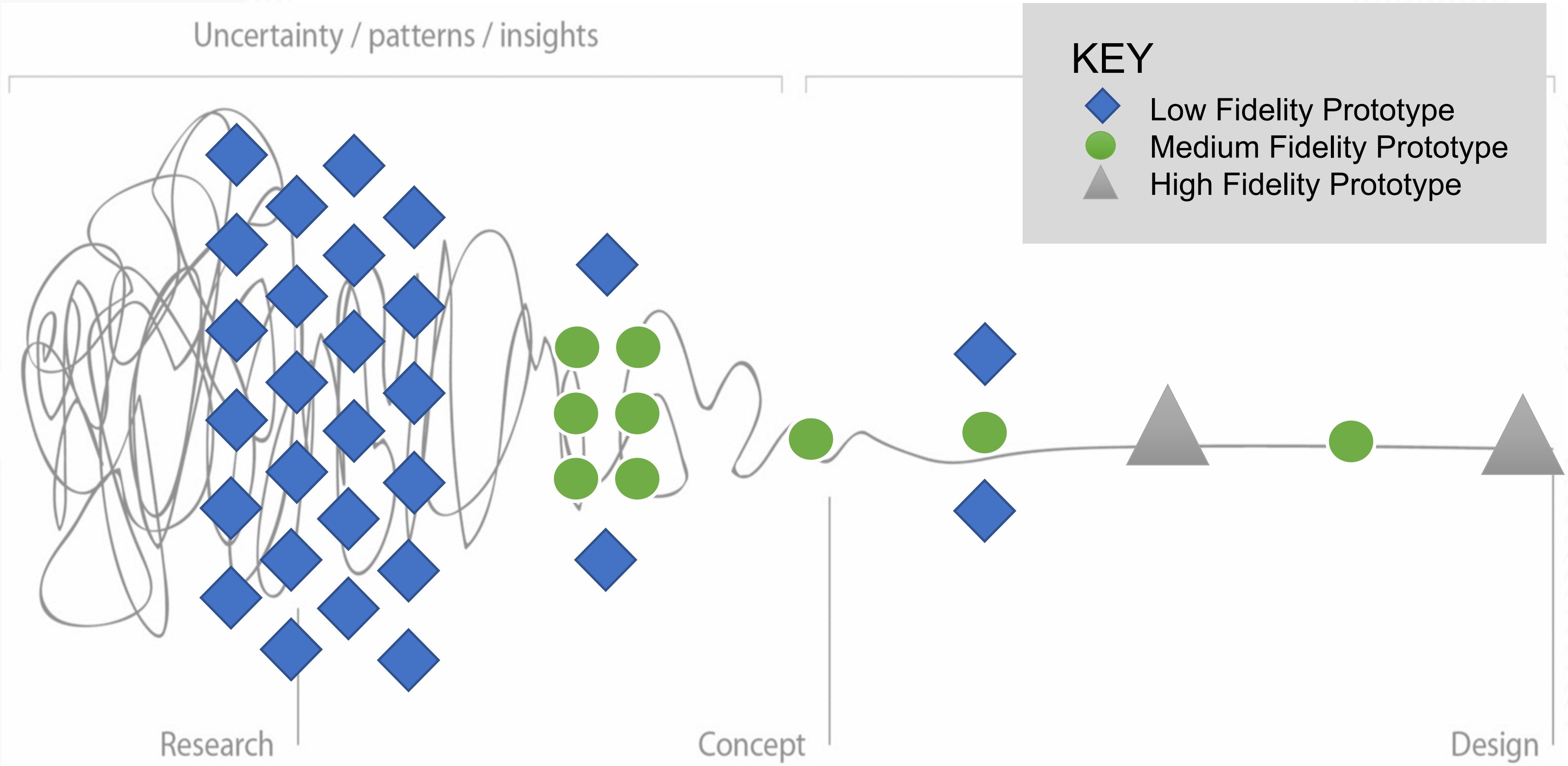
Be wary of fixating

Know when to abandon an idea

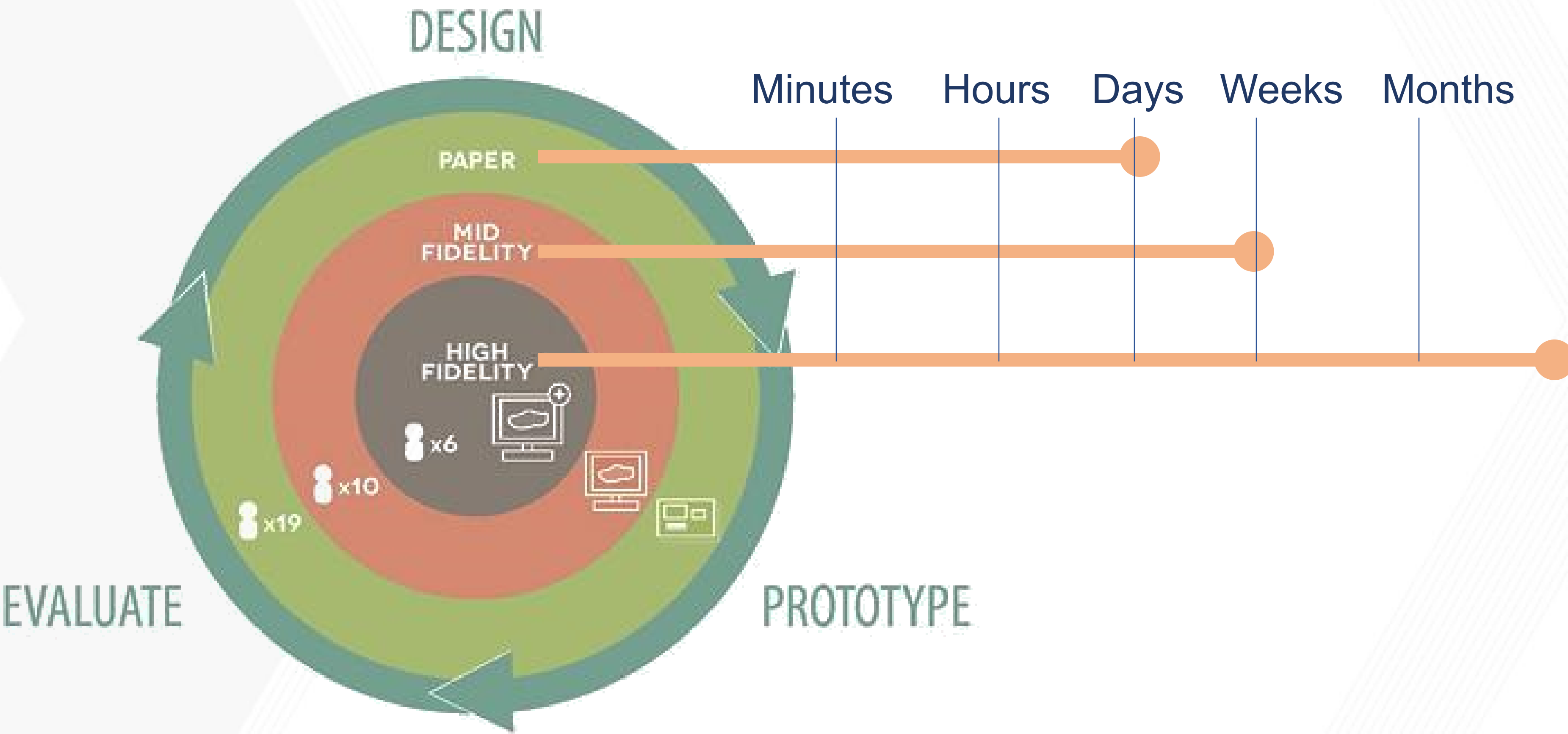
Remember this?



Remember this?



Evaluation is a concurrent task during product development



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

What do prototypes do?

Variable	Design Heuristic
Testing	Construct a clear testing objective
Timing	Early prototyping is the most critical
Ideation	Prototypes lead to functional ideas
Fixation	Fast prototyping reduces fixation
Feedback	Feedback may induce corrections but also increase fixation
Usability	End-user testing may enhance performance assessment accuracy
Fidelity	Higher fidelity representations lead to accurate interpretation of the design

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.

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

Start prototyping with a clear hypothesis and specifications. Otherwise you are building an art exhibit!

Prototyping Strategies

1. How many concepts should be prototyped in parallel?
2. How many iterations of each concept should be built?
3. Should the prototype be virtual or physical?
4. Should subsystems be isolated?
5. Should the prototype be scaled?
6. Should the design requirements be temporarily relaxed?

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*

- # of iterations depend on:
  - If difficult to meet the requirements with lesser iterations
  - Difficulty of manufacturing processes
  - Team's experience with prototyping

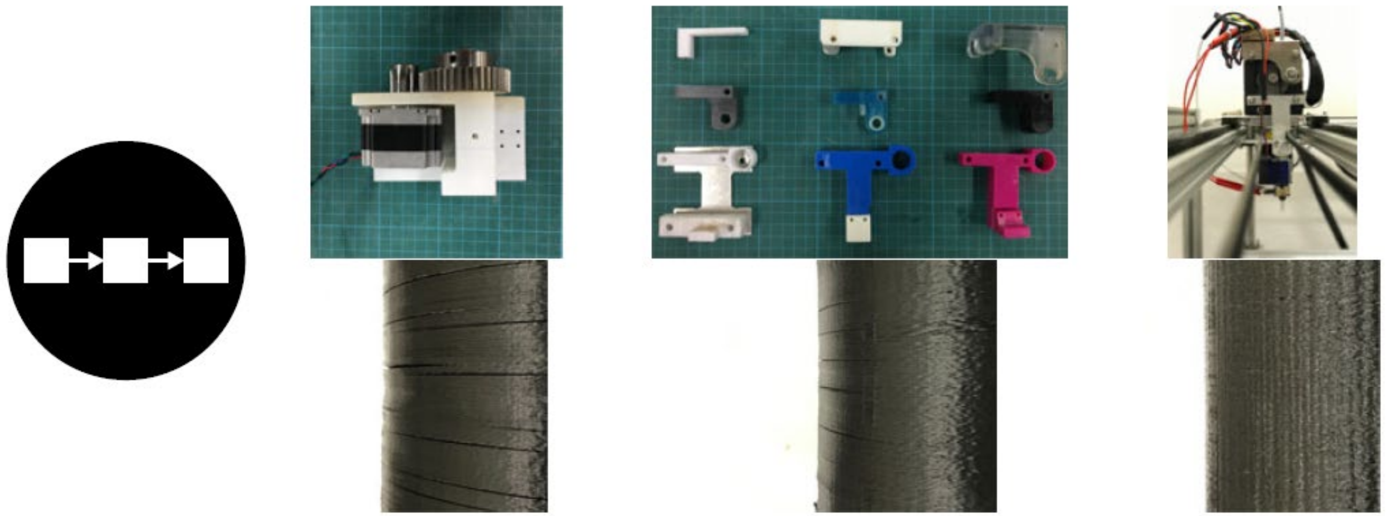


Figure 6. An example of iterative design. (Left) Initial design; (centre) a series of three iterative refinements; (right) the final design for a large-scale 3D printer extrusion head. The reliability of the print process gradually increased with each iteration (test prints shown below each design).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

Prototyping Strategies – *Number of Concepts*

- # of concepts depend on:
  - If evaluation ranks of multiple concepts are close enough
  - Sufficient materials are available
  - Sufficient time is available

Figure 9. An example of competitively produced prototypes, from the 30.007 course at SUTD. (from left to right) A flying-rolling robot; rolling robot with enhanced traction wheel; rolling robot with active camouflage; rolling robot using exo-skeletal modular pendulums; integrated design for full project (semi-final design). These designs are part of a student design hackathon, which in turn is part of a larger university wide competitive project to develop advanced ISR robotics.

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

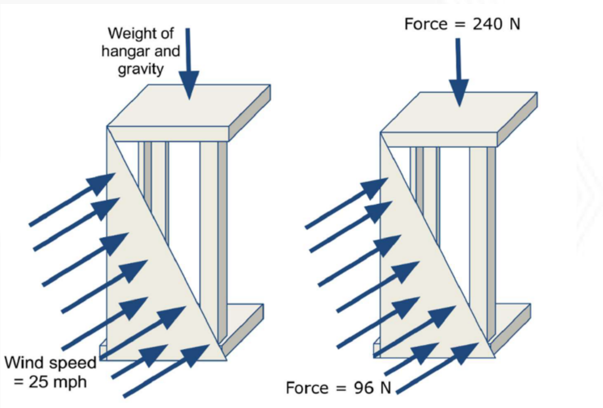


Figure 28: FEA Load conditions on the Base

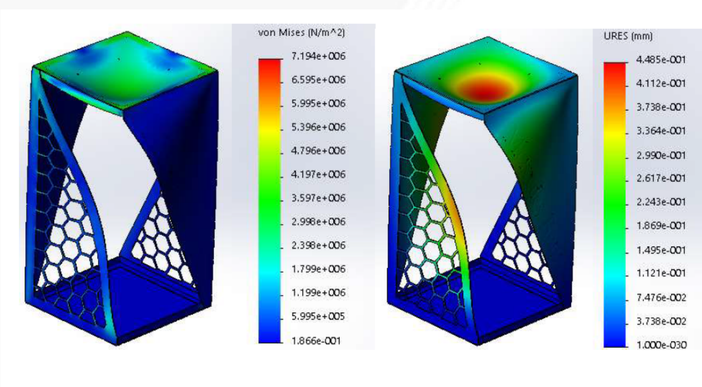


Figure 29: FEA results for von Mises stress (left) and displacement (right)

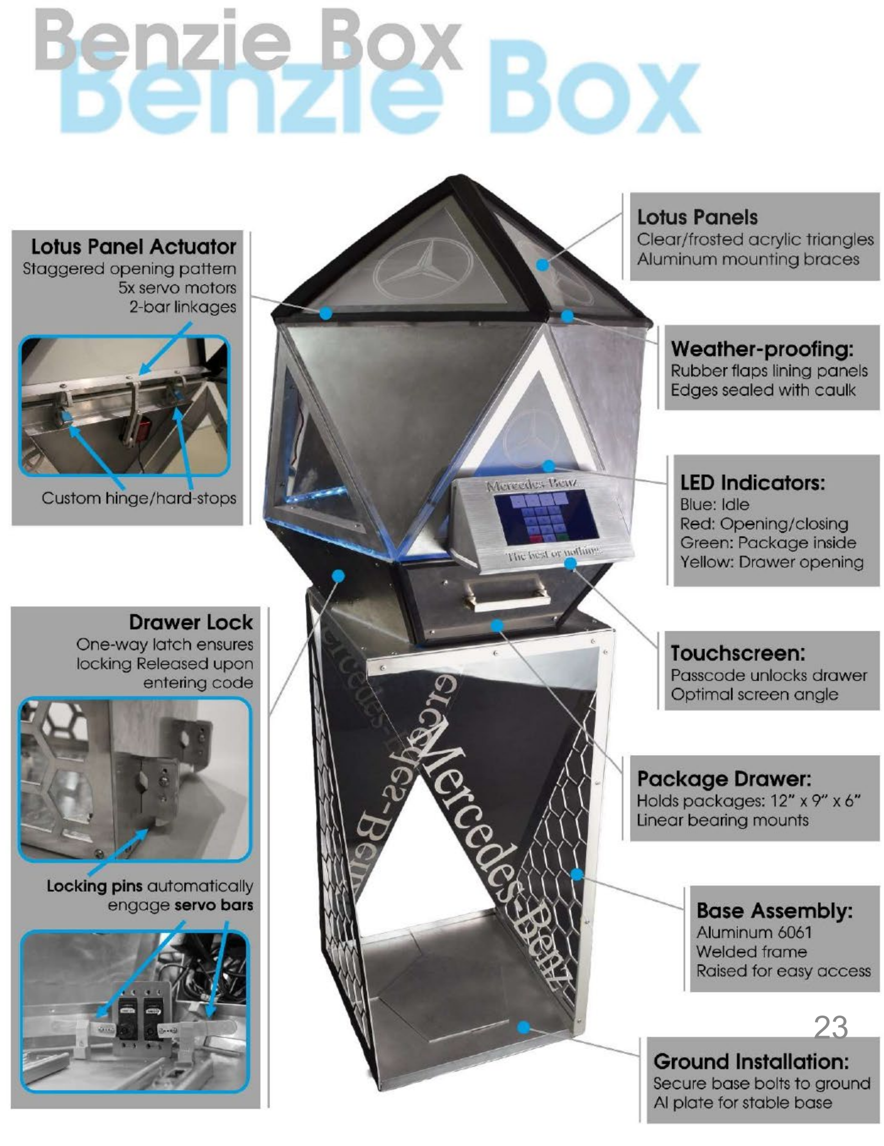


Figure 36: Final Working Model

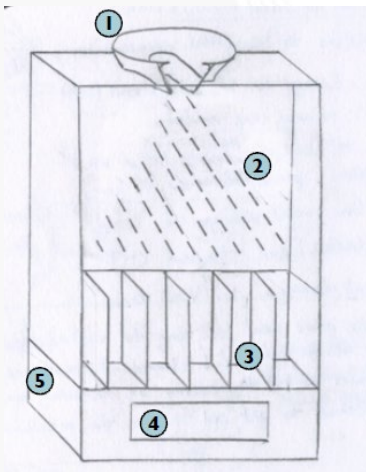
Prototyping Strategies – *Subsystem Isolation*

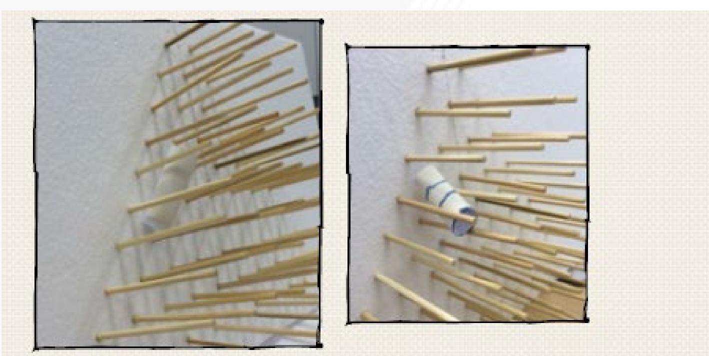
- If interfaces between subsystems are predictable
- An isolated subsystem can be properly tested
- Few subsystems embody critical design requirements

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.

Prototyping Strategies – *Scaling*

- If known scaling law will permit accurate knowledge gain by looking at scaled model
- 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

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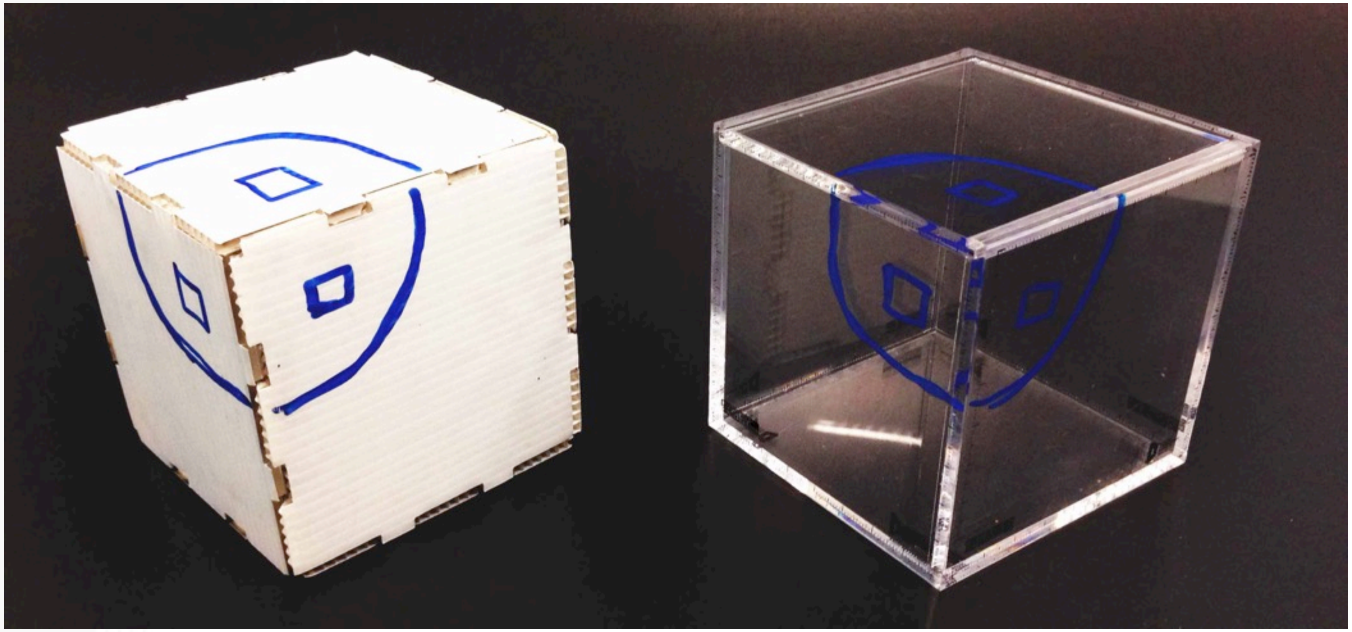
Prototyping Strategies – Relaxing Requirements

- 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.

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

Prototyping Strategies - Simplified

Individual Techniques	Objectives: Refinement	Exploration	Communication	Active Learning	Reduce cost	Reduce time
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

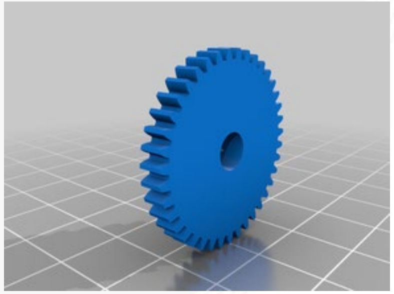
- Mixed prototypes enable prototyping in complex systems where it may be difficult to model the entire system with a single approach. They also enable the integration of various levels of fidelity.
- Mixed prototypes typically emerge at later stages of prototyping once subsystem prototypes are integrated.

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.

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

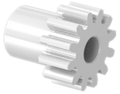


- Option B:

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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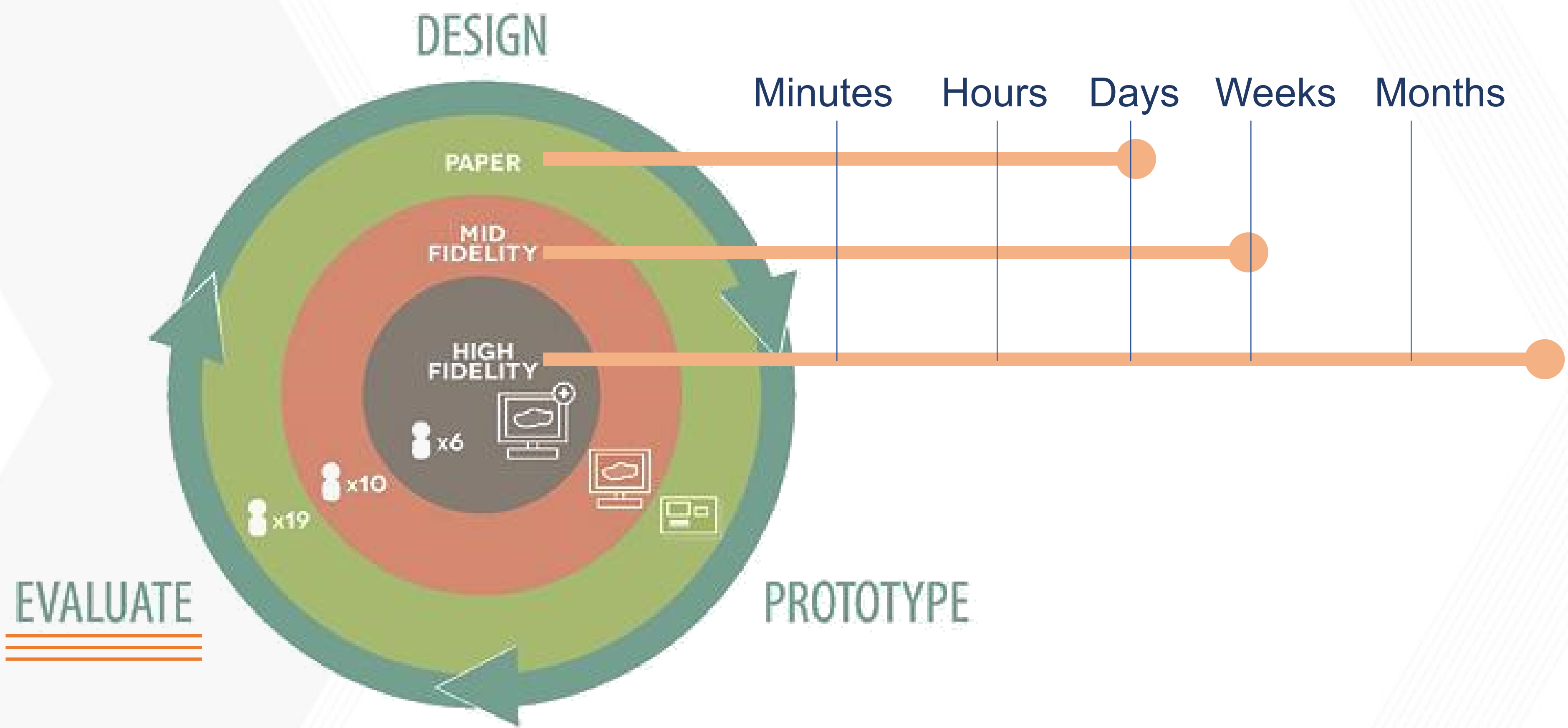
What is this prototype and what is it testing?

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

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!

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

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.

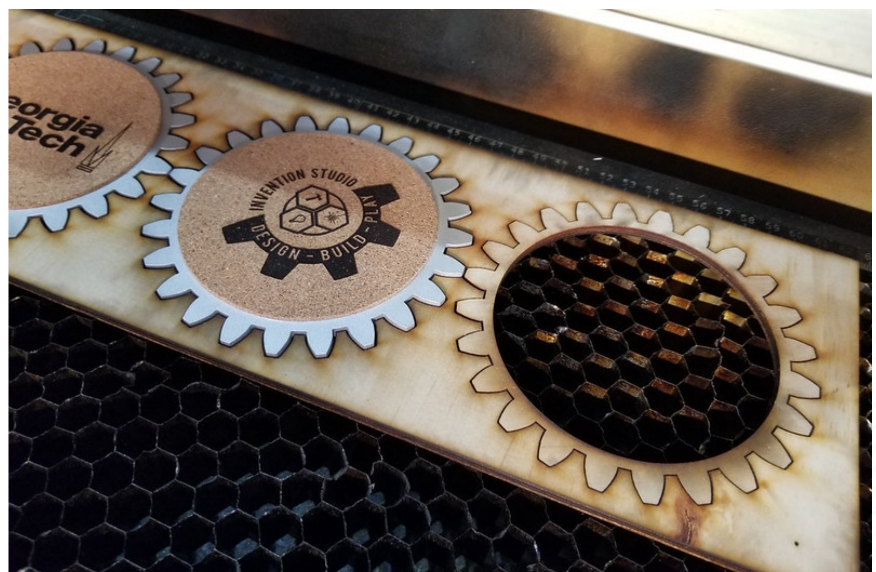
Cost: 0.5 weeks of design time, ~$60-150 of ordering cost

Dos:

- Make Prototypes for a Reason
- Watch Out for the Sunk CostFallacy
  - Make sure that you grant an appropriate amount of time/money to your prototype

Resources for Prototyping

- Invention Studio
- Montgomery Machining Mall (M&F 7a-6p, T/W/ Th 7a-7p)
- ME Electronics Lab (M-F, 7a-5:30p)
- Aero Maker Space
- Digital Fabrication Lab
- The MILL
- The HIVE (IDC)



How to Help the MMM Help you.

- Before asking for custom components, check to see if something is available!
    - Don't ask for a welded frame out of custom tubing, when you could design your prototype to accommodate **80/20 extrusions** with pre-made hardware.
- Don't ask for a tighter tolerance than is necessary!
    - +/-0.001" takes a lot more time and effort than +/-0.01"
- Refresh the proper ways to dimension things!
    - https://www.youtube.com/watch?v=OF3S6BjMKsI
- Double check your drawings/requests.
    - http://tinyurl.com/GTRI-Fab
- Ask expert machinists for their opinions!

Are you designing a prototype or prototyping your design?

Reimbursement Process

- Process Overview: https://mecapstone.gatech.edu/resources/reimbursement-guidelines/
- Check your team's reimbursement limits here: http://mecapstone.gatech.edu/Projects_Sp2020
- 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: 24^{th} April 2020
- Contact: lucinda.erimsan@me.gatech.edu

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Register for the Expo *(before 13th March)*

- Use the link below to register your team: http://expo.gatech.edu/login/

- **Only ONE team leader** should create the team and add team members. Team members can later login to edit the details.

- In your team's description field, please state your team's category by entering one or several of the following keywords –
  - "**Sponsored**",
  - "**Entrepreneurial**" and/or
  - "**Community Development/ Sustainability**".

- Student FAQs are addressed at this link: https://capstone.gatech.edu/expo/students/

- Send technical questions to webmaster@capstone.gatech.edu

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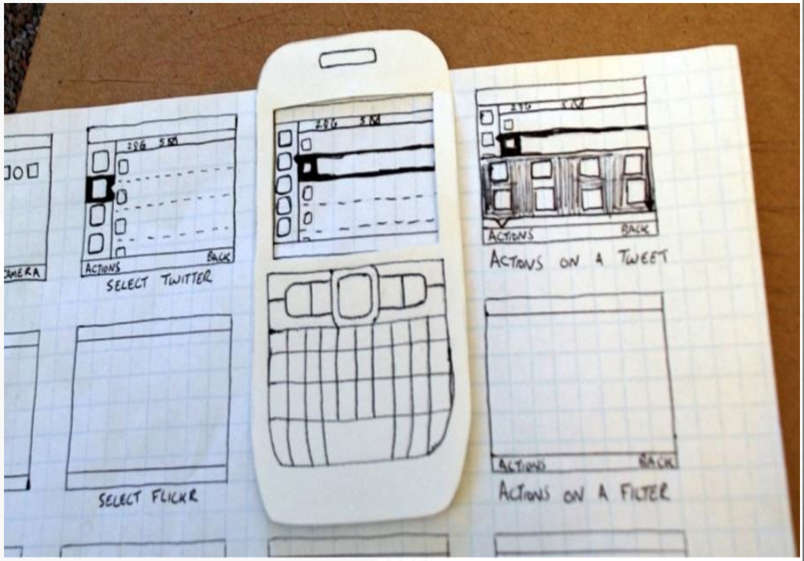
All The Best!

Paper and Cardboard are your Friends



http://letsmakerobots.com/robot/project/cardboard-robot-series

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/


rotimatic
rotimatic


ZIMPLISTIC
ROTIMATIC
2010
2010
2009
2009
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2011
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Primary Considerations for Prototyping

1. Timing
   - Earlier rather than later
   - Timing is more important than time spent
2. Purpose
   - Explore alternatives
   - Test Functionality/Usability/Form
   - Find Failure Modes
3. Fidelity
   - High Fidelity: reduces variety, increases time spent, increases accuracy, limited iterations
   - Low Fidelity: increases variety, reduces time spent, reduces accuracy, foundation of iterations

Prototyping through Innovation Framework

Frame for Desirability	Frame for Feasibility	Frame for Viability
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 a cordless handheld vacuum.	**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 a cordless handheld vacuum.	**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 a cordless handheld vacuum.
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.

What do Prototypes Prototype?

- **Role**: Tools for role prototyping include Storyboards, journey mapping, scenario diagramming and video mockups.
- **Look and Feel**: Tools include making looks-like models, works-like models, mood boards, wire-framing interactions, interactive demos, volume studies and paper prototypes.
- **Implementation**: Tools include defining business models, value propositions, cost / revenue analyses, technical specs, partnerships, production methods, distribution models, proof of concept prototypes and workflow diagrams.

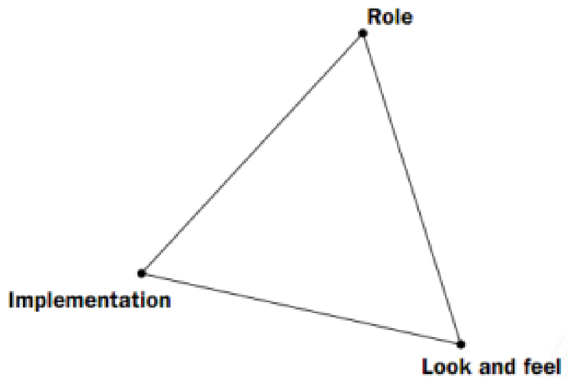
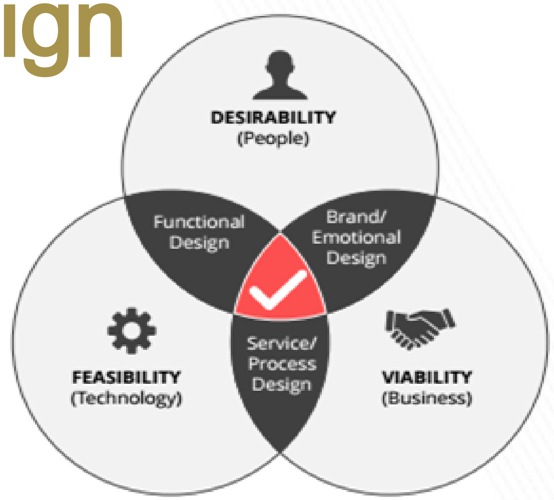


Figure 1. A model of what prototypes prototype.

http://blogs.ischool.berkeley.edu/ict4se/files/2010/09/Prototypes_prototype.pdf

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

Prototyping Strategies - Summary

Technique	Context Variable	Heuristic	Assessment -2 Disagree Strongly	-1 Disagree	0 Neutral	1 Agree	2 Agree Strongly
Iteration	(performance)	There is potential for significant performance increase					
	(fabrication)	A fabrication method can be chosen that will permit iteration.					
	(resources)	The expected cost of iteration is relatively small compared to the total budget.					
	(time)	The expected time to iterate is relatively small to the total project timeline					
	average the above	Low average: pursue one only. <--> High average: pursue several iterations.					
Parallel Concepts	(resources)	There are sufficient resources to prototype multiple concepts.					
	(time)	There is sufficient time to prototype multiple concepts.					
	(ranking)	Rankings of several concepts are very close (e.g. from Pugh chart).					
	average the above	Low average: pursue one only. <--> High average: develop multiple concepts.					
Scaling	(models)	Scaling law(s) will permit accurate system modeling via a scaled build.					
	(feasibility)	Scaling will significantly increase the feasibility of prototyping.					
	average the above	Low average: use a full size model. <--> High average: use a scaled model.					
Subsystem Isolation	(interfaces)	Interfaces between subsystems are predictable and re-integrable.					
	(requirements)	1 or 2 subsystems embody the critical design requirements.					
	(resources)	Testing a subsystem would substantially reduce expense of resources					
	(testing)	Testing of an isolated subsystem will validate a key function					
	average the above	Low average: integrate the system. <--> High average: isolate subsystems.					
Requirement Relaxation	(requirements)	The requirements require refinement					
	(concept)	At this stage, concept development is the most critical					
	(resources)	A reduced requirement prototype will significantly reduce resource usage.					
	(usage)	At this stage it is important to simulate usage scenarios					
	average the above	Low average: use rigid requirements. <--> High average: relax requirements.					
Virtual Prototypes	(effort)	Virtual prototype(s) will reduce effort compared to a physical one(s).					
	(availability)	The required tools to develop a virtual model are available					
	(data)	A vritual model will provide accurate test data					
	(design)	A virtual model will facilitate other needs: complex topology, integrated testing					
	average the above	Low average: use a physical model. <--> High average: use a virtual prototype.					

Camburn, Bradley & Dunlap, Brock & Gurjar, Tanmay & Hamon, Christopher & Green, Matthew & Jensen, Dan & Crawford, Richard & Otto, Kevin & Wood, Kristin. (2014). A Systematic Method for Design Prototyping. Journal of Mechanical Design. 137. 10.1115/1.4030331.

Product Development in Industry

- Is different for different industries
  - Consumer Product Design → Agile Design Methodology
  - Defense and B2B Products → Waterfall, TRL/MRL
- Agile Design Methodology
  - Focused on iteration and revisions
  - More qualitative
  - More classically associated with Industrial Design
- Technology/Manufacturing Readiness Level
  - Focused on risk evaluation
  - More quantitative
  - More associated with Engineering
  - For products/projects over $1M