Product development & engineering design

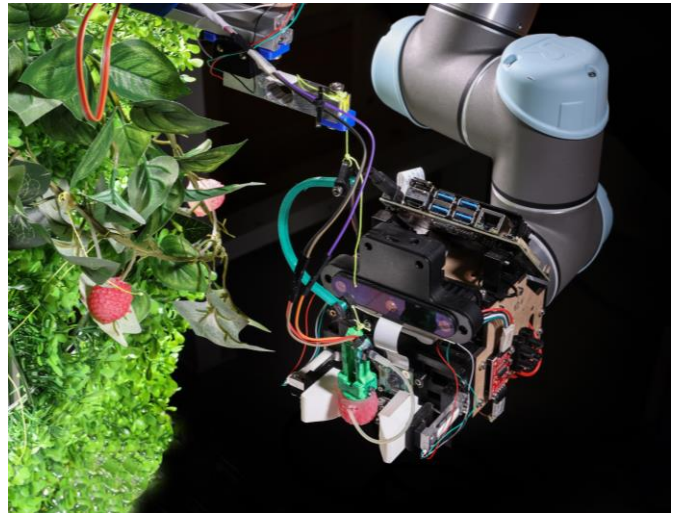
ME-320

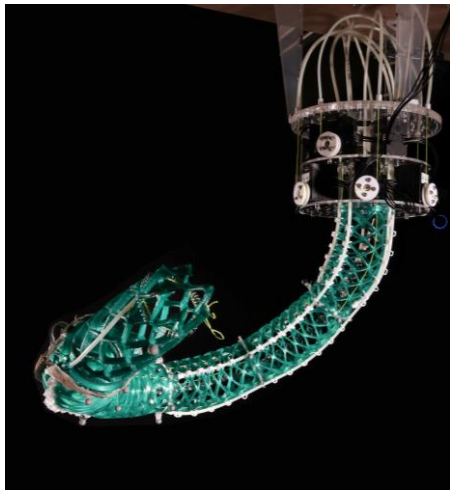
PROF. JOSIE HUGHES

Lecture 1: Introduction, Motivation & Project

About Me…

- MEng, Information Engineering, University of Cambridge
- PhD, Robotics, University of Cambridge
- Post-doc, MIT CSAIL
- Assistant Professor, CREATE Lab, 2021





Please shout/wave when I talk to fast ☺

Teaching Team

TAs

- Nana Obayashi
- Francesco Stella
- Stefan Ilic
- Sudong Lee
- Cheng Pan
- Arnaud Klipfel

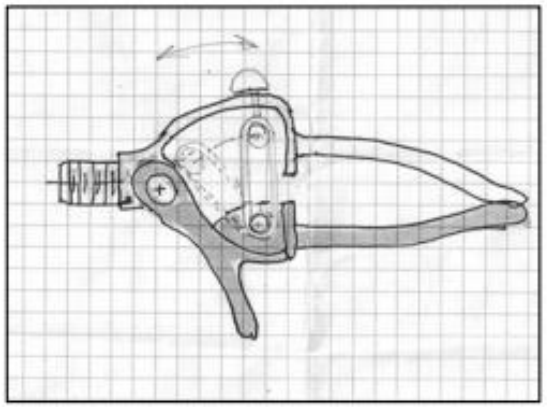
Expertise in Mechanical Design, Electronics, Control & CAD

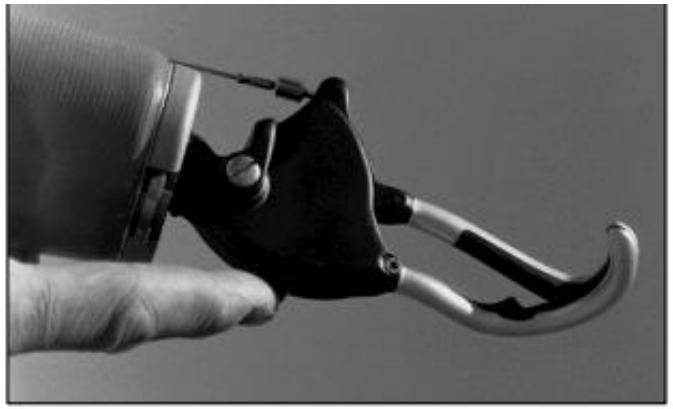
Question for you!

https://ttpoll.com/p/designefpl

What is Product & Engineering Design?

Engineering design is a systematic process in which designers **generate**, **evaluate**, and **specify devices**, systems, or processes whose form and function achieve objectives while satisfying constraints.





"The knowledge of technical systems or analysis is not sufficient to understand the thought processes that lead to successful synthesis or design."

The science of how we make things

Dym, C. L., A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, 2005, "Engineering Design Thinking, Teaching, and Learning," ASEE Journal of Engineering Education 94(1):103-120.

Product & Engineering Design…

"The way we think, a bone is a link; a joint is a bearing; a muscle is an actuator; ligaments and tissues are springs…"
"Superb preparation in good, practical arts -- foundry, forge and machine shop."
- Robert Mann

Informed creative thinking.
- Woodie Flowers

"If you understand people's values better, you can create better products and services for them. That's the future of design.“
- Harry West

Design is a passionate process.
- Alex Slocum

Creativity

Innovation

Understanding people

Problem Solving

Mechanical Design is Central…

Design is driven by **fundamental mechanical** engineering concepts applied to solve problems

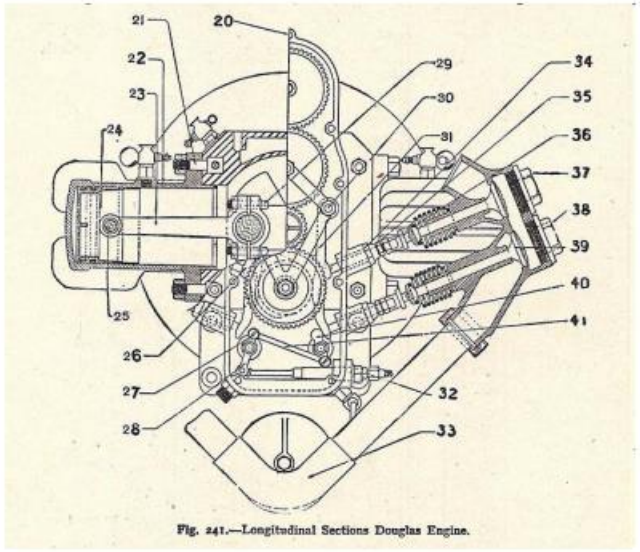
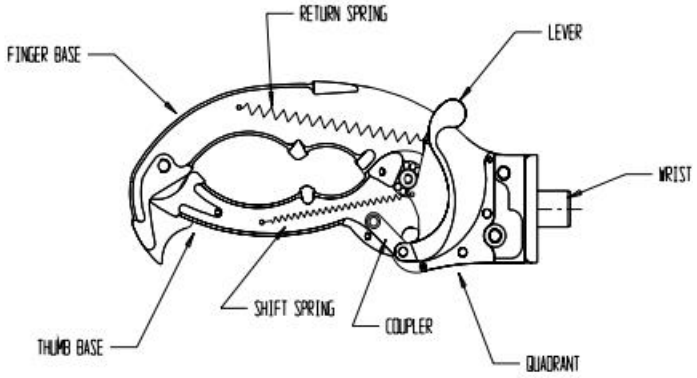
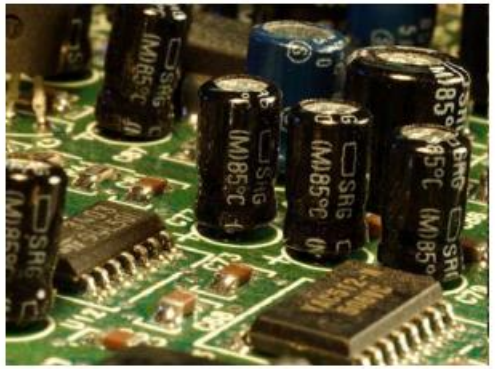


Fig. 241.—Longitudinal Sections Douglas Engine.



Courtesy of TRS Inc. Used with permission.



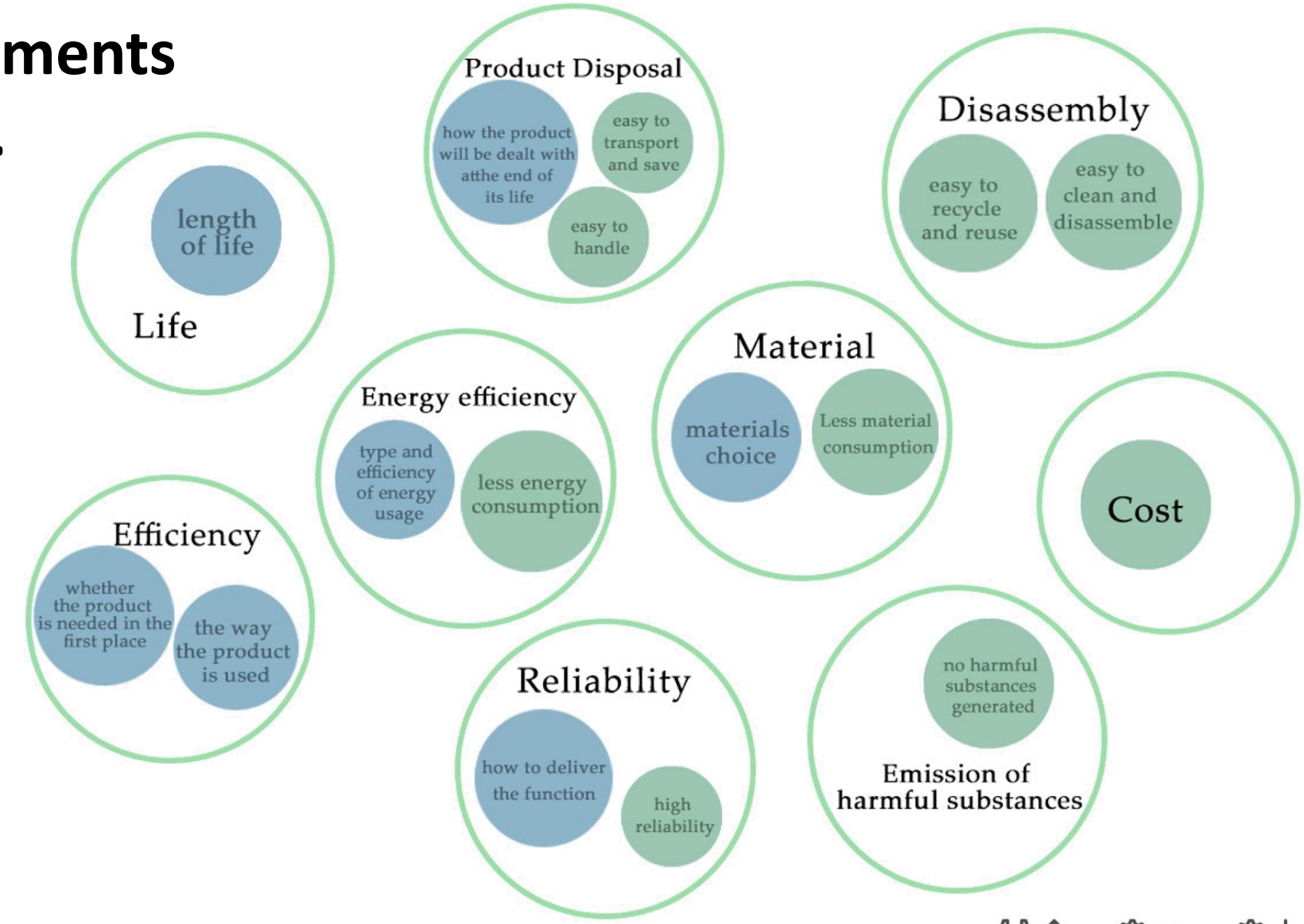
Product & Engineering Design…

Why it is in important?

Increasing need for energy and resource efficiency.
Need innovative and creative solutions.

Product & Engineering Design…

The requirements must shift…



Product & Engineering Design…

Suggestions for examples of successful product design.

Notable Examples: Successes

iPhone

- Clean, dependable and quality products.
- Design is a key focus
- Focus on user experience

Takeways: Good technology and good aesthetics, fills a user need

Notable Examples: Successes

Automatic Transmission

Offered convenience, easy of use and improved strength

Takeaway: Filled a need, improved life for the consumer.

Notable Examples: Successes

Ball point pen

During several decades many inventors tried to improve on the fountain pen without much practical success.
Ball point offered low cost, effective alternative

Takeways: Filled a market need, low cost and effective

Product & Engineering Design…

Suggestions for examples of failed product design.

Notable Examples: Failures

Juciro: Wifi Juicer

- Over-engineered, overly complex device, which included 400 custom parts
- Replaces simple squeezing of fruit
- Does a juice machine truly need to be connected to the internet?
- Juicero was a pricey appliance $400

Takeway: Avoid over-engineering, ensure you understand consumers

Notable Examples: Failures

Google Glass, wearable, voice-controlled Android device that resembled a pair of eyeglasses and was aimed at eliminating mobile devices.

The Failure: It cost $1,500, looks unappealing, privacy concerns and lack of product support.

Takeaway: Ensure there is a market need

Notable Examples: Failures

Microsoft Zune: Mp3 player

- Released 5 years after the first iPod
- Functioned as well as an ipod
- Despite >$9million on advertising, poor sales
- Was not better than an ipod, and less ‘cool’

Takeaway: Don’t copy competitors, you need creativity or improvement

Good Design is…

01. **Good Design is innovative.**

02. **Good Design makes a product useful.**

03. **Good Design is aesthetic.**

04. **Good Design makes a product understandable.**

05. **Good Design is unobtrusive.**

06. **Good Design is honest.**

07. **Good Design is long-lasting.**

08. **Good Design is thorough down to the last detail.**

09. **Good Design is environmentally friendly.**

10. **Good Design is as little design as possible.**

Dieter Rams

Challenging as subjective, depends on application, depends on the needs

Product & Engineering Design…

…is Research and Development

Research:
Technology Development

- Unstructured methods
- Difficult to plan
- Unpredictable

Development:
Product Development

- Structure methods
- Generally planned
- Predictable

Product & Engineering Design…

Technology Development

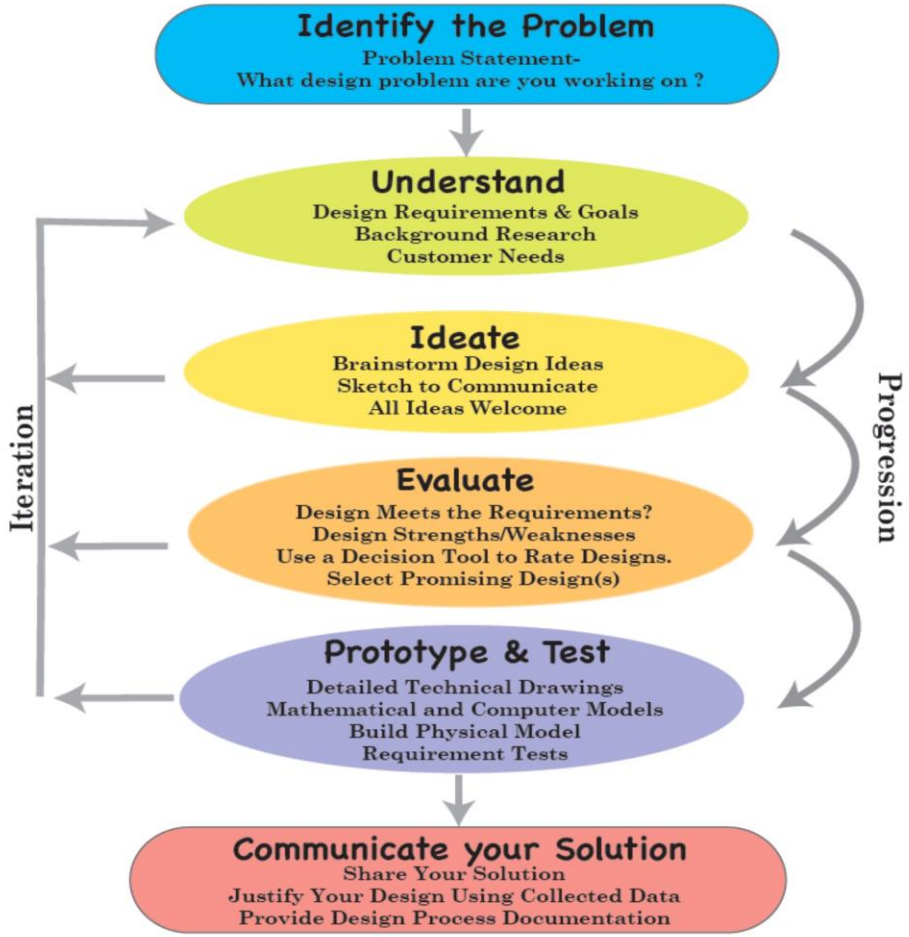
Engineering Principles (component level):

- Mechanics
- Materials
- Electronics
- Software/control

System level integration

Manufacturing/production

Product Development Methodology



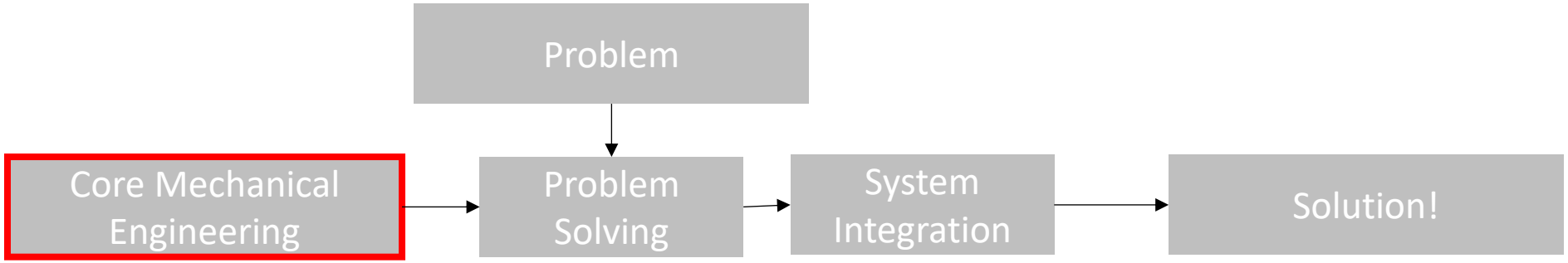
Learning Objectives

- Understand the Product Development Process
- Learning By Doing
  - Apply tools learned in class
  - Apply and share existing knowledge
  - Improve team work and communication skills
  - Improve project management skills

- Have Fun

Course Philosophy

- Learn by doing
- Experience full product design cycle’
- Real World Problem
- Work in a team
- Build teams reflecting the relevant skill distribution
- Innovative thinking
- Projects open to innovation and brainstorming



Assessment

- 100% Group project
  - Progress reports to TA
  - Project portfolio – ongoing deadlines
  - ‘Competition Score’
  - Final Report

Group Work

- At the end of the project, you will each be individually asked to give a distribution of how you believe you have each contributed to the project, e.g.

  Person A: 30%
  Person B: 25%
  Person C: 25%
  Person D: 20%
  Person E: 0%

- In extreme cases where there is concern regarding lack of input form team members this can be used to adjust the score
- Please come and talk to us as soon as there is a concern regarding a member of the team so we can actively help to fix it!

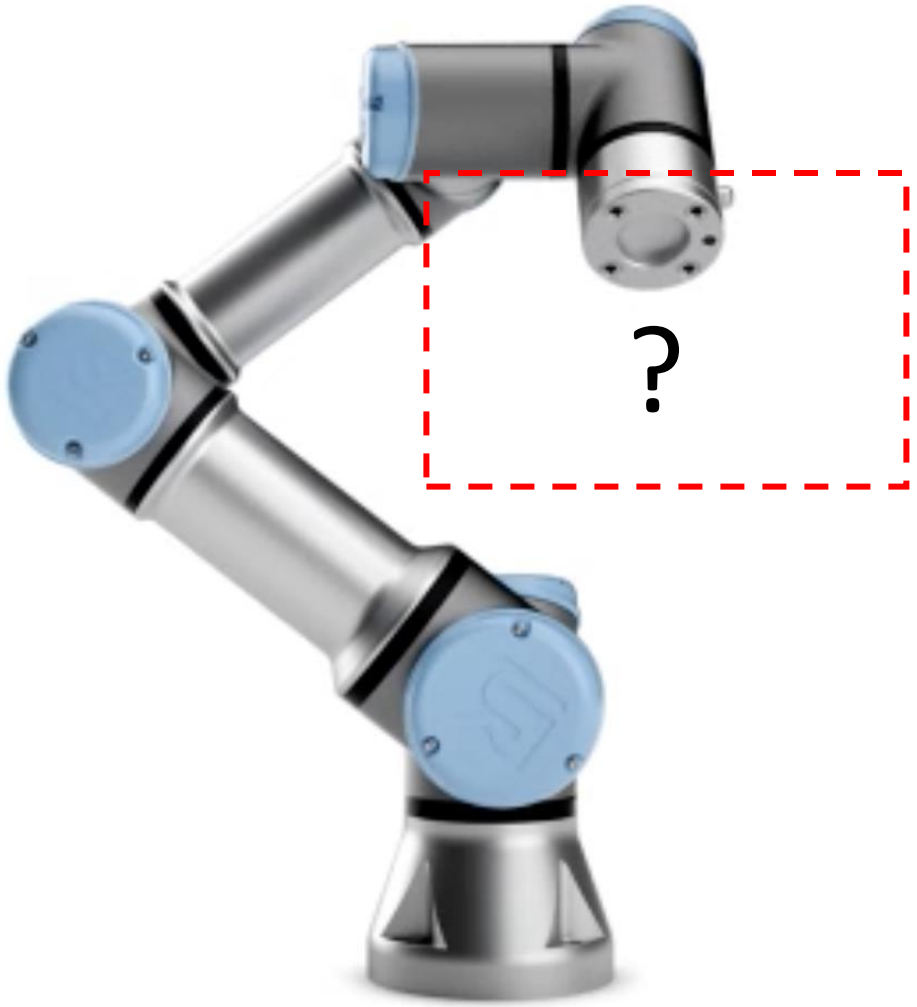
Team Project

- Interdisciplinary teams (5 students)
- Feedback from TAs (Design Reviews)
- Continuous feedback/assistance (project sessions)
- Process “paced” by theory in lectures
- Use DLL/SPOT for development
- Each team will be given a base kit or set of parts with additional parts available on request
- Each team will have an additional ‘budget’ to spend on prototyping, you are responsible for your own budgetting

Schedule

- **Lectures:**
  - First 4-5 week, 8:15-10:00 (for the first 4 weeks)
  - Later weeks, 8:15-9:00
- **Practical Session:** 9-11 (we may need to split everyone into two groups in the SPOT…)
- **Drop-in sessions during the week:**
  - Monday 9-10 ?
  - Friday 12-13 (or any time) ?

Your Engineering Design Problem

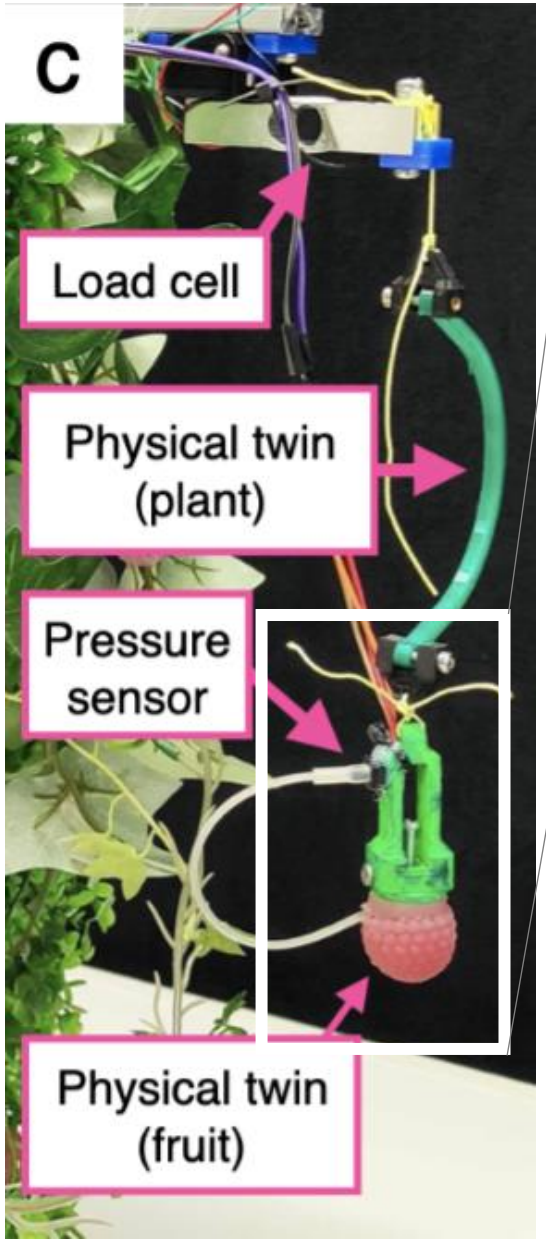


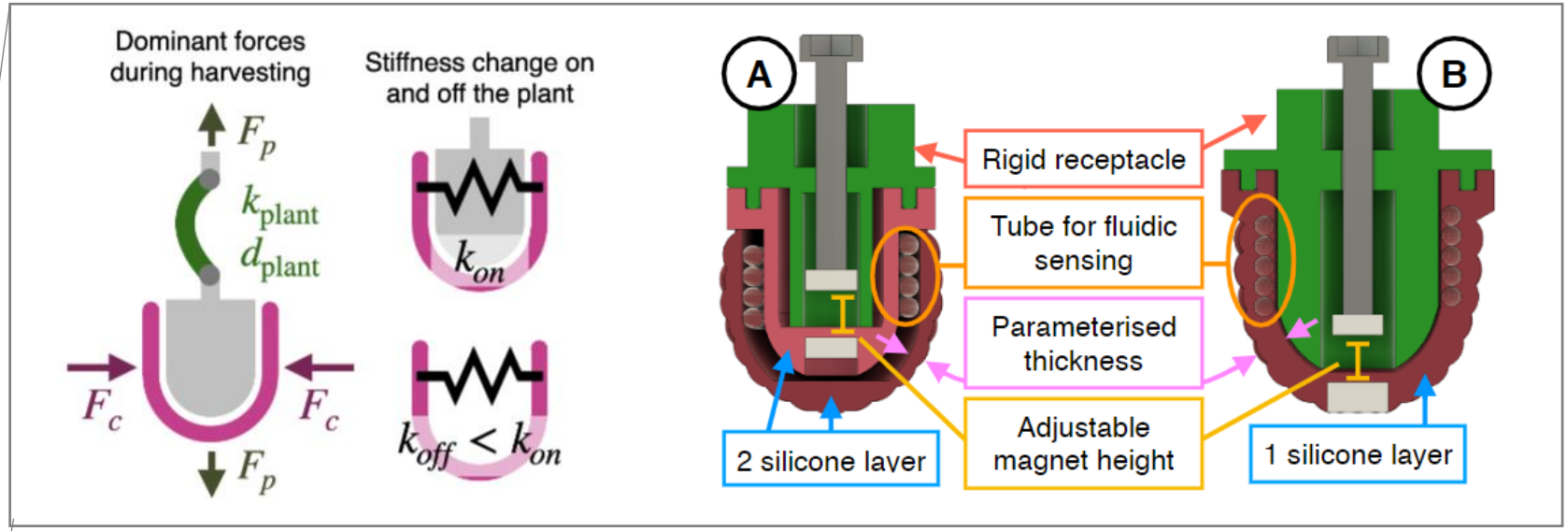
Develop a Robotic Gripper to harvest soft fruit

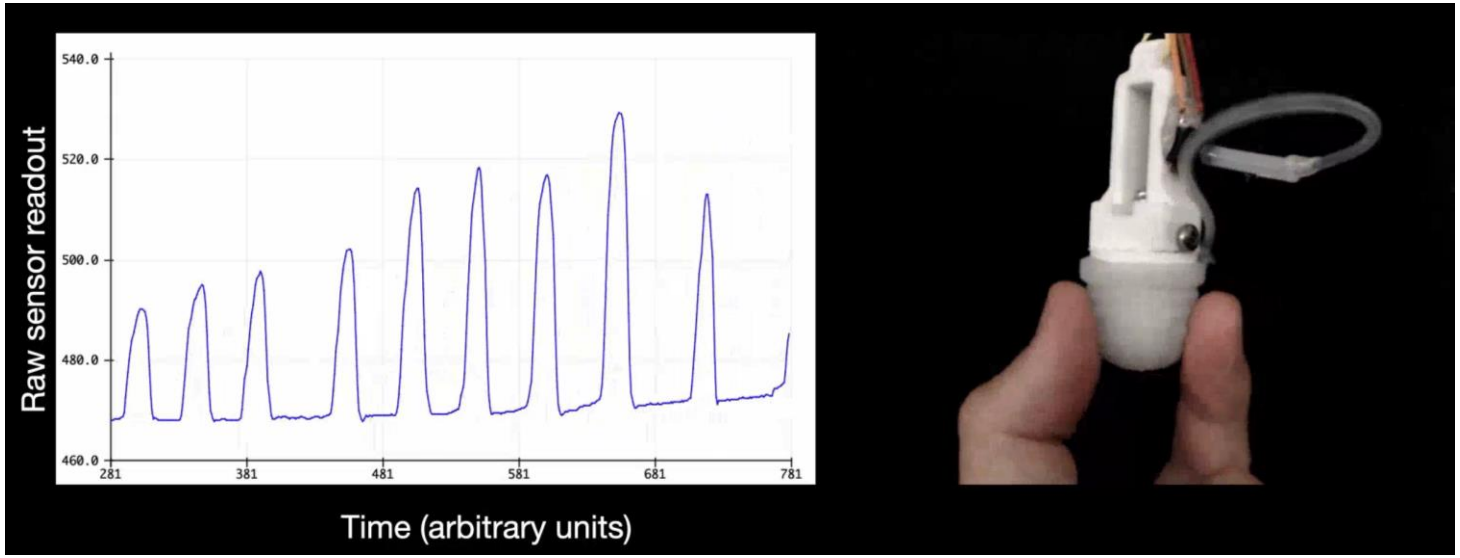
Your Engineering Design Problem

Harvesting **ripe berries** from the plant without damaging them.

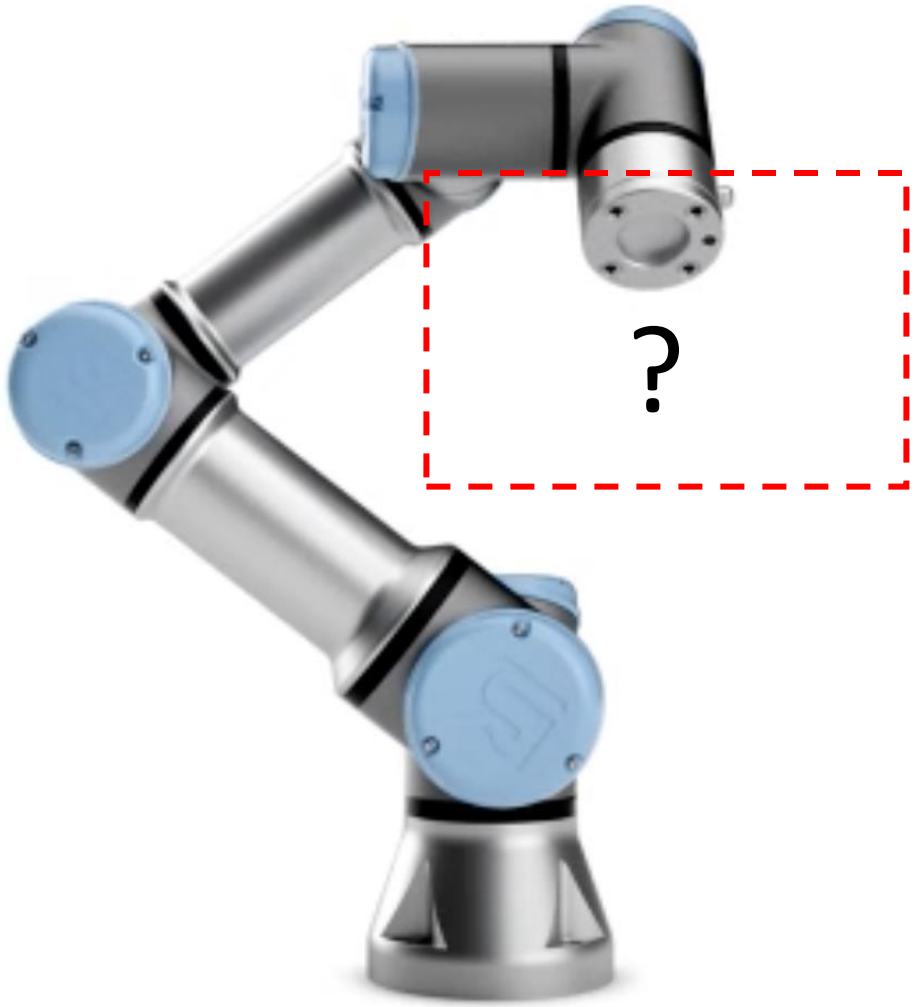
Real world problem → lack of labour for harvesting, food left wasted in the fields


C
Load cell
Physical twin (plant)
Pressure sensor
Physical twin (fruit)


Dominant forces during harvesting
F_p
k_{plant}
d_{plant}
F_c
F_c
F_p
Stiffness change on and off the plant
k_{on}
$k_{off} < k_{on}$
A
B
Rigid receptacle
Tube for fluidic sensing
Parameterised thickness
Adjustable magnet height
2 silicone laver
1 silicone layer


Raw sensor readout
540.0
520.0
500.0
480.0
460.0
281
381
481
581
681
781
Time (arbitrary units)

Your Engineering Design Problem



Develop an end effector for a 6 dof robot arm:

You will have 5 minutes to ‘harvest’ as many raspberries as possible.

Your Engineering Design Problem

Soft Fruit Objects

The fruit (raspberries, blackberries and strawberries) can be of varying color, stiffness and size, however, they have two classes:

- **Ripe fruit** will be red or black and will have a higher conductivity (corresponding to sugar content) in colour and stiffer
- **Un ripe** should be left on the plant. This will be white or lighter red, and will have a lower conductivity.

Fruit (ripe and un-ripe can vary in size from 10mm diameter to a 30mm diameter. If too much force is applied to the fruit it will be considered to be damaged during harvest

Ripe

Un-ripe

Your Engineering Design Problem

Scoring

Object Picking	Score
Pick of ripe fruit without 'damage'	15
Pick of ripe fruit with 'damage'	10
Pick of 'unripe' fruit	-5
Object Detection & Placement	
Detection of ripe or un-ripe fruit	10

Specifications

- The gripper should use no more than 3 actuators
- The gripper should have a size which is less than 20 x 20 x 20 cm
- The gripper must be able to be mounted on the end of the UR robot end effector
- To UR5 robot can be manually moved down up/down above the item until at a desired height, the gripper control can then be activated with a single key press, and then robot moved vertically down.
- The identification of the object should be printed to the screen (via. Serial monitor, or other)
- There is a maximum of 5 minutes to attempt as many raspberries as possible.
- Teams have one minute to assemble the gripper onto the robot.

You need to consider….

- Mechanism design for harvesting
- Sensing of ripe and un-ripe
- Force control to grip with enough force

- Efficiency, useability, repeatability, reliability, ease of manufacture, ….

Many Gripping Solutions…

A

Yale Model T42

B

Ultra-Fast Robot Hand

E

OpenBionics Modular Robotic Gripper

F

Compliant Bistable Gripper

C

Active Adaptive Gripper

D

Permanent Magnet Gripper

This is not a trivial problem!

Your Engineering Design Problem

You need to develop:

Overall concept & strategy for solving the problem

Hardware

- Mechanical design
- Actuation & control
- Sensing mechanism
- Interface and control to the gripper

Communication of the solution

- CAD/Diagrams
- Pitch

Project Work

Component	% of grade	Deadline
Teams & DLL Safety	-	Week 2
Concept Section & Gantt Chart	15%	Week 4 (on Moodle)
Design Review 1 (Process Check)	5%	Week 5 (in class)
Design Review 2 (Process Check) & Updated Gantt Chart	5%	Week 8, Nov 6th (in class)
Engineering Drawings, schematics & updated Gantt Chart (	15%	Week 4 (on Moodle)
'Product' Pitch	15%	4th December (in class)
Solution Test Performance	30%	Last two weeks of the semester
2 Page Final Report	15%	8th January
Returning of parts (in the form they were given)	-20%	10th January

Deadlines are Wednesday midnight for that week unless stated otherwise

Activities

	Topic
Week 1	Intro to Design, The project. Design Process, Design Thinking
Week 2	Brainstorming, Ideation and Concept Selection
Week 3	**Guest Lecturer: Research, References and Searching**
Week 4	Prototyping & Sketching
Week 5	Engineering Design: Actuators & mechanisms
Week 6	Engineering Design: Materials, adhesives
Week 7	Engineering Design: Micro-controllers + Sensors
Week 8	3D Printing and Fabrication, Engineering Drawings + FEA
Week 9	Design Review, Pitching, Writing and Communication
Week 10	**Guest Lecturer (Start up Expert)**
Week 11	Reverse Engineering/Learning From Mistakes
Week 12	IP/Copy Right/Approval/Standards/Ethics
Week 13	Process Planning, Manufacturing, Environmental considerations
Week 14	Final Testing in the SPOT

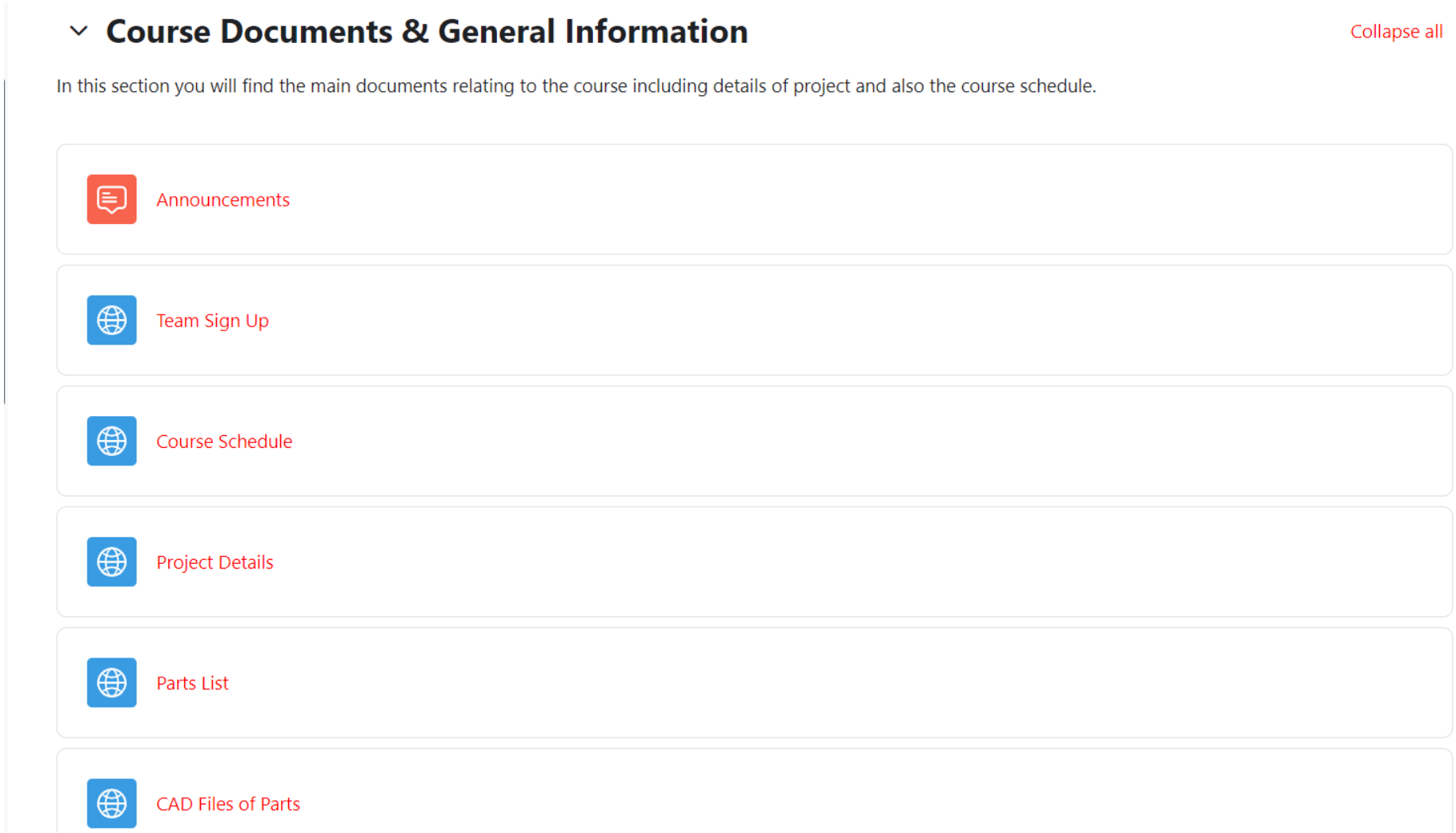
Course Resources

- Moodle
  - Lecture Notes will be posted
  - Recordings of the lectures will be posted shortly after the lecture
  - All project work should be uploaded on Moodle by one member of the team
- Notion Wiki
  - Details of the course and assessment

- Any problems – feel free to email me: josie.hughes@epfl.ch
  This is a **relatively new** course!

  → Please provide feedback as we go!

Moodle: Resources



Notion Wiki

ME-320 Course Home

Welcome to the ME-320 Notion Wiki! Here you will find all the details regarding the course structure, assessment details, pats and equipment.

- Project Task
- List of available equipment
- Assessment Details
- Course Schedule
- Project Groups
- Team Budgets

Any problems, questions, or feedback please get in touch with josie.hughes@epfl.ch

Best of the luck with the course!

Software & Computing…

- CAD Software (Fusion 360 recommended)
  CAD given for standard parts
- Arduino Software
- Python

→ It is up to you, if you have a preference!

Week One: Activities

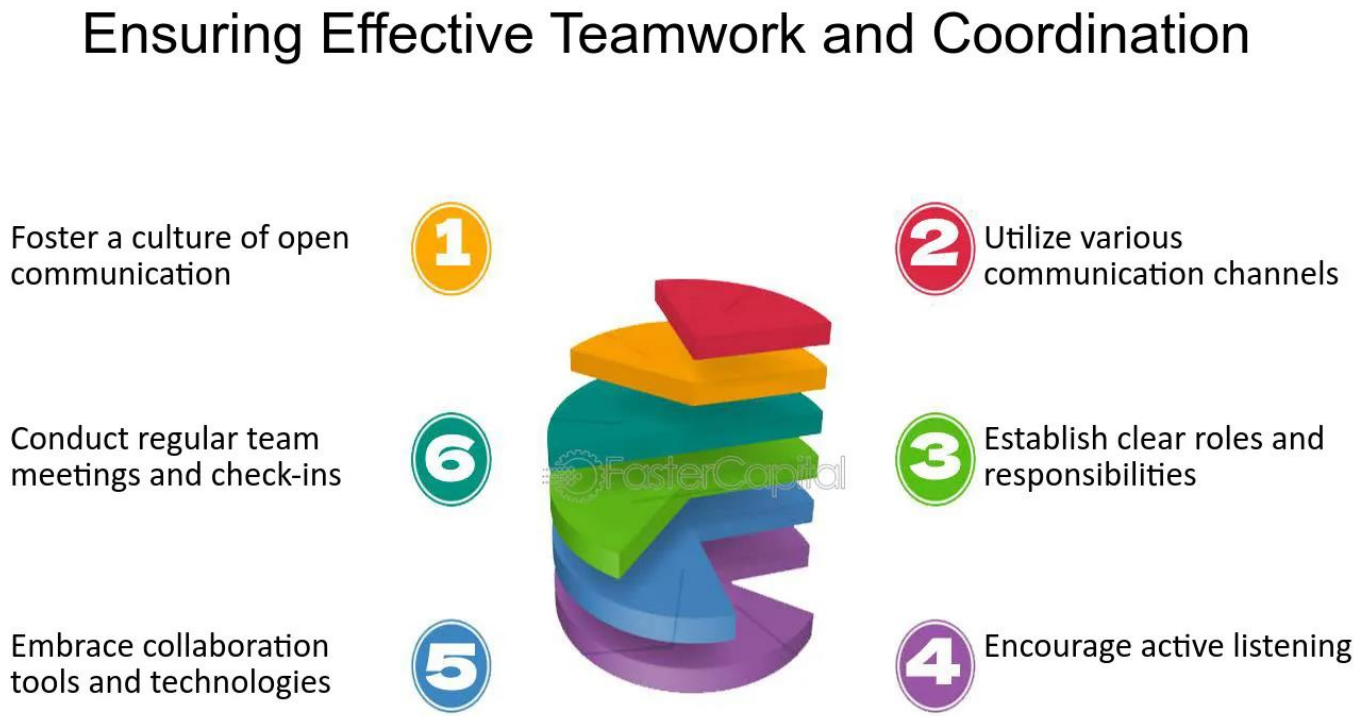
- Form teams of 5
- Sign up on the google doc on Moodle
  If you are not signed up by next week (Tuesday evening), you will be randomly allocated

https://docs.google.com/spreadsheets/d/1GiQcrJ2ttffkiwstNVEjvSFxKUSYCRr5Wniq3QOz7_c/edit?gid=0#gid=0

Team Sign Up

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Team Sign up**												
2	Groups of 5 only. Add Group name, and full details of thoose in the team												
3	Deadline: Tuesday 17th Mid-day												
4	For thoose not registered, you will be randomly allocated												
5	If your name isn't on the list (was taken on 20th Sept), please add your name and email						**I would like to be randomly assisgned**						
6	**Group # and Name**	**Name (First, Last)**	**Sciper**	**Email**			**Name**	**Sciper**	**email**				
7	**Group 1**												
8	**Add group name here**												
9													
10													
11													
12	**Group 2**												
13	**Add group name here**												
14													
15													
16													
17	**Group 3**												
18	**Add group name here**												
19													
20													
21													
22	**Group 4**												
23	**Add group name here**												
24													
25													
26													
27	**Group 5**												

Team Work



In your team, think about:

- What is the appropriate structure, should you have a team leader? Should you split up the tasks?
- How are you going to communicate, what tools are you going to use?
- What are your expectations in terms of work-load and timing – what other courses/loads do you have in the team?

Week One: Activities

- Download the necessary software
  - CAD
  - Arduino
- Safety instructions for using the SPO
  - **Step 1:** Mandatory basic training (even if you have done it before) – available from Friday
  - **Step 2:** Specific training e.g. laser cutting, 3D printing, …., sign up for specific ones (first come first served!)

The training is for an individual, not a group!

Any Questions?

Product development & engineering design

ME-320

PROF. JOSIE HUGHES

Lecture 1: Introduction & Project

The Design Process

The Design Process

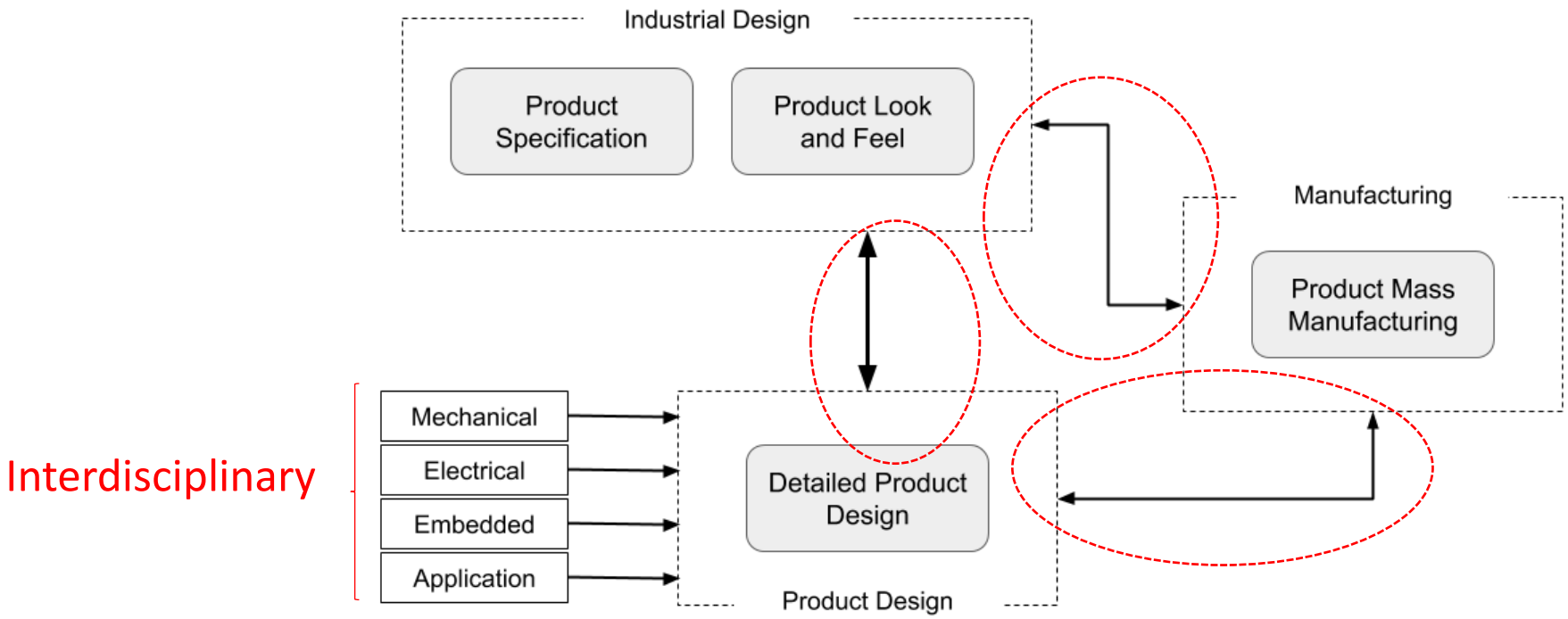
What does design incorporate?

The Design Process

- **Mechanical Design:** the physical principles, the proper functioning, and the production of mechanical systems ← Primary focus
- **Industrial design:** pattern, color, texture and consumer appeal ← But shouldn't be forgotten

The optimum starting point in product development is good mechanical design

The Design Process



- The optimum starting point in product development is good mechanical design
- Different facets of design are inter-related

The Design Process

Starting Point

A market need or a new idea

The Design Process

The end point

Full specification of a product that fills the need or embodies the idea.

The Design Process

Starting Point

A market need or a new idea

The Design Process

The end point

Full specification of a product that fills the need or embodies the idea.

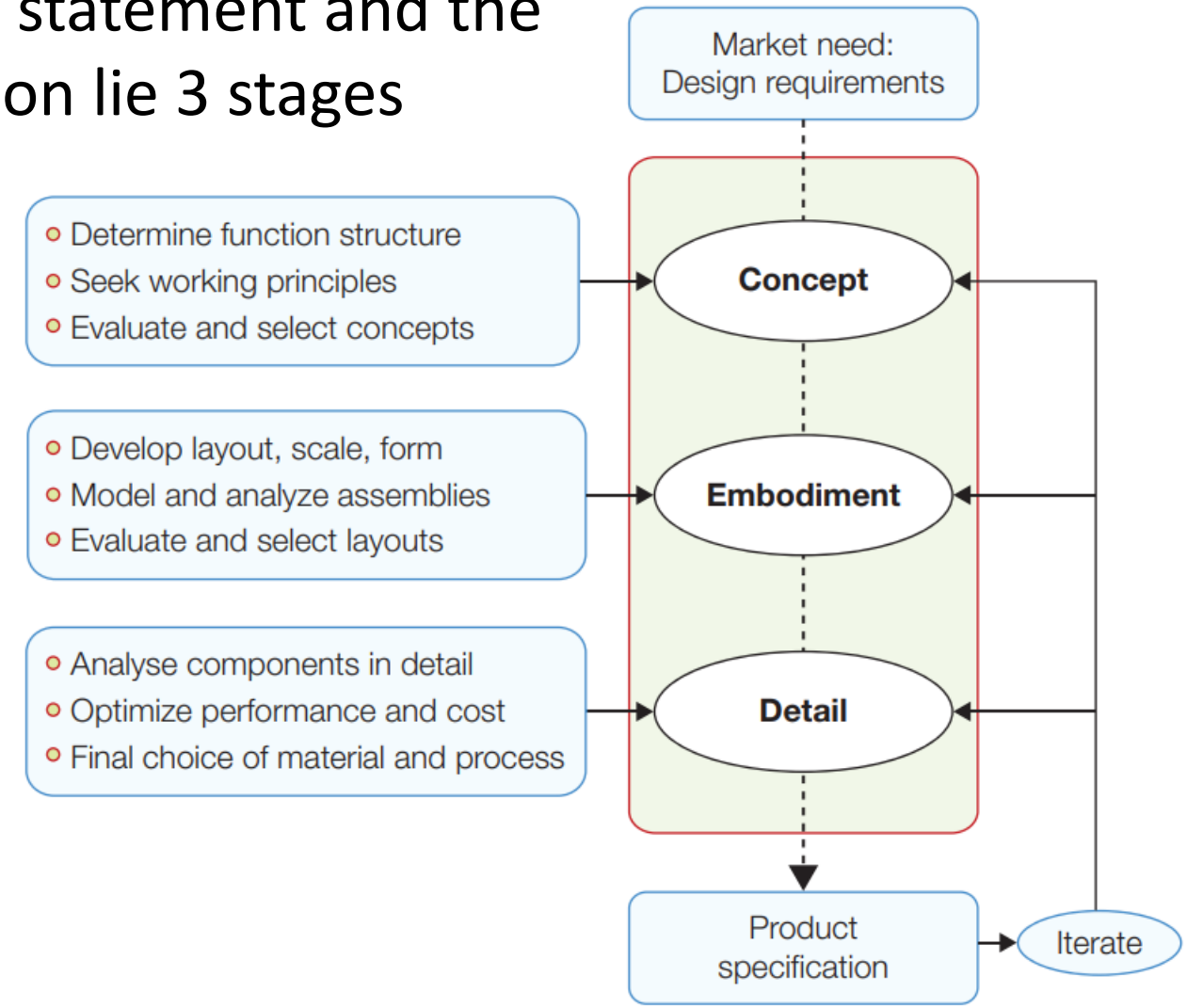
- A need must be identified before it can be met.
- It is essential to define the need precisely

Need Statement: e.g.
"A device is required to perform task X,"
Expressed as a set of design requirements

Should be solution-neutral (that is, it should not imply how the task will be performed)

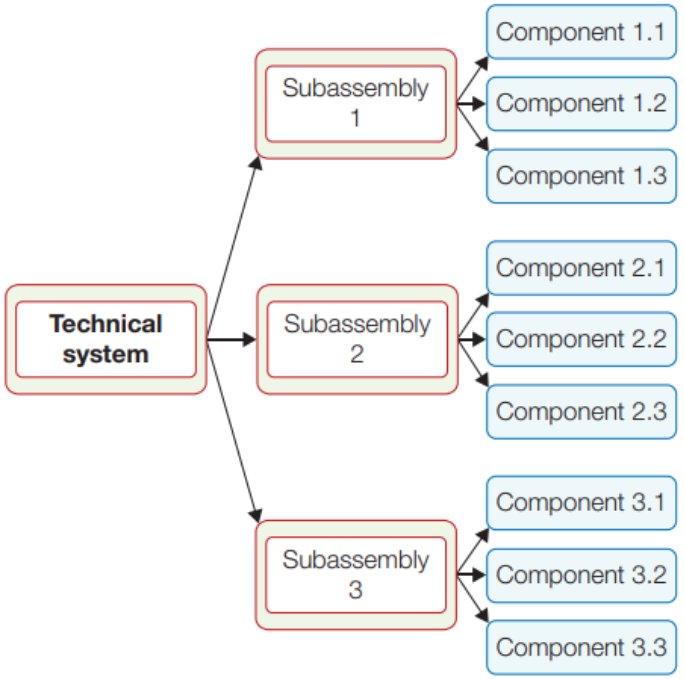
The Design Process

Between the need statement and the product specification lie 3 stages

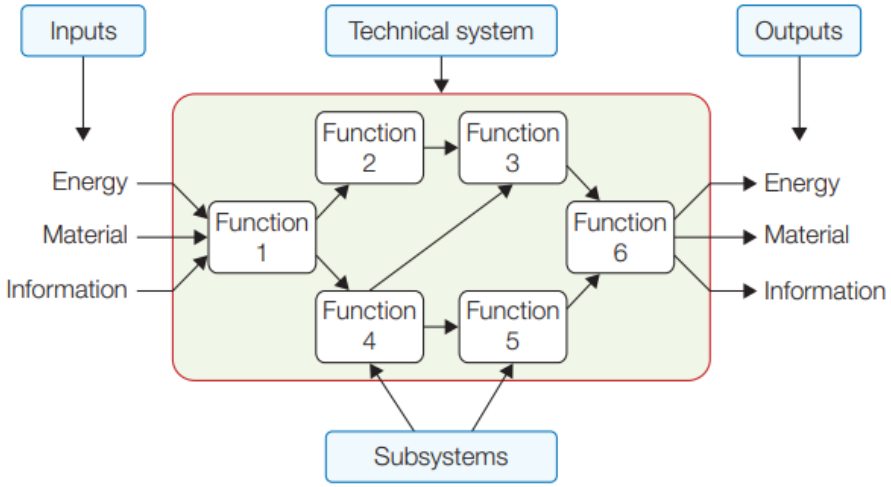


The Design Process

How do we represent concepts?



A technical system

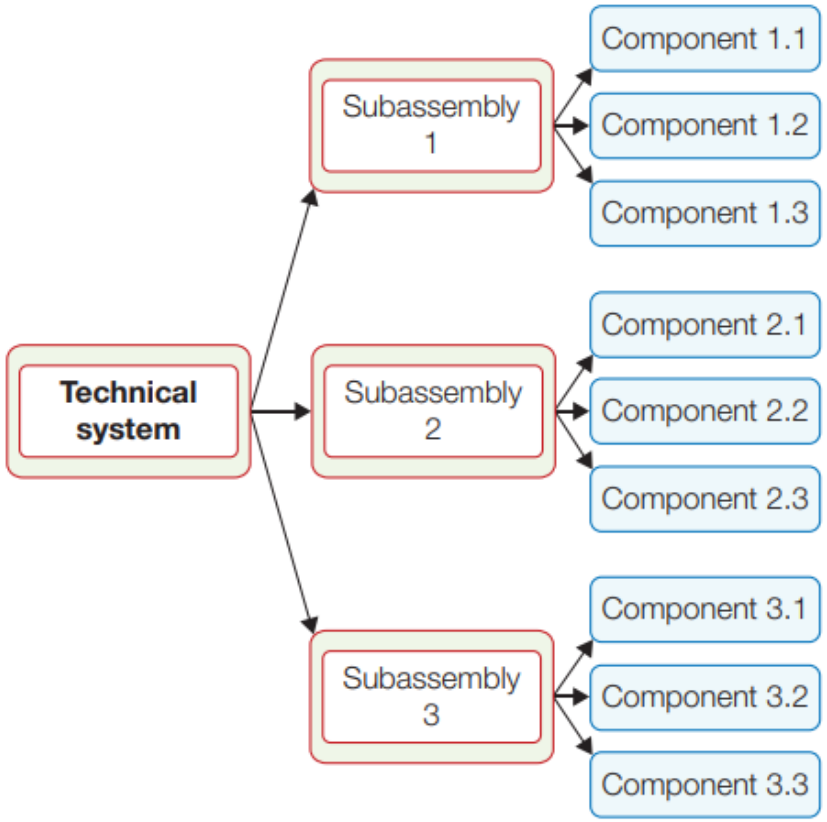


Functional Analysis

The Product: a Technical System

A technical system consists of subassemblies and components that enable the required task.

Cat = System



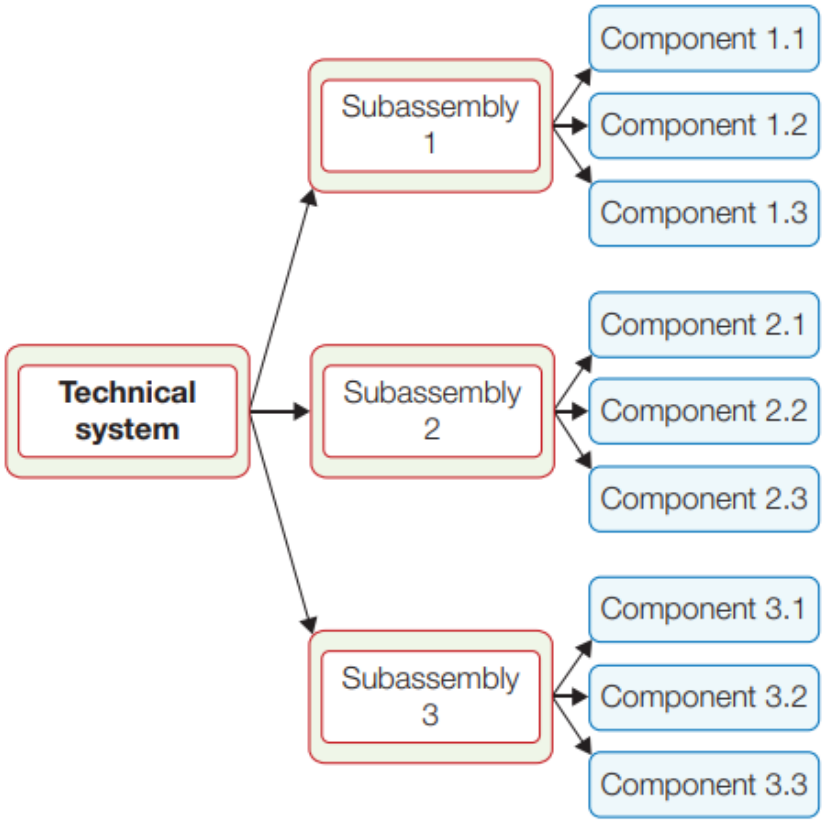
What would a sub-assembly or a component be?

The Product: a Technical System

A technical system consists of subassemblies and components that enable the required task.

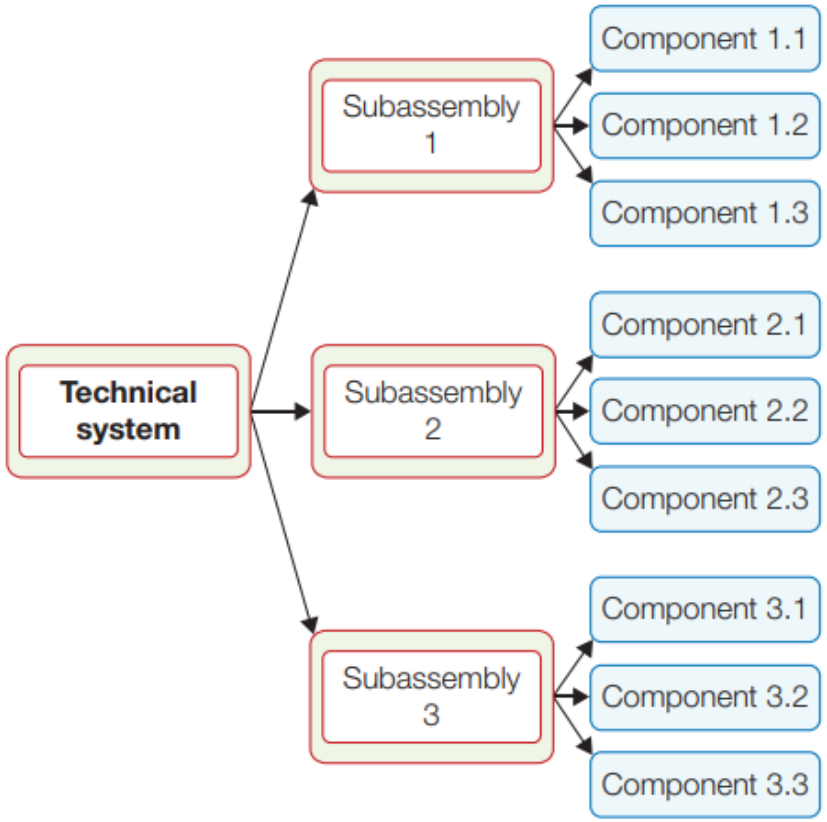
Cat = System

Sub-assembly: head, body, tail, leg
Components: Femurs, quadriceps, claws, fur



The Product: a Technical System

A technical system consists of subassemblies and components that enable the required task.



Decomposition useful for analyzing an existing design but challenging for the design process

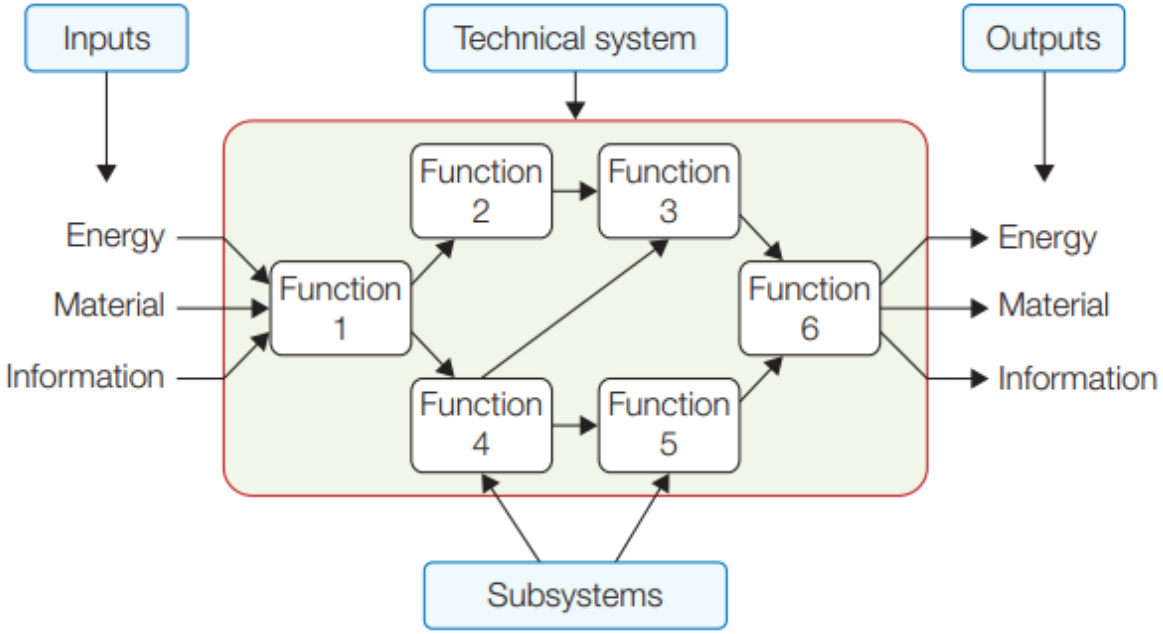
Instead, considering a product as a series or inputs, flows and outputs can be used…

The Product: System Analysis

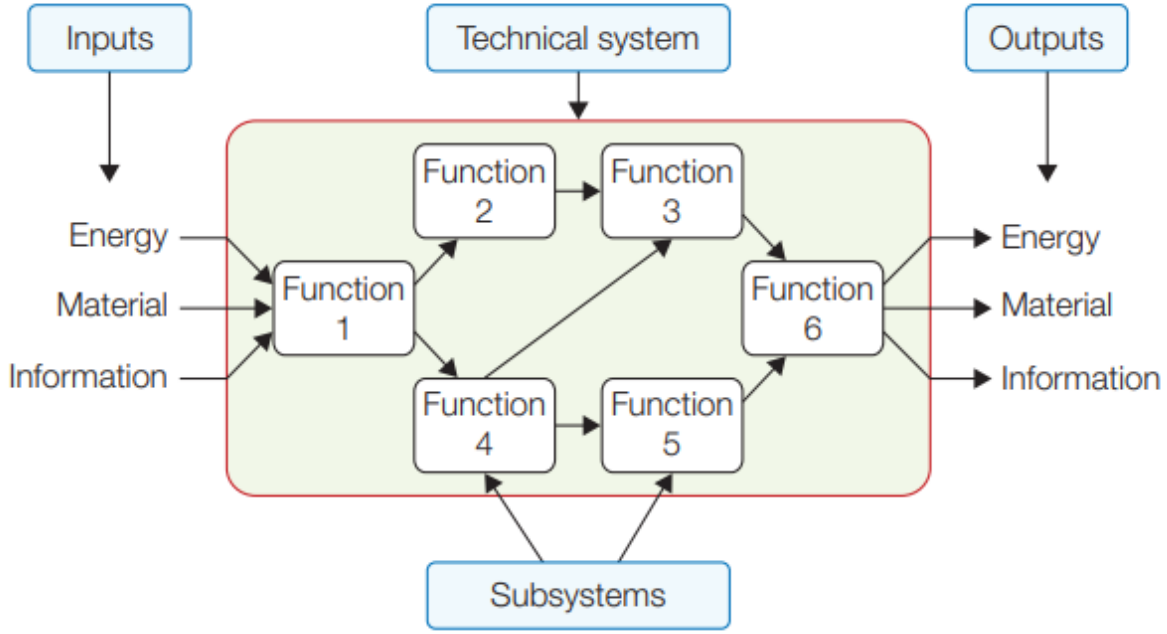
Considers the inputs, flows, and outputs of information, energy, and materials

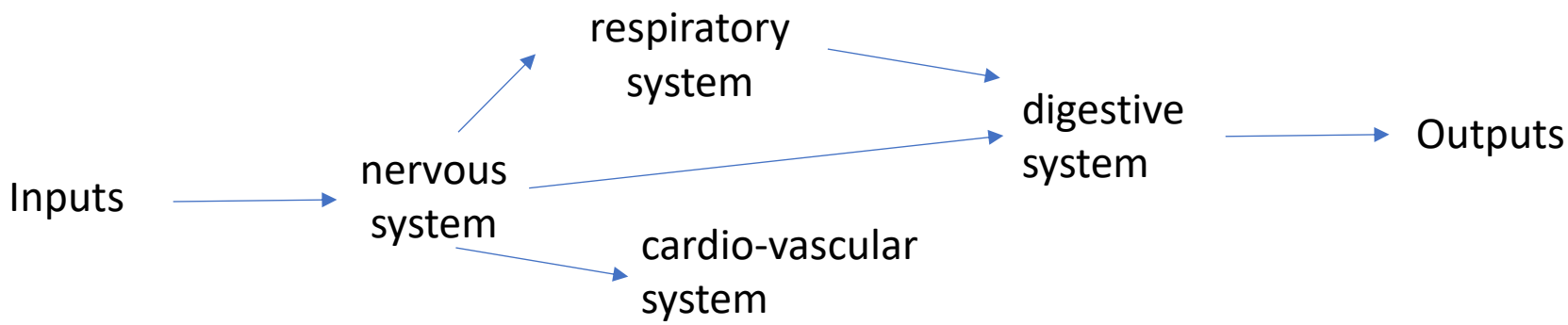
e.g. Motor: Converts electrical into mechanical energy

Alarm: converts information into noise



The Product: System Analysis





The Product Pathway

Functions → **Concepts** → **Embodiment** → **Detailed Design**

Ways of performing the function

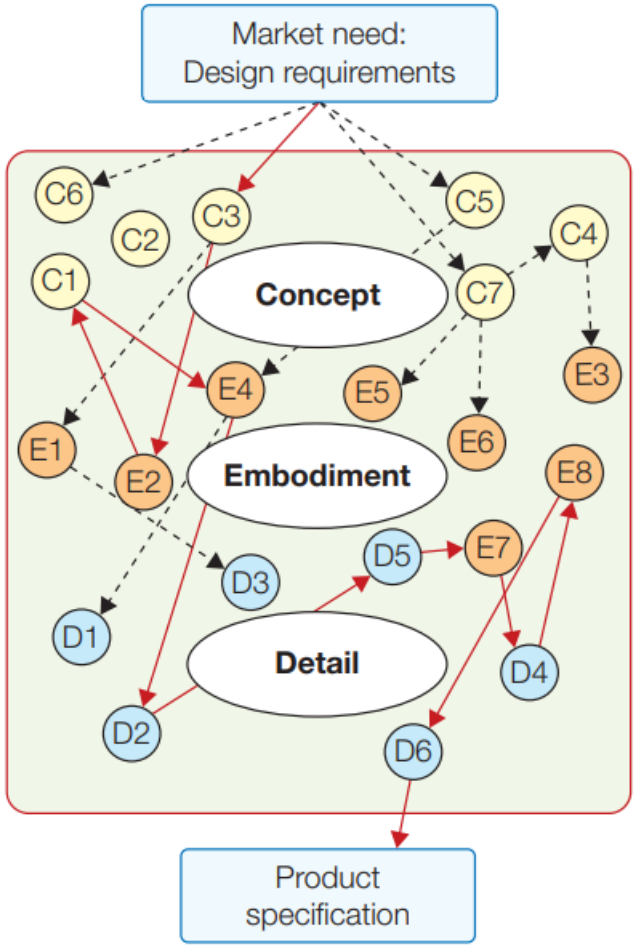
Take promising concepts and analyze.

Drawing, analysis, testing, optimization

↓

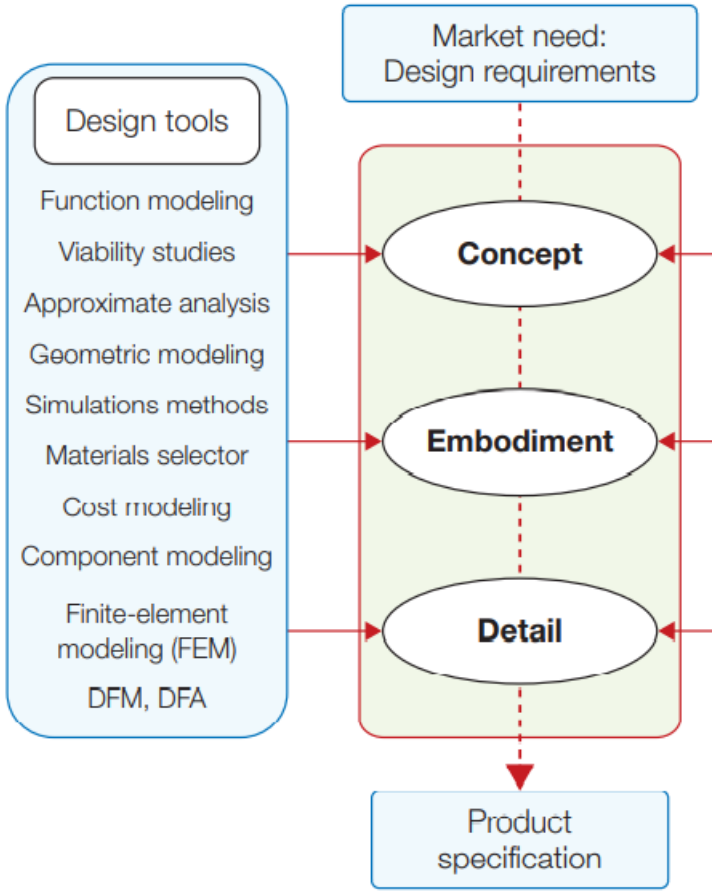
Detailed production specification

The Product Pathway



Convoluted path from market need through to product specification.

Design Tools

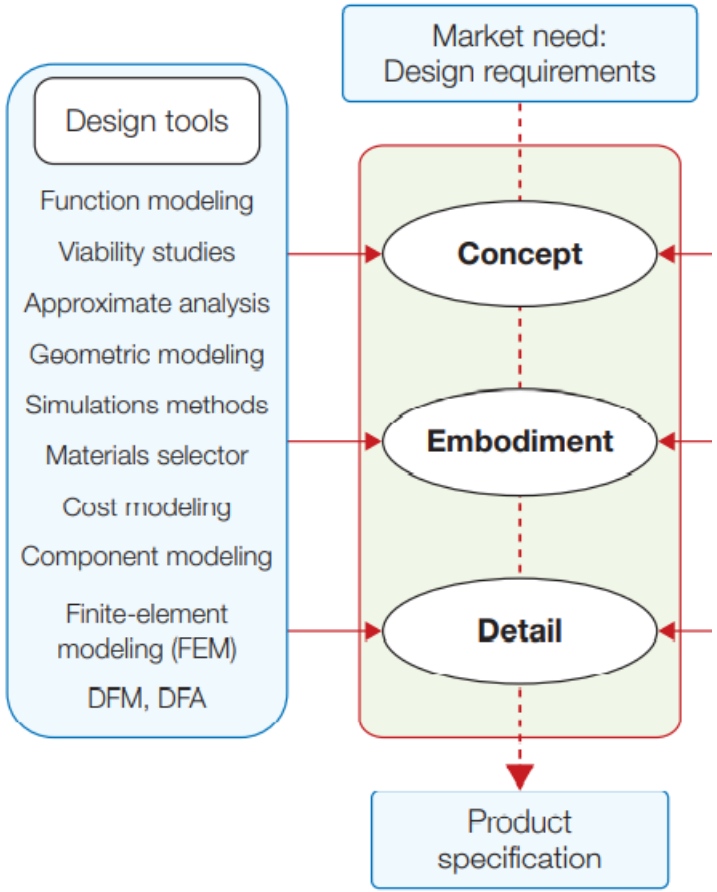


The tools enable the modeling and optimization of a design:

- **Function modelers** suggest viable function structures.
- **Configuration optimizers** suggest or refine shapes.
- Geometric and 3D solid modeling packages allow visualization and create files that can be downloaded to numerically controlled prototyping and manufacturing systems.
- **Optimization**, DFM, DFA, and cost estimation software allows manufacturing aspects to be refined.
- **Finite element (FE)** and computational fluid dynamics (CFD) packages allow precise mechanical and thermal analysis

There is a natural progression of the tools used…

Design Tools



approximate analysis and modeling at the conceptual stage

more sophisticated modeling and optimization at the embodiment stage

and precise analysis at the detailed design stage

Types of Design

Original Design: it involves a new idea or working principle (the ballpoint pen, the compact disc).

- Can be driven by new materials (e.g. high-purity silicone enabled the transitory)
- Can be driven by new demands: space technology stimulated the development of light weight composites

Original design sounds exciting, and it is.
But most design is not like that.

Types of Design

It is not always necessary to start from scratch...

Almost all design is **adaptive or developmental**. The starting point is an existing product or product range.

For example, to:

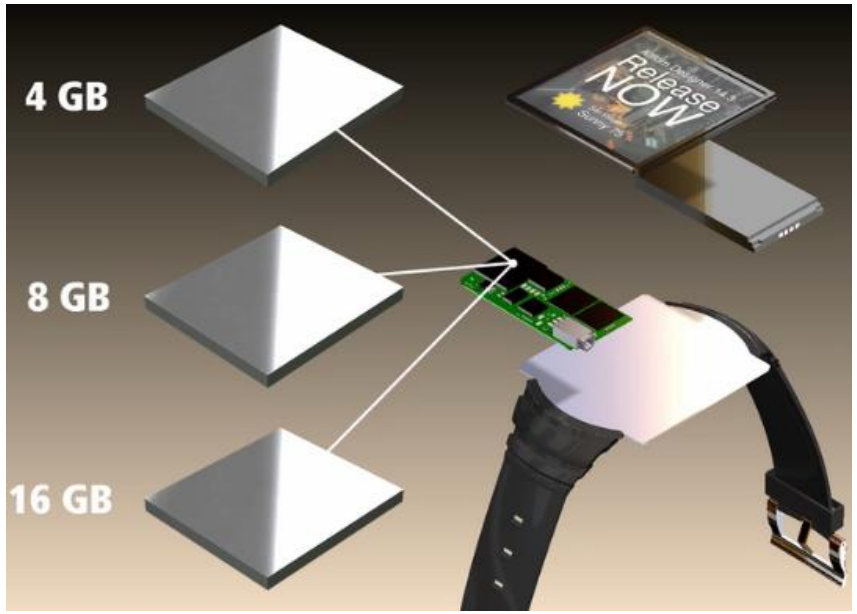
- Enhance performance
- Reduce cost
- Adapt to changing market conditions

Adaptive design takes an existing concept and seeks an incremental advance in performance through a refinement of the working principle.

Types of Design

It is not always necessary to start from scratch...

Variant design involves a change of scale or dimension or detailing without a change of function or the method of achieving it.

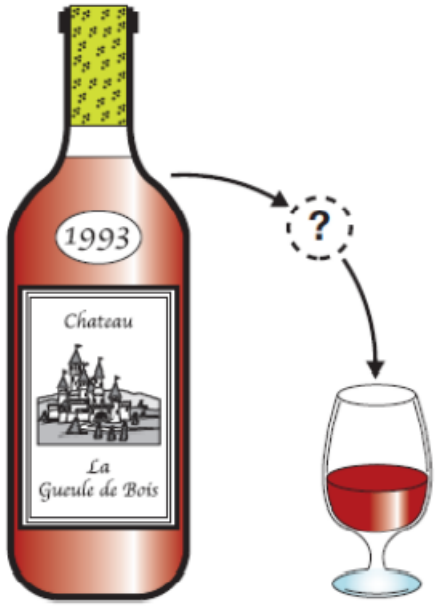


Altium Chips

For example:

- The scaling up of boilers, or of pressure vessels, or of turbines, for instance.
- Change of scale or circumstances of use may require change of material
- Small boats are made of fiberglass, large ships are made of steel; small boilers are made of , large ones of steel

Case Study: Devices to Open Corked Bottles



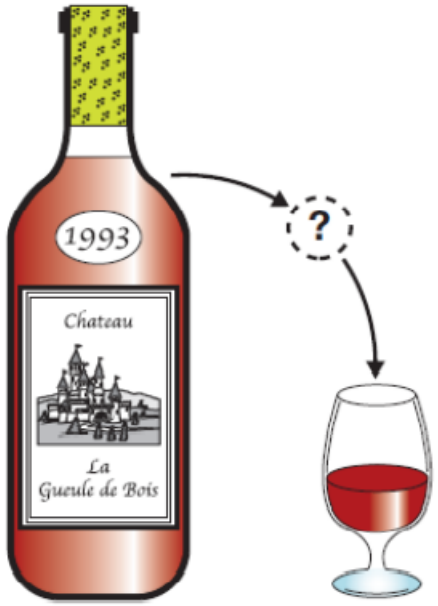
Corked bottle creates a market need
→ Need to access the wine inside.

What is an example of a non-solution neural need statement?

What is a good solution-neural need statement?

Inspired from M. F. Ashby, Materials Selection in Mechanical Design, 4th Edition

Case Study: Devices to Open Corked Bottles



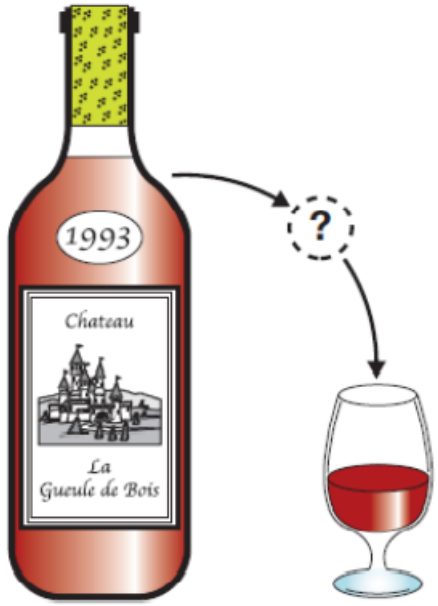
~~"A device is required to pull corks from wine bottles."~~

"A device is required to allow access to wine in a corked bottle with convenience, at modest cost, and without contaminating the wine."

Inspired from M. F. Ashby, Materials Selection in Mechanical Design, 4th Edition

Case Study: Devices to Open Corked Bottles

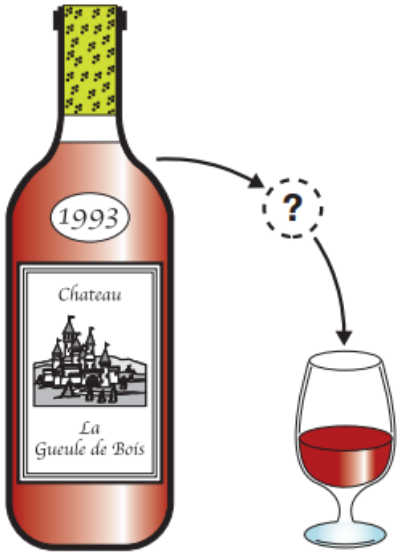
"A device is required to allow access to wine in a corked bottle with convenience, at modest cost, and without contaminating the wine."

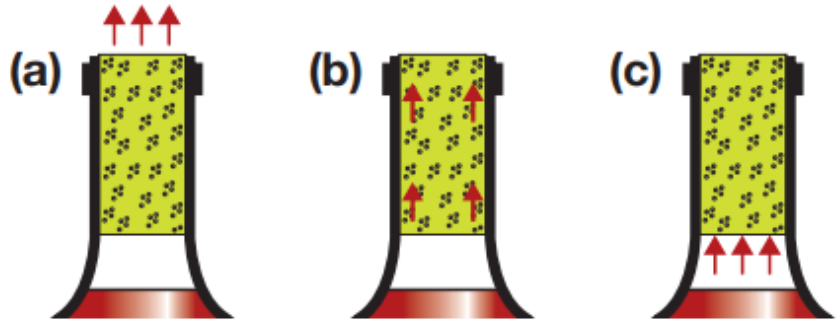


Propose at least four different mechanism to address the needs statement

Inspired from M. F. Ashby, Materials Selection in Mechanical Design, 4th Edition

Case Study: Devices to Open Corked Bottles

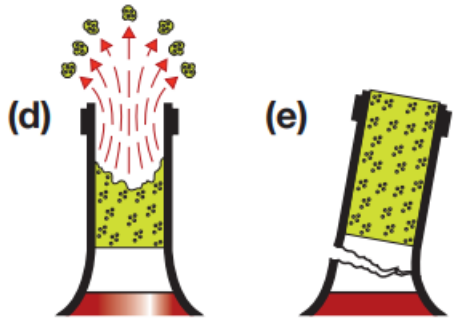




axial traction (pulling)

Shear Traction

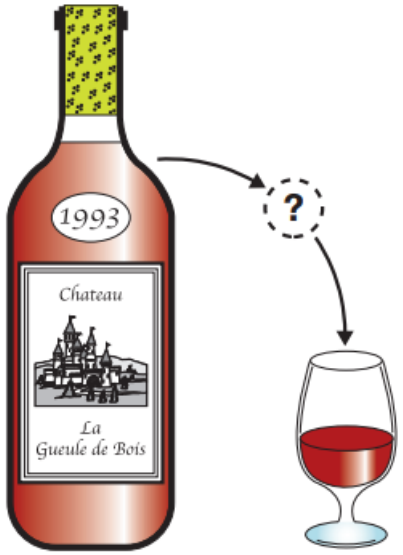
Push from below

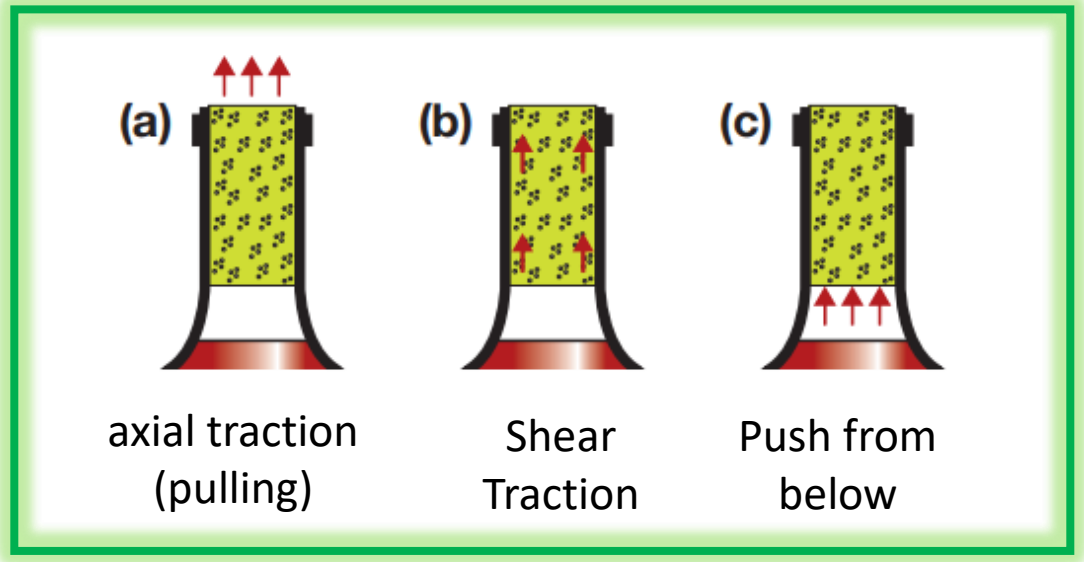


Pulverize the cork

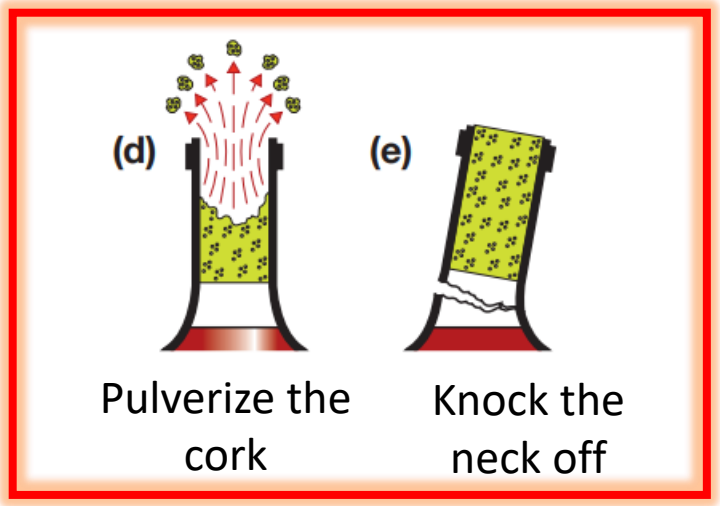
Knock the neck off

Case Study: Devices to Open Corked Bottles



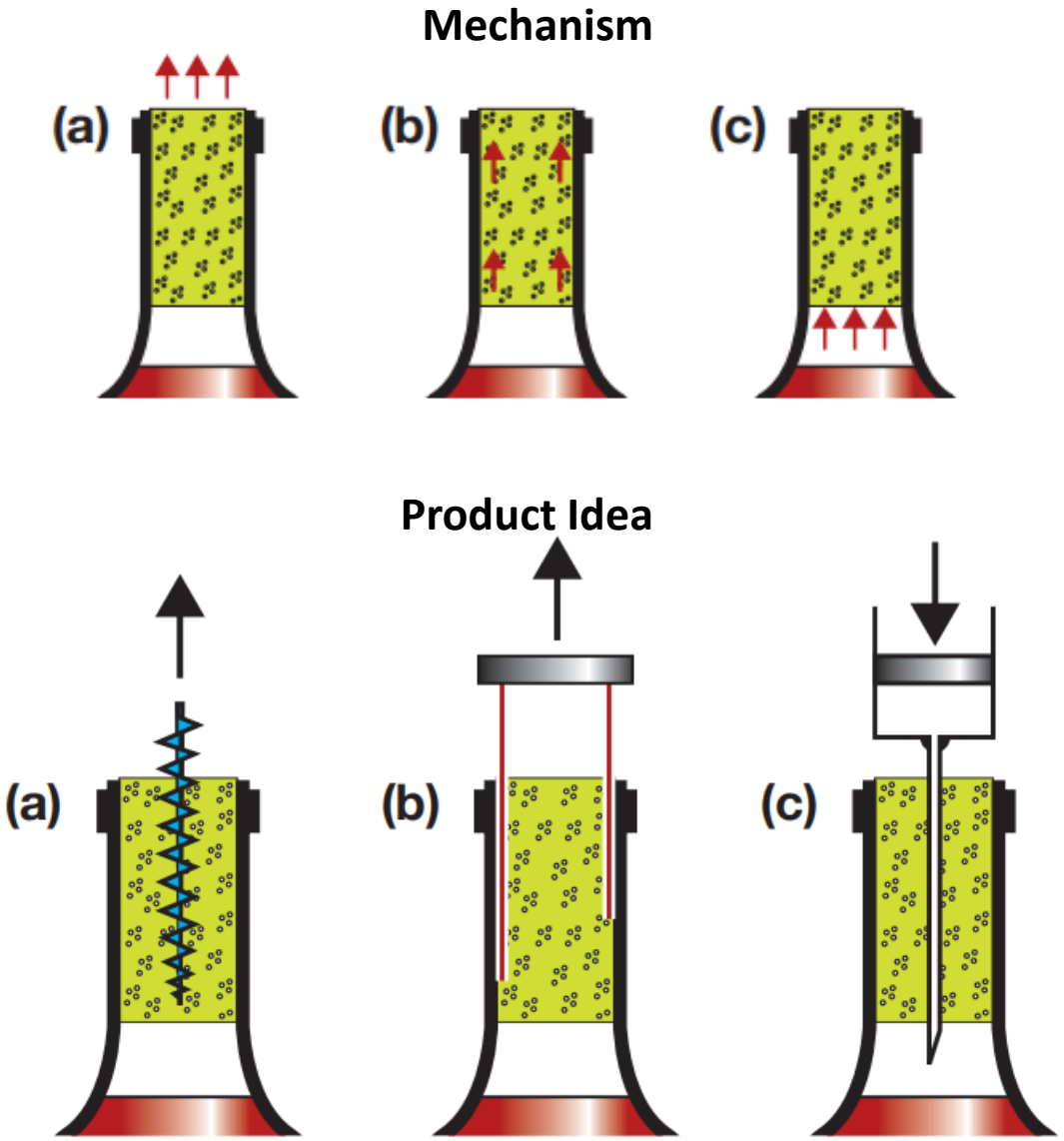


Select as reasonable designs → take forwards



eliminate these on the grounds that they might contaminate the wine

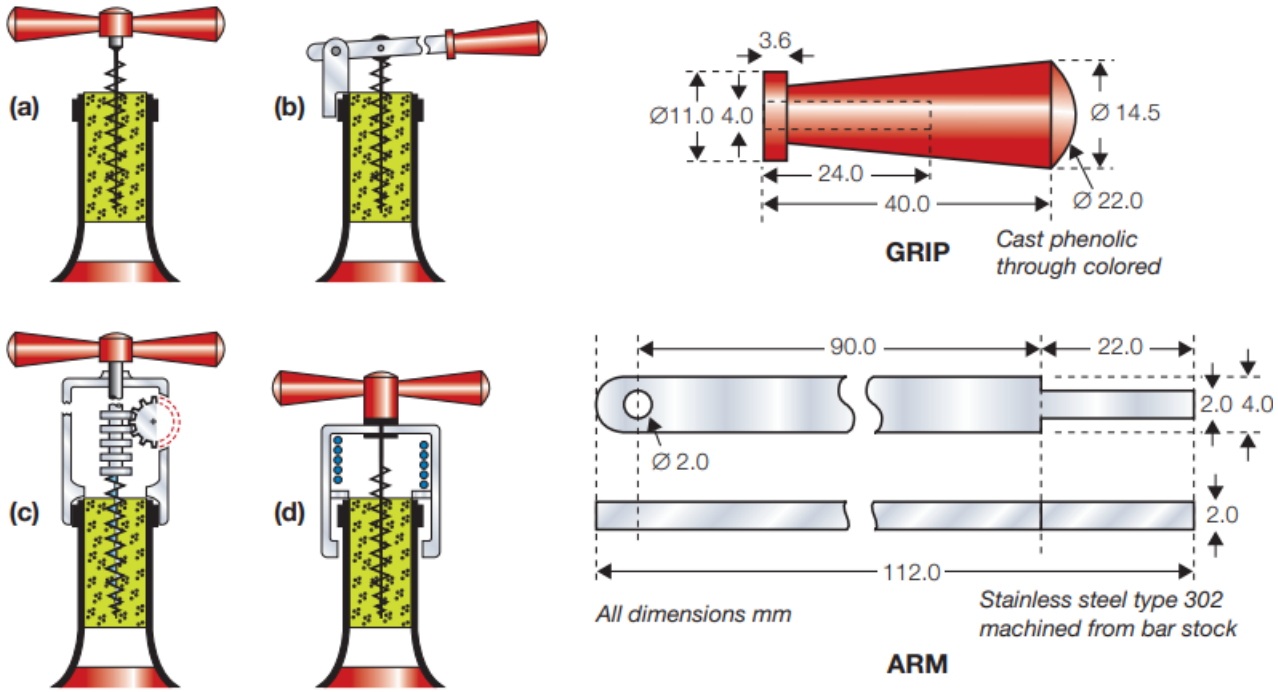
Case Study: Devices to Open Corked Bottles



a) Screw is threaded into the cork to which an axial pull is applied
b) Slender elastic blades inserted down the sides of the cork apply shear tractions when twisted and pulled
c) The cork is pierced by a hollow needle through which a gas is pumped to push the cork out.

Case Study: Devices to Open Corked Bottles

Design Variation



IGURE 2.9

eft: embodiments: (a) direct pull; (b) lever-assisted pull; (c) gear-assisted pull; (d) spring-assisted pull (a spring in the body is ompressed as the screw is driven into the cork). *Right:* detailed design of the lever of embodiment with material choice.

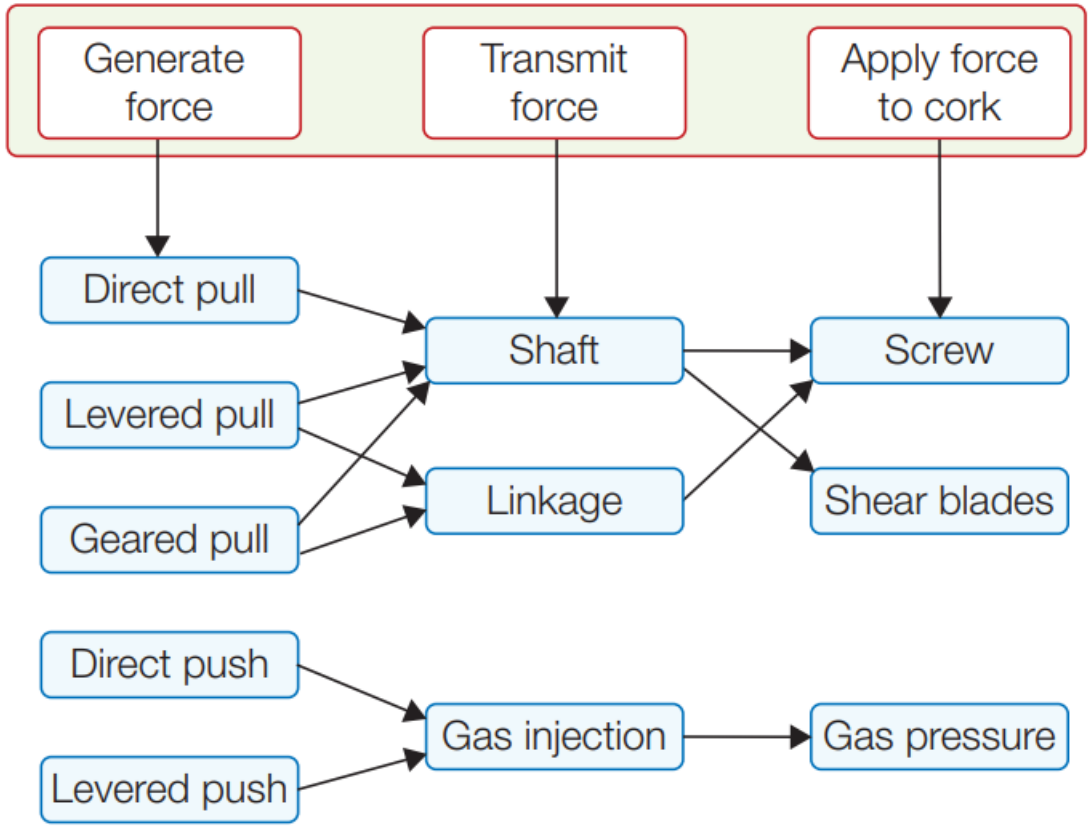
Embodiment sketches for axial traction.

a) The first is a direct pull
b) Levered pull
c) Geared pull
d) Spring-assisted pull

The embodiments identify the functional requirements

Case Study: Devices to Open Corked Bottles

Function Structure



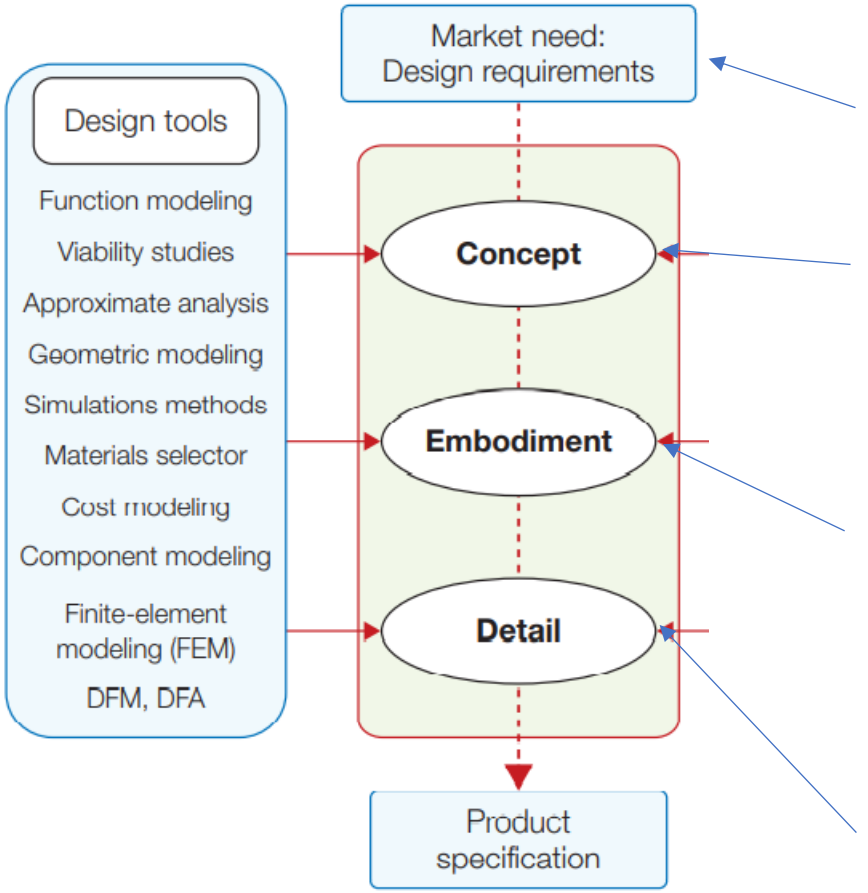
Three functions:

- Generate a force
- transmit a force
- apply the force to the cork

Case Study: Devices to Open Corked Bottles

The final choice of material and process forms part of the detailed stage of design leading to full specifications to enable manufacture

Design Process



Design is an iterative process.

The starting point is a market need captured in a set of design requirements.

Concepts for a product that meet the need are devised.

If concept is believed to be viable, proceed to….

Embodiment: Working principles are selected, size and layout are decided, and initial estimates of performance and cost are made.

If embodiment is believed to be viable, proceed to….

Design Stage: optimization of performance, full analysis of critical components, preparation of detailed production drawings

Design Process: Variations in process

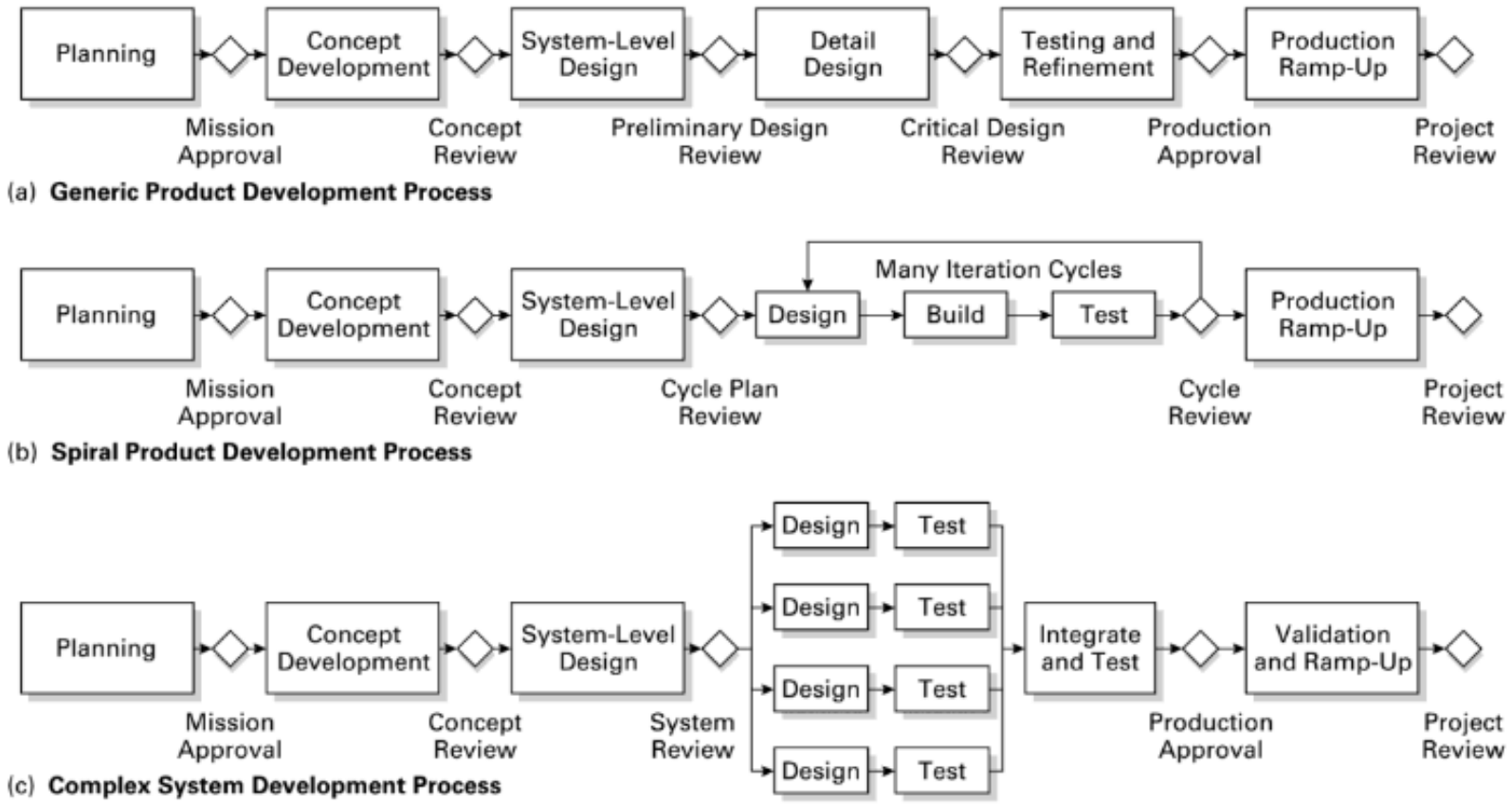
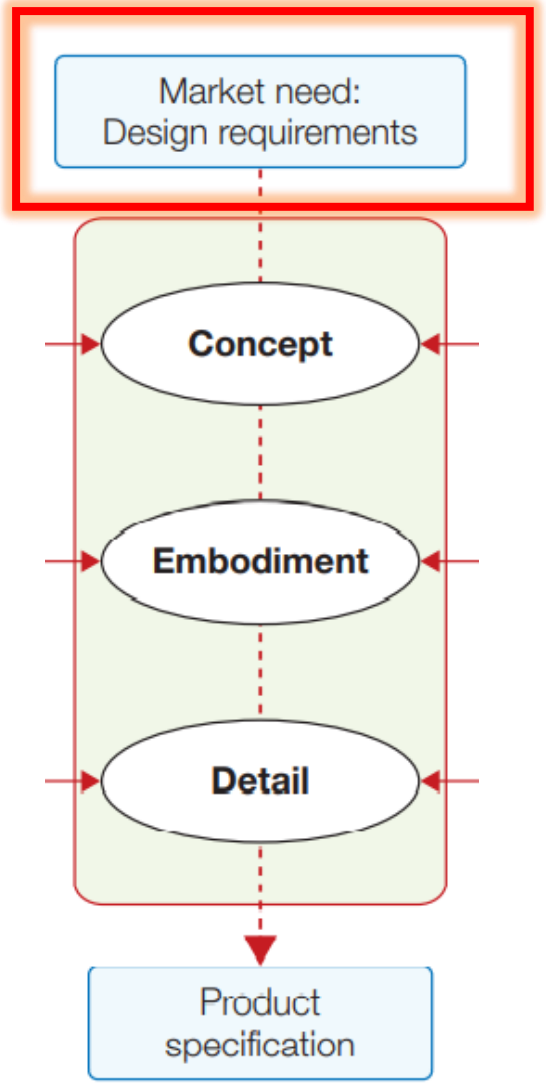
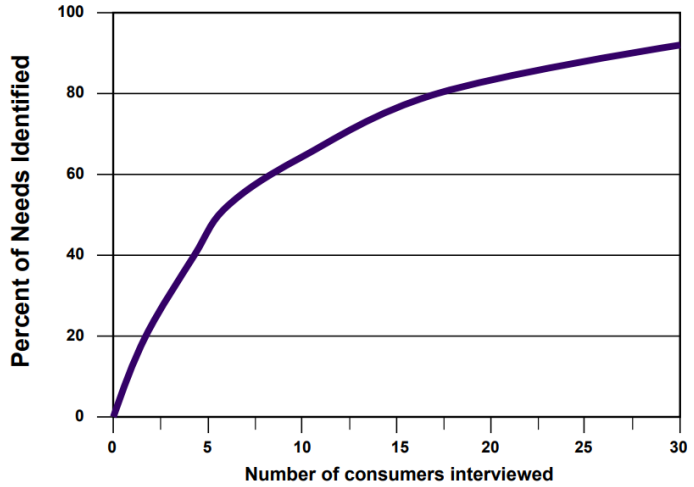


EXHIBIT 2-5 Process flow diagrams for three product development processes.

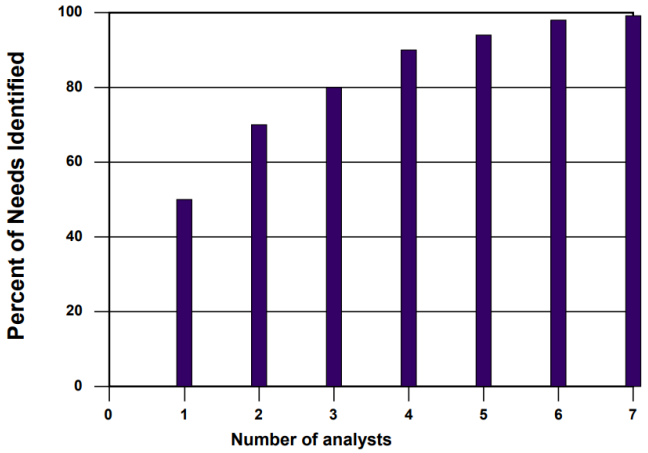
Customer Needs



- Define the Scope
  - Mission Statement
- Gather Raw Data
  - Observation
  - Interviews
  - Focus Groups
- Interpret Raw Data
  - Need Statements
- Organize the Needs
  - Hierarchy
- Establish Importance
  - Surveys
- Reflect on the Process
  - Continuous Improvement



How Many Analysts?



Needs Statement

Structing Needs

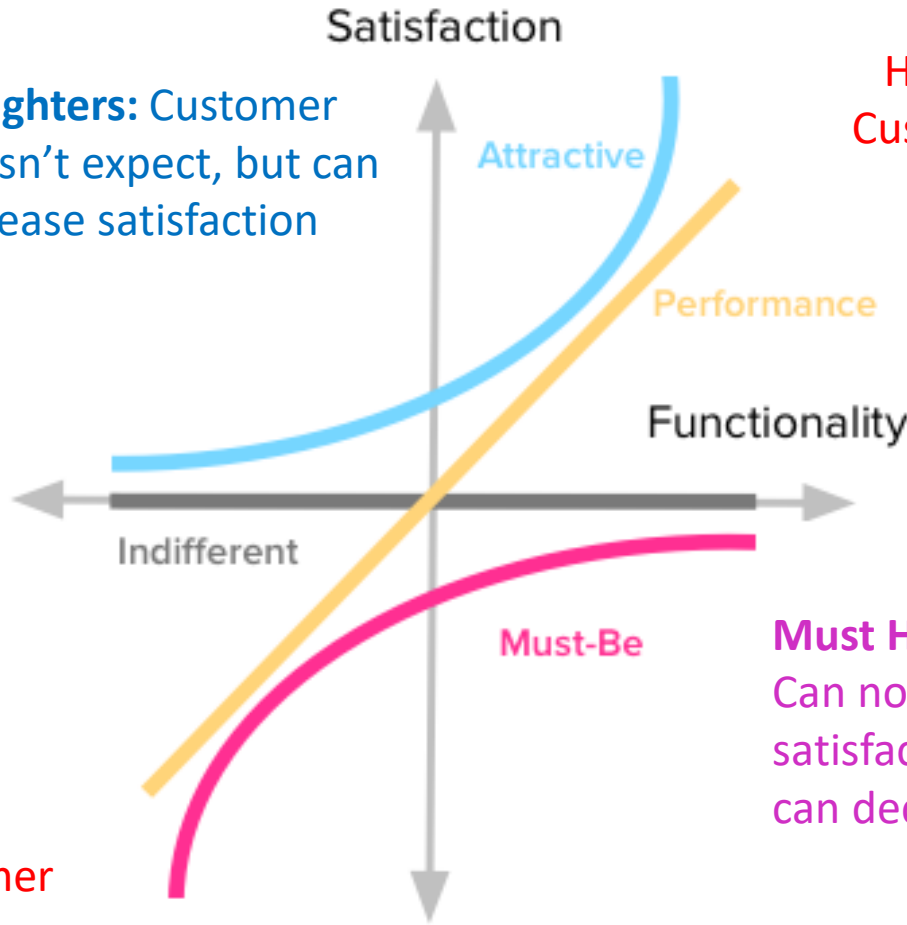
- Primary Needs (*Strategic Needs*)
- Secondary Needs (*Tactical Needs*)
- Tertiary Needs (*Operational Needs*)

- Must Haves
- Delighters (Latent Needs!)
- Linear Satisfiers
- Neutrals

Kano-Diagrams

How to determine the important needs

- Must Haves
- Delighters (Latent Needs!)
- Linear Satisfiers
- Neutrals



Delighters: Customer doesn't expect, but can increase satisfaction

Happy Customer

Linear: Desired quality (measurable technical metrics)

Neutral: No change with Feature

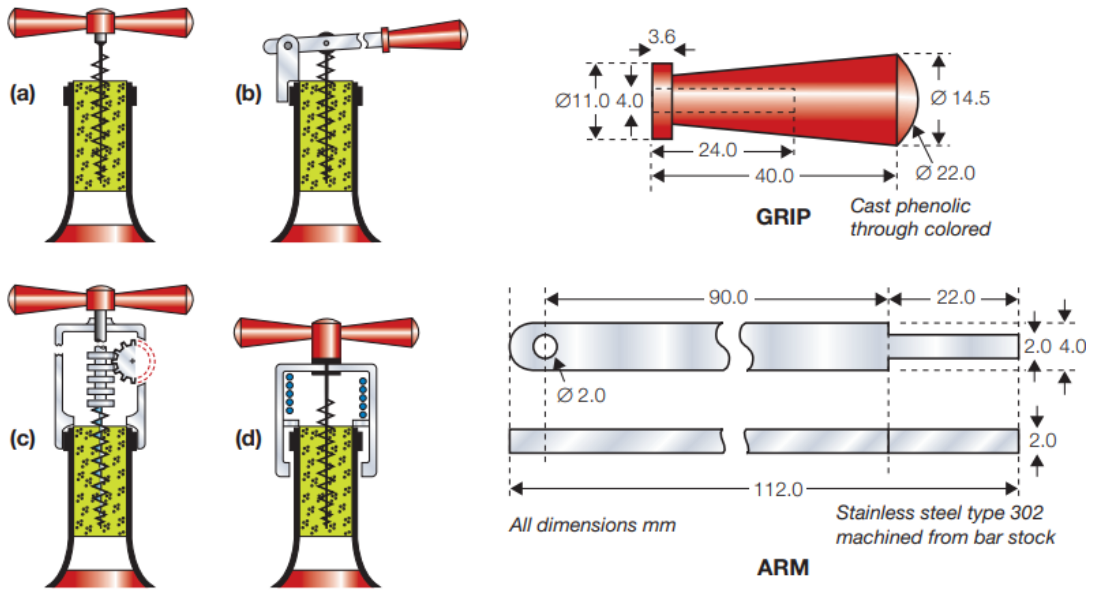
Must Haves: Can not increase satisfaction, but can decrease it

Sad customer

Kano-Diagrams

What could be example of each for our wine cork remover?

- Must Haves
- Delighters (Latent Needs!)
- Linear Satisfiers
- Neutrals



IGURE 2.9

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Any Questions?

Product development & engineering design

ME-320

PROF. JOSIE HUGHES

Lecture 1: Introduction, Motivation & Project