An introduction to design engineering

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An introduction to design engineering

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Introduction

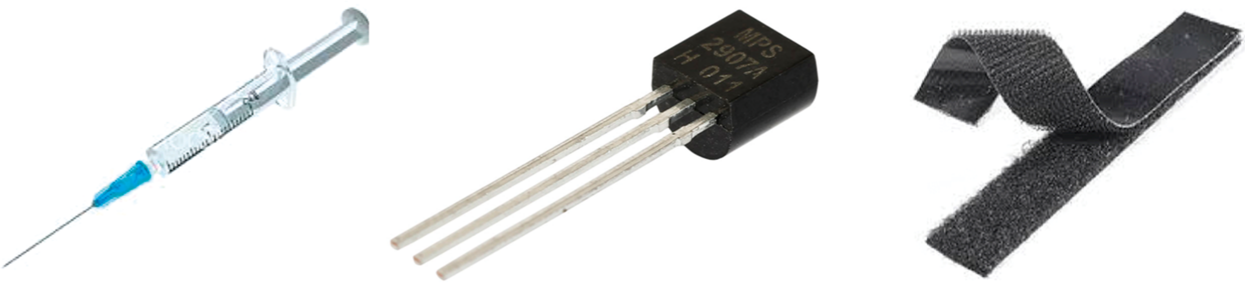
Much of the world around you is designed in some way. Modern living relies on the products, systems and services created to support how we live. Design comes from the ability to think creatively – to be able to imagine ‘what if …?’ and come up with something that didn’t exist before.

Some of the greatest human achievements have come from creative design engineering, allowing the realisation of some truly remarkable change in our world. Design engineering has helped to transform the environment, create incredible super-structures on land and sea, and even helped people travel to, and live in, space (Figure 1).

(a) (b) (c)

Figure 1 Examples of design engineering: (a) the Hoover Dam; (b) the Millau Viaduct; (c) the International Space Station

At the same time some of the smallest designs have enabled the biggest steps in the progress of humanity. The way people live has been changed by incremental advances in medicine, food production and many of the materials and devices people use on a daily basis (Figure 2).



(a) (b) (c)

Figure 2 ‘Small’ design engineering innovations that have made huge contributions: (a) a disposable hypodermic needle; (b) a transistor; (c) Velcro fastening material

Design engineering has also developed many of the most important systems and services, from individual right up to global and universal scales. These systems have supported radical scaling up of human activity in a huge range of areas (Figure 3).

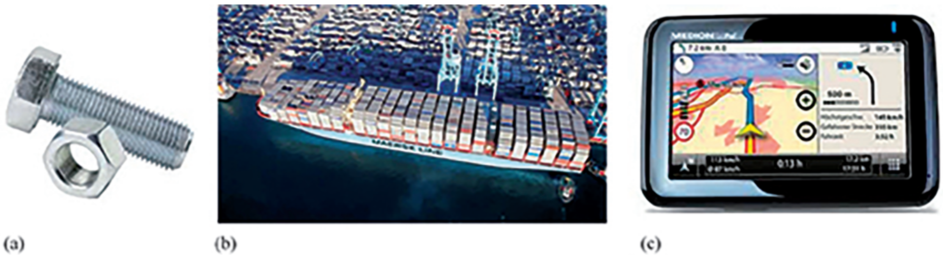


Figure 3 Examples of designed systems and services: (a) a standardised component system; (b) a distribution and transport system; (c) a satellite navigation (satnav) system and service

Design can be the fashionable, eye-catching products and images you probably think of. But design is also the least noticeable (and often most important) services and systems. This course will introduce you to some characteristics and drivers for design, some of which you might not have come across before, and start to explore how data can be used to inform design decisions.

This free course, *An introduction to design engineering*, looks at the way in which engineers use ideas and approaches from the discipline of design thinking to inform their work. The complexity that people bring to design problems is introduced, along with some basic methods of dealing with such complexity.

This OpenLearn course is an adapted extract from the Open University course T192 *Engineering: origins, methods, context*.

Learning Outcomes

After studying this course you should be able to:

- understand the broad scope of design engineering
- recognise the main drivers for design engineering
- describe how human variation impacts on design engineering
- apply some basic concepts and methods from design engineering to explore creative solutions to clearly defined real world problems
- demonstrate skills in communication, presentation, information handling and numeracy through the completion of activities.

1 Design beginnings

As soon as you read the word ‘design’ you probably formed some idea of what you think it is. It is a word that can be used in many ways and can mean different things to different people. Even in a specialised discipline like design engineering there are many different definitions and types of design activity. To complicate things further, design can be a verb or a noun: you can ‘design a design’. So it is important to remove as much confusion and contradiction as possible when discussing anything containing the word ‘design’.

This course introduces design in a particular way based on both theory and practice. It will include discussion of design but you will also be expected *to design* – to actually try techniques and develop skills that are useful in the process of designing. This practical approach to learning and practice is also at the heart of design engineering.

This section starts by discussing a few characteristics of design that you may not have come across before.

1.1 Design is more than aesthetics and appearance

It can be easy to think of design as only styling, fashion or the appearance of objects. You only have to look at the variety of similar products in shops to see that some design products have an obvious focus on appearance. External variations in kitchen appliance design often take place without actually changing the underlying product, in order to remain up to date or fashionable, or to fit in with other market drivers (Figure 4).

Figure 4 Aesthetic and external variation in products with the same underlying function

In this course, design is presented as much more than this – as something that is valuable as both a process and the outcome of that process. Good design brings aesthetic and functional elements together to create something that is greater than the individual parts. Many designers would argue that good design embodies *both* – the aesthetics are pleasing because of the utility, and the function is expressed in the appearance.

Consider bridges, for example, where the function of the bridge often relates directly to the shape of it – how the bridge looks is related directly to how it works. The Forth Rail Bridge is over 100 years old and fulfils its function by supporting very heavy moving trains using three balanced cantilevers. These cantilevers give the bridge its distinctive shape, and this shape is also aesthetically pleasing – it looks attractive (Figure 5). People have written books, poems and songs about this bridge – and it has also had cameos in film and computer games! The effect of this piece of design engineering goes far beyond solving the single problem of crossing water.

Figure 5 The Forth Rail Bridge demonstrates a practical and aesthetic solution to the challenge of designing a bridge

Good design is more than simply looks and aesthetics – the best design engineering is a result of blending both the aesthetic and the functional. As you will see later in the course, this comes from blending different types of thinking and approaches in the process.

1.2 Design is more than products and objects

Some products are not much use on their own: they require other elements around them to enable them to work. For instance, your mobile phone wouldn't be much use without a whole range of supporting products and systems to enable it. These other elements are also designed.

Consider the design of the electricity supply system in the UK. In particular, think about the infrastructure that supports it (the power stations that generate the electricity, the wires that transport it, the substations along the route), the individual products used to access that system (sockets, wiring, light fittings), and then the service provided (energy companies, maintenance agreements). It would not be possible to design one without the other – the products depend on the system of electricity supplied, and the supply of electricity depends on the demand created by the products (Figure 6).

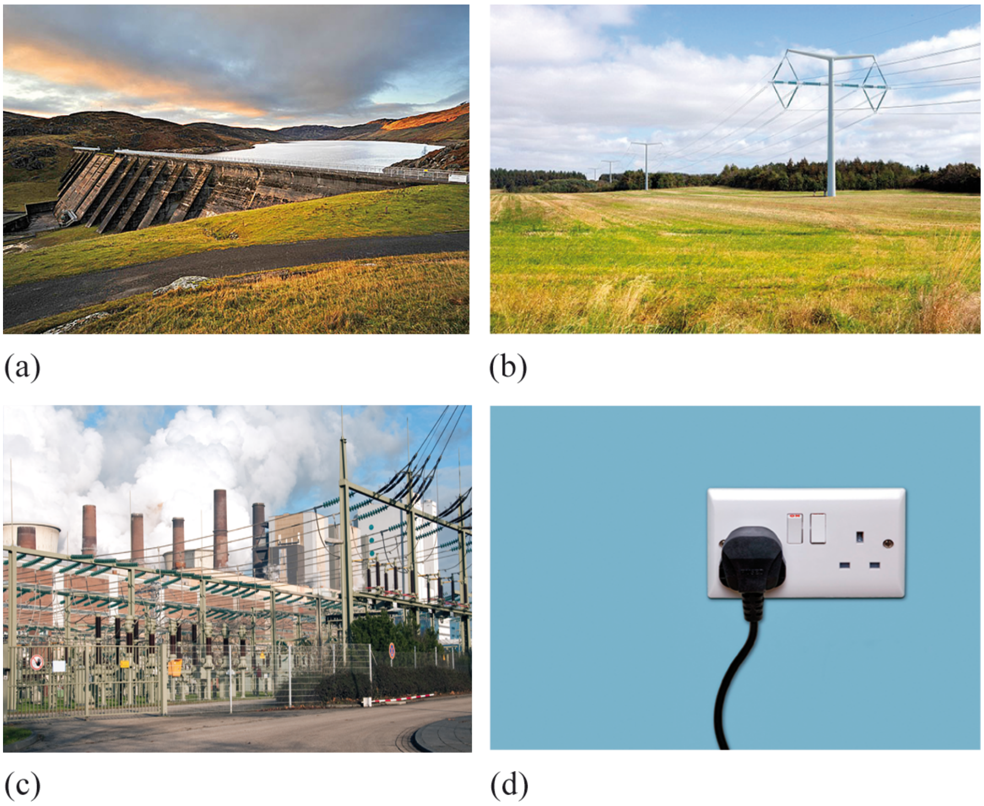


Figure 6 Some of the elements that make up the system of electricity supply in the UK: (a) hydroelectric dam; (b) pylons carrying transmission wires; (c) substation; (d) electrical socket and plug

Behind this simple relationship is an entire range of products, specifications, systems and services that are all required to ensure the consistent supply of electricity. Even the way in which these elements are used, a process, can be designed. These terms are defined below.

Box 1 Design engineering terms

- Product – an object created to fulfil some function or purpose.
- Specification – a detailed description of the design and materials used to make something.
- Process – a series of events that are performed in sequence in order to fulfil some overall aim.
- Service – an activity or event provided in order to fulfil or support some specific need.
- System – a collection of elements that connect to form a coherent group that serves some purpose or function.

When the focus is only on the product itself, other elements around a design can sometimes be forgotten. Many design engineering companies now actively look beyond their products to design systems and services as well. For example, some lighting companies will now sell a 'service to provide light' rather than just individual light fittings.

In doing so they provide a service to maintain (and even sometimes operate) a lighting system.

Design is more than simply creating a product – services, systems and processes can also be designed. Even when a design is simply for a product, the chances are it will require these other design elements to support it.

1.3 Design is not just for designers

Design takes place at every single stage in any project. Even the smallest design sub-task can be approached creatively, often leading to significant innovation and improvement when it is scaled up. In many world-leading product design companies, the design of apparently insignificant elements and components is given as much attention as the overall design because this can lead to other benefits.

In some cases the smallest components may have a significant effect. Take Trunki, for example, an internationally successful product that failed to get funding on the BBC television programme *Dragons' Den* due to the strap clip breaking during demonstration. Despite this failure, its designer continued with the product, realising that the problem could be overcome through further design and testing (Figure 7).

Figure 7 Children's hand luggage product Trunki

This is an extreme example of a small detail having a large consequence, but the lesson is important – you never know what detail might matter most. The principles of design can be applied usefully to *all* stages of a project and even beyond. The smallest detail in a project needs to be designed just as much as the overall project.

1.4 Design is much more than just solving a single problem

Problem solving is a significant motivation for design – you come across a problem and you want to solve it. But how do you know you are solving the right problem? What if what you do solves the original problem but creates another problem? Worst of all, what if solving a problem actually makes things worse?

A large part of good design engineering is about understanding and selecting the right sorts of problem to solve. In fact, the best design is about carefully shaping problems and framing them to generate a solution that improves more than the original problem. In some cases the solution that comes from the design process can have very little to do with the original problem but does much more. As Nigel Cross says in his book *Design Thinking* (2011), the best designers give the client something they didn't even know they wanted.

Good examples of this approach are the design innovations made by the company Tetra Pak (Figure 8). Each of these designs solves multiple problems at the same time to create a complete design – for example, the openings have to be reinforced for strength in storage and transport but also have to be easy to open. A potential solution to one of these conditions might lead to problems with the other, so solving both problems at the same time becomes important.

Figure 8 Examples of packaging designs that solve multiple problems to create successful design projects

In many ways solving individual problems is relatively easy if the resources are available. What is often far harder is solving the *right* problems with the *best* solution(s). Part of the skill of a design engineer is not only defining problems to solve but also working out *how* those problems might be solved. Being able to see problems from a range of different viewpoints and then distilling these is an important skill for the designer.

Design is not simply solving a problem – it is about selecting and framing the right problems. The best design goes beyond simple problem solving and creates something new.

1.5 Design is about thinking around the object

There is another way of thinking about design that makes it much more interesting and challenging. The job of the designer (and especially the design engineer) is to try to think of the things that no one else thinks of. Designing involves creating something new, and this means that it will have new consequences. Designers consider these consequences as well as the design itself because they know that this will lead to a more successful outcome – problems can be imagined before they become reality, and other opportunities can be taken advantage of.

Consider a product being designed for an extreme or challenging environment. If only the product itself is considered and the context is ignored, it's very unlikely the product will succeed. For example, in offshore design engineering, the nearest materials and backup are not very easy to access (Figure 9), meaning that the installation and operation of products really matters. The designer has to think about many different aspects of a design at the same time – installation, removal, repairs and maintenance, decommissioning – in addition to the artefact itself. When only the product itself is considered this almost always leads to other problems in the wider system, leading to costly failures and extended repair times.

Figure 9 An offshore oil platform, an environment where the design has to consider more than just the product itself

Design is not simply thinking about an object, it considers what is 'around' the object – the context, operation, repair, or replacement. The best design results in solutions that consider more than simply a static object.

1.6 Design is …

Some of the ideas presented on previous pages might be new to you and you might consider design in a slightly different way after thinking about them. A definition of design is not provided here because it is better for you to start developing your own understanding of it. Before moving on, there are a few last characteristics of design for you to consider.

Firstly, design is a *process*. It is something that people do with a specific aim or goal in mind. The process may not lead to a single perfect solution and part of that process might be to define what 'solved' means. But it is the journey that makes the difference. If you knew where the process was going to end up, then you wouldn't need to design in the first place.

Secondly, design makes use of creative and analytical attitudes, approaches and skills. Using only creative methods or only analytical methods in a design process rarely leads to successful projects. But by applying both, the design engineer can draw on the most effective methods to approach complex challenges.

Finally, design has a purpose and creates change. It is an inherently practical pursuit – it is not only theoretical or imaginary. The output from the design process is the creation or change of some aspect of the world around us.

As you work through the rest of the course bear these three ideas in mind. You are expected to start to become a designer. In doing so you will be engaging in a process of analytical and creative activity – all with a view to making a change in the world around you.

2 Inspiring design engineering

When you study and practise design, you are exposed to many ideas of what design engineering is. Many of the examples might be familiar to you, but some might be quite new or appear odd to be included as design engineering.

This is the real value of good design engineering: because it is not one fixed thing it can be applied creatively in different ways to any project in order to drive innovation.

Activity 1 Interesting design engineering

Allow 15 minutes to complete this activity

Watch the following video in which the T192 course team present some interesting examples of design engineering.

As you watch the video, use the list from Design is more than products and objects to note down which type(s) of design each example in the video might be:

- product
- specification
- process
- service
- system.

Video content is not available in this format.

Discussion

Six examples were presented by the course team. Here are a few notes on each; you may have come up with different observations and that's absolutely fine. But see how your ideas compare to these notes.

Whole life cycle lighting design: this was an example of products (the light fixtures and fittings), systems (the control of the lighting components) and a service (a level of service to provide light). The focus in the example was on the service aspect and how continuous design consideration throughout the operation had improved energy efficiency.

Standardised components: the nut and bolt example showed how important specifications and systems are in producing these components. Such products have to meet a commonly agreed specification to ensure accurate and predictable replication of component parts.

Manufacturing and materials: the examples of chair designs showed the importance of manufacturing and materials in the design process. Design cannot take place without such considerations and it can even be inspired by new developments in both.

Digital prototyping: this is the process of creating something virtually, before physically making it. When used as part of an overall design process it can change how people design and how they work together in a project.

Roundabouts: the roundabout is an example of a product that is also part of a designed system (the road system), and perhaps even a process (of dealing with traffic at intersections). It shows how a change at the product level can make a change at the system level.

The extension to the V&A in London: the final example was about the complexity of modern design projects such as the new V&A extension in London. Making this a successful design requires a diverse set of people with a range of skills who all work collaboratively towards a common goal.

2.1 My definition of design

Now it's your turn to come up with your own definition of design. Don't worry about getting this 'right'; there are no right answers to this. (Although some answers are better than others!)

Have a think about ideas that may have occurred to you after reading the previous sections. Think, too, about the kind of design engineering that inspires you and the specific type of engineering you may be interested in.

Activity 2 My definition of design

Allow 15 minutes to complete this activity

Come up with your own definition of design by writing a short paragraph stating what you think it is. Start the definition with 'Design is...' and use no more than 50 words.

Don't worry about getting it right; this is really about your own ideas and thinking at this stage of learning about design engineering.

2.2 Summary of Section 2

In this first section you came across several ideas of what design might be, as well as a few things that it is not. These were presented to make you think about design in ways you might not have done before.

In summary, you saw that:

- design is more than aesthetics and appearance
- design is more than products and objects
- design is much more than just solving a single problem
- design is not just for designers
- design is about thinking around the object.

Design was also noted to be any of the following (or even a mix of them):

- product
- specification
- process
- service
- system.

In the next section you will have a look at some of these examples of design engineering.

3 Design drivers

All designed objects or design projects have a reason behind them. Very often the reasons may seem quite obvious: to serve a function, to meet some specific need, or to be useful in some way. For most designs there is more than one reason, and some designs can have quite complex sets of motivations and drivers.

For example, there are a whole range of reasons for creating a plastic water bottle like the one in Figure 10 – as well as the obvious, functional reason of storing water. These reasons will have come from different sources, and will also vary depending on when in the design project the reason came about.

Figure 10 A plastic water bottle is the shape it is for more than simply the obvious, functional reasons

Activity 3 Function and purpose

Allow 15 minutes to complete this activity

Pick an object near to you and list some reasons for it being designed the way it is. If you can't think of an object, then use the example of a plastic water bottle given in Figure 10.

Try thinking about: what the design does; how it does something; who benefits from it (and how/why).

Discussion

Your answer will depend on what object you chose. Check that you came up with reasons that considered: what the design does; how it does something; who benefits from it (and how/why), and so on.

The following reasons are for the example of the water bottle:

- to contain water
- to drink water from easily and quickly

- to be a good size and shape to be held in a hand
- to work immediately and without breaking, spilling or leaking
- to be a cheap solution for the person using it
- to be a cheap product to manufacture for the company
- to have sufficient strength and structural integrity to resist loads due to stacking while on display, in storage and during transportation
- to be readily compacted for ease of recycling.

From this activity you will probably have come up with a list of statements that were specific to the product you were considering. If you were to repeat the activity for a range of different products, you would come up with more reasons. But you would also start to see common patterns of reasons, and these reasons would be indicators of what people want and need from products. These are known as design drivers.

3.1 Common design drivers

Here are a few examples of some common design drivers.

Box 2 Common design drivers

- To meet a need: all people have certain basic needs such as shelter, food and warmth. Meeting these needs often requires creative design and problem solving. In addition, people require more complex systems such as healthcare, education, or access to other services such as telecommunications. Needs are often immediate reasons and very strong drivers for design – everybody has needs that have to be fulfilled.
- To solve a problem: almost every time you come across a problem you use some sort of design process to create a new solution or workaround. Most problems are obvious and are identified when people encounter them. But some problems can be very complex, or might be only a symptom of an underlying problem. A creative designer can deliberately use *problem finding* and *problem framing* techniques to identify and develop potential designs.
- To fulfil a desire or demand: desires and demands are perhaps less critical than needs or problems but they are still significant drivers and have arguably become much more important in modern lifestyles globally, as average living standards increase. These are usually psychologically or socially driven factors, such as the desire to have the same (or better) product as one’s peers.
- To improve something: the need to improve something follows on from the driver of problem solving. Being able to do something better, faster or more reliably are all examples of improvement that can be significant drivers of design. In fact, much of modern product design and development is what is called incremental design, where small changes are made to existing products or systems in order to change them in some way.
- To respond to change: existing solutions to problems, needs or desires are not static – they tend to change as circumstances change. People’s desire to have the latest technology or keep up with the latest fashionable trend is a strong driver for

design change. Similarly, new technologies, manufacturing or other opportunities allow designers to update and recreate existing designs. Changes to environmental conditions, such as global warming, may also require a change of approach. Design is rarely a static thing.

- ‘Just because’: while it’s true that very few design offices have the chance to simply design for the sake of it, some do engage in this speculative activity as part of their business. For example, Google and Apple both encourage staff to take time each week to work on personal projects, and many of these either inform future projects or become innovative products themselves. Of course, these individual design projects then have their own drivers, and being able to identify and explore these drivers is important.

Figures 11 and 12 show some examples of these design drivers.

In the list above, you might notice how similar many of the items appear at first. Quite often a project will have multiple drivers, and they may change over the course of the project.

(a) (b) (c)

Figure 11 Examples of design drivers: (a) food production systems are driven by the human *need* to eat; (b) traffic lights solve the *problem* of controlling large volumes of traffic; (c) tablet computers are driven by people’s *desire* for a particular type of device and interface

(a) (b) (c)

Figure 12 Examples of design drivers: (a) light bulb efficiency and longevity are driven by *improvement*; (b) mobile phones are constantly driven by technology *change*; (c) many online services and apps are driven *just because* the developers can create something quickly and test it

Activity 4 Reasons for design drivers

Allow 15 minutes to complete this activity

Go back through the reasons you identified for the design of the object you chose in Activity 3, and identify which design drivers you think best match each reason. For each reason and driver give a brief explanation of how they relate to each other.

There are no right answers to this activity – you will have a particular opinion and view of what matters most in your chosen design. What matters is how important you think each driver might be, and that you try to see other drivers of design that you might not have thought about before.

Discussion

As before, the water bottle is used as an example. Your own answers will be different from the examples below because you will have started with different reasons and probably a different object. Look especially for those drivers that you might not have thought of initially.

Table 1 Example answers for Activity 4

Reason from Activity 3	Design driver
To contain water	Problem – this is the basic problem of storing water in a way that doesn't leak.
To drink water from easily and quickly	Need – this is the basic need – to drink!
To be a good size and shape to be held in a hand	Desire – this is something that is desirable, but it's not absolutely essential.
To work immediately and without breaking, spilling or leaking	Improve – bottle design is changing all the time and some are better than others at reducing spills.
To be a cheap solution for the person using it	Change – it perhaps responds to new ways of manufacture? Or new materials?
To be a cheap product to manufacture for the company	Need or desire – not sure, it depends on the company's driver?
To have sufficient strength and structural integrity to resist loads due to stacking while on display, in storage and during transportation	Problem – this is the problem of moving the bottles around without breaking them.
To be readily compacted for ease of recycling	Improve – this helps make the bottle production more sustainable.

In Activities 2 and 3 you concentrated on products, but design drivers apply to system and service design as well. Most products also require consideration of systems or services to operate effectively. For example, the demand for electricity in the UK requires multiple elements to be designed: not just physical products (such as those shown in Figure 6), but also systems and services to organise and regulate the supply. Each of these aspects of a design project will also have particular drivers and it is important to keep these in mind when working on any design project.

A key design skill is the ability to recognise different types of design driver and use them to identify creative opportunities and possibilities. Whenever you come across a problem in real life, you have probably found a driver for design.

3.2 Design driver examples

Practise your understanding of design drivers by giving examples of each type of design driver defined in Section 3. For each one, try to consider the *primary* design driver from the point of view of the user.

Activity 5 Exploring design drivers

Allow 20 minutes to complete this activity

Use the table below to suggest an example of a design that responds to each of the drivers listed. Write each one as a single sentence summary point and try to explain how the design responds to the driver. (See the top line for an example.)

Table 2 Example of a design

Driver	Design	How?
To meet a need	Mobile phone	My mobile phone meets the need of communicating with other people by allowing me to contact anyone I know directly and at any time (if they're there…)
To meet a need	*Provide your answer...*	*Provide your answer...*
To solve a problem	*Provide your answer...*	*Provide your answer...*
To fulfil a desire/ demand	*Provide your answer...*	*Provide your answer...*
To improve something	*Provide your answer...*	*Provide your answer...*
To respond to change	*Provide your answer...*	*Provide your answer...*
'Just because'	*Provide your answer...*	*Provide your answer...*

Discussion

Below are some examples; you may have chosen very different ones and that is absolutely fine. Compare your own examples to these and consider how well they exemplify the stated driver.

Table 3 Example of a design - suggested answers

Driver	Design	How?
To meet a need	Mobile phone	My mobile phone meets the need of communicating with other people by allowing me to contact anyone I know directly and at any time (if they're there…)

To solve a problem	Tin opener	A tin opener solves the problem of how to open a can of food. I put this as solving a problem because there are lots of different types of tin opener and also different ways of opening a tin.
To fulfil a desire/ demand	National Grid (the entire system!)	Our desire and demand for instantly available energy is the main driver for the National Grid in the UK. The individual elements in the system might solve problems or meet needs, but these all serve the main purpose of fulfilling people's desire for instant energy.
To improve something	Double-glazed window units	Modern double-glazed windows improve the thermal performance of older single-glazed windows. Some of them even look okay.
To respond to change	Laptop computer	My laptop makes use of a solid-state hard drive, a technology that came down in price significantly at the time of writing.
'Just because'	Web services	Web services, like Mr. doob, are sometimes developed simply because their developers can, or want to, explore a new technology, or see what is possible. Sometimes, simply playing with something leads to radically new ideas.

As mentioned at the start of this section, identifying precisely what the primary driver is can be difficult. A project may spend time in the early stages trying to set these out very carefully to get it off to a good start. These projects recognise that the primary driver has a huge impact on how the later stages of a design progress – affecting decisions, approvals and validation.

3.3 Summary of Section 3

In Section 3 you came across the concept of a design driver, which was defined as follows:

Box 3 Design driver

Design driver – a factor that motivates the design process, for example:

- to meet a need
- to solve a problem
- to fulfil a desire/demand
- to improve something
- to respond to change
- or 'just because'.

There can be other drivers but these are common to many projects and will serve as a definition for this course.

When you read this section you may have found it difficult to isolate some drivers or to think of examples specific to a single driver. For example, when does a 'need' become a 'problem' (or a problem become a need)?

In reality, most designs have multiple drivers and motivations behind them. These drivers can also change during the design project and even during the lifetime of that design. But most design projects have a primary driver that is the main reason for the project in the first place, and this primary driver almost always involves people.

4 Designing for people

Everything that is designed comes into contact with people at some point. This is mostly through the use of a design, but people are also involved in less direct ways, such as manufacturing, installation or maintenance. Design failure very often occurs because of failures to take account of people. A consequence of the involvement of people is the complexity they bring. Just consider the numerous variations of any object around you. Why are there so many shapes of cup, of mobile phones or of cars? Why can one person seem to operate an object easily while other people find it hard? And why can't anyone solve the problem of comfortable seats on a train?

This variation and complexity arises from differences between individual people. People are not all the same and their behaviour is certainly not predictable. Here are a few key variations a designer might consider:

- People vary physically, meaning that design for people has to take account of a wide range of sizes, shapes and adjustments.
- People have different preferences and thoughts, meaning that what they feel about design and how they interact with it varies considerably.
- People have a range of circumstances and contexts (family, friends, employment, etc.).
- People have different experiences and knowledge, which means that a designer might have to make a range of assumptions.

All of these variations mean that designing for people can be a complex process. Dealing with this complexity is a central part of design. In this section you will look at these variations and complexities in greater detail, but this section starts by considering one obvious variation – the physical sizes of people. You will use this variation to explore how design can blend a variety of analytical and creative approaches to respond to design drivers.

4.1 People and variation

Start by considering how you would begin designing an object that has to 'fit' to people, such as a simple desk or table. People using it will vary in size and these differences might be quite extreme (at the time of writing, the tallest person recorded had a height of 2.72 m and the shortest woman alive is 628 mm tall). What sizes should you start with? Is a single height acceptable? If not, how many sizes might you need?

Activity 6 Human variation

Allow 20 minutes to complete this activity

(a) What is the *difference* in height between the tallest recorded man (2.72 m) and the shortest living women (628 mm)? Calculate the answer in millimetres, then express this in metres to 1 d.p.

(b) What is the midpoint between the two extremes of height (the average of the two)? Would this be a sensible value to take as a starting point for a design?

Discussion

(a) The difference is found by subtracting the shortest from the tallest. Both heights need to use the same units before subtracting. First, convert 2.72 m into mm (2.72 m × 1000 = 2720 mm)

Then subtract: 2720 mm − 628 mm = 2092 mm

So the difference in height is 2092 mm

Convert this to metres, by dividing by 1000: 2092 mm ÷ 1000 = 2.092 m

This is equal to 2.1 m, to 1 d.p.

(b) To find the midpoint you could halve the difference between the two heights and add it to the smaller height. Adding the two heights together and dividing by 2 will give the same result and is the usual way to find an average.Average height = (2720 mm + 628 mm) ÷ 2 = 1674 mm, or 1.7 m to 1 d.p.

Without more information this would not be a sensible value to take as a 'typical' height. You need to know more about the distribution of heights, not just the extreme values, to make that judgement.

As it happens, 1.7 m is not too far from the average height of some groups of people, but you cannot be sure of this without more information.

Solving the problem of human variation is not a simple exercise. If you design a product to suit people at a particular height, you may then be limiting access for other people. Figure 13 shows a typical ticket machine in the UK. If you have used a machine like this, you might have wondered whether the designers took any account of human shape and sizes at all – or you might have found the machine comfortable to use. It all depends on your point of view.

(a) (b)

Figure 13 A common type of ticket machine in a UK train station: (a) a view of the machine from 2 m away; (b) a tall user's view of the keypad when standing at the machine. Note how difficult it is to see the keypad screen (from the tall person's point of view).

At some point decisions are required to be made about the properties of a design in progress. The ticket machine shown in Figure 13 had to be defined in terms of height, width and depth, and every component had to be located in relation to this to allow it to be manufactured. In making these decisions, however, you might solve the problem for some people but make it worse for others. Knowing how to think about difficult decisions like these can be useful as a designer. Because several different factors are involved, you need to use particular ways of thinking through this type of design problem.

4.2 Practical variation

One way to approach a design problem is to use your own knowledge and experience. You may not be a furniture, automotive or aeroplane designer but you probably have considerable experience of sitting down! Making use of this personal knowledge might seem trivial, but it is the start of all creative problem solving. The key is turning this personal knowledge into information you can use in any design process.

Activity 7 Seat and desk height

Allow 20 minutes to complete this activity

Measure the height from the floor to the seat and the desk or table where you study.

Make your measurements in millimetres and note them down somewhere for use in the next activity. Even if you don't usually study at a desk or table, find a place like this that you can use for this activity (and the next one).

Calculate the difference between these two heights in mm.

Discussion

For example, a typical desk might be 758 mm above the floor, and the seat 540 mm above the floor.

The difference between these two heights is 758 mm − 540 mm = 218 mm.

What you have done in Activity 7 is to measure something that already exists. You have an existing desk and you have given a value to a property of it. Now, when you talk to other people about your desk you'll be able to state the height in a way that they will understand.

Before you take this measured height as the perfect desk height, it is worth checking this assumption. Once again you will use a practical method to do this.

Activity 8 Experimenting with desk heights

Allow 20 minutes to complete this activity

Adjust the height of your desktop by using accessible materials you have around you. For example, you could use a flat surface like a tray propped up on books, or a folder with some DVD cases underneath it. What you are looking for is some way to quickly and easily adjust a stable surface that you are able to use. If you have quite a high desk, then you might want to find a lower one, such as a table, to start the activity.

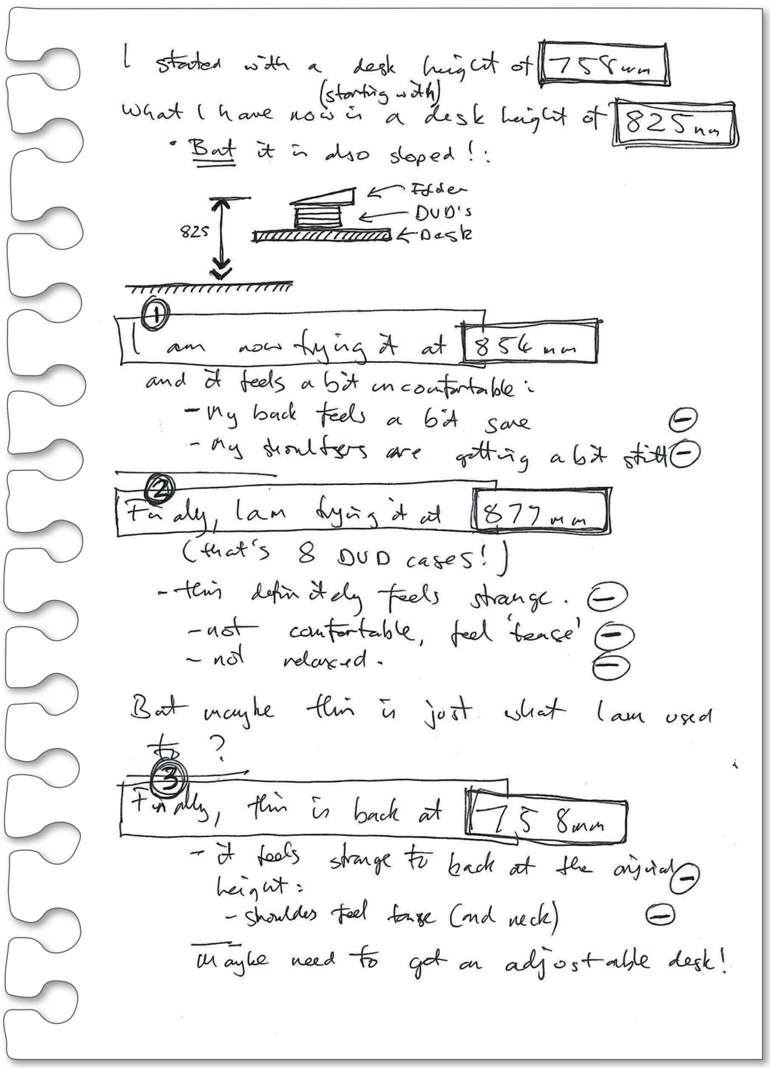
Try working on your desk at different heights, and note down how it feels to work at each height. (Is it more or less comfortable than the original height?) Once you have found a height that feels comfortable, take a note of the difference in height from what you were using previously.

Take a few pictures of your adjusted desktop. A discussion of this activity will follow in the main text – but don't read on until you have tried it.

Discussion

Here is one person's answer.

> I used DVD cases to prop up a folder. This did actually change the way I wrote notes quite dramatically. At a higher height (about 3 DVD boxes) it felt a lot more comfortable.
>
> Higher than this and it felt a bit strange – not comfortable for my shoulders and arms.
>
> Here's a picture of the notes I took:



I started with a desk height of 758mm
(starting with)
What I have now is a desk height of 825mm
• But it is also sloped!:
Folder
DVD's
Desk
825
① I am now trying it at 856mm
and it feels a bit uncomfortable:
– my back feels a bit sore
– my shoulders are getting a bit stiff
② Finally, I am trying it at 877mm
(that's 8 DVD cases!)
– this definitely feels strange.
– not comfortable, feel 'tense'
– not relaxed.
But maybe this is just what I am used to?
③ Finally, this is back at 758mm
– it feels strange to back at the original height:
– shoulders feel tense (and neck)
Maybe need to get an adjustable desk!

Figure 14 Example answer

As I went through these tests I measured each one as a full height from the floor. But I could easily have measured the difference between the desk and the height of the folder. I might even have measured it in DVD cases – one case is about 16 mm, and I used 4 of them
(4 × 16 mm = 64 mm).

This all suggests I might not have my desk high enough – a bit of a problem considering it's screwed to the wall … I might need to come up with a creative solution to that as the next problem.

This technique is called design prototyping, where you create a quick physical mock-up of a design idea in order to test some aspect of that idea. It is exceptionally useful because it is quick and simple, and you get instant feedback on the problem you are exploring. Almost all design problems can be prototyped (even systems and processes) and this is a key method in any design engineer's toolkit.

The prototype you have just made can also provide two types of information. When you increased the height of your desk you might have noted whether it felt uncomfortable and whether this discomfort is acceptable or not. Or you might have compared two heights to see which one is more (or less) comfortable. You are no longer only measuring height; you are also making judgements about the desk at these heights. In both cases you now have new items of information, and they are of different types. The height of the desk is quantitative information, while what you think and feel about the new height is qualitative information.

The height you are working with is fine for one person (you!) and it is possible to imagine that other people of about your own size might also be quite happy with that height. But the original problem was more general: what height should you use to design a desk to 'fit' people? In other words, you are interested in finding a height that many people will find comfortable, and one way to do this is to find out how many people might find a particular height comfortable.

To expand the problem beyond your own experience you need to use other techniques.

4.3 Numerical variation

When it comes to designing for large numbers of other people it becomes impractical to ask every individual what they think. But the same practical methods you have just used can be scaled up using statistical methods. For example, from Activity 8 you now have a desk height that suits you, and you might assume that most people of your size will also like that desk height. So now you need to know how many people are the same size as you. For that you need to make use of statistics.

Box 4 Working with datasets

A dataset is a collection of data, usually presented in the form of a table. In engineering, numerical data is particularly important.

The range of a dataset is the difference between its largest and smallest values.

It can be useful to distinguish between two different types of data:

- Discrete data is data that can take only certain values.
- Continuous data is data that can take any value (often over a particular range).

For example, metric screws are available in certain thicknesses and lengths. The dataset of screw lengths available might include 12 mm, 16 mm, 20 mm and 25 mm. It would not include 12.312 mm or other lengths in between these standard values. This is discrete data.

In contrast, a person's height can take any value (though you might reasonably expect it to lie between the two extremes quoted earlier!). The only restriction is the accuracy to which you choose, or are practically able, to measure it. This is continuous data.

Activity 9 Discrete and continuous data

Allow 15 minutes to complete this activity

Identify each of the following as discrete or continuous data:

(a) the number of students in a tutor group

(b) the distance from a person's home to the nearest bus stop

(c) the price of a ballpoint pen, in pence
(d) wind speed, measured in kilometres per hour.

Discussion

(a) Discrete – you can have only a whole number of people.
(b) Continuous.
(c) Discrete.
(d) Continuous (though if you used the Beaufort scale to measure wind speed the data would be discrete).

Before carrying out a detailed analysis of any dataset, it is a good idea to examine the values to see if any patterns or unusual values stand out. You should never ignore data because it is different from what you were expecting, but if a dataset does contain surprising values, it is a good idea to question them in case a mistake has been made. You might look for the following:

- Missing data – for instance, if you are given a table of data that has obvious unexpected gaps in it.
- Spurious precision – for instance, if a number is quoted to more significant figures than is plausible, or too few significant figures to be useful for the intended purpose.
- Dubious data, perhaps caused by a misplaced decimal point.
- Coded values, where the data provider may have used a code to indicate something, such as a missing value.
- Constraints – for instance, there may be some good reason why the data has to lie within a particular range.
- The presence of outliers – single values that are very different from the rest of the dataset.

Having checked that your dataset looks valid, you can perform calculations on it. For example, it may be useful to find the average of a set of values.

You have probably come across the idea of an average before, and you may also know that there are different kinds of average. The most useful types of average are usually the mean and the median.

Box 5 Average values: mean and median

Finding the mean of a dataset: To find the mean of a set of numbers, add all the numbers together and divide by however many numbers there are in the set.

Finding the median of a dataset: To find the median of a set of numbers:

- Sort the data into increasing (or decreasing) order.
- If there is an odd number of data values, the median is the middle value.
- If there is an even number of data values, the median is the mean of the middle two values.

These basic statistical tools are useful when it comes to designing for people.

Activity 10 Statistical methods

Allow 20 minutes to complete this activity

Below are the heights of 15 people taken at random from the general population.

Heights (mm): 1671, 1817, 1763, 1733, 1722, 1745, 1773, 1778, 1725, 1696, 1689, 1718, 1735, 1705, 1734.

(a) Write down the minimum and maximum values in this dataset. Hence calculate the range of heights.

(b) Calculate the mean height, based seon all the data values. Give your answer to the nearest mm.

(c) State the median height, based on all the data values.

(d) Compare the mean and median heights to your own height, and calculate the difference to each.

Discussion

(a) Minimum = 1671 mm, maximum = 1817 mm.

Range = 1817 mm − 1671 mm = 146 mm.

(b) To find the mean value, add the 15 different values together and divide by 15. All heights are in mm.

1671 + 1817 + 1763 + 1733 + 1722 + 1745 + 1773 + 1778 + 1725 + 1696 + 1689 + 1718 + 1735 + 1705 + 1734 = 26 004.

Mean height = 26 004 mm ÷ 15 = 1734 mm (to the nearest mm)

(c) Putting the heights in order gives (in mm): 1671, 1689, 1696, 1705, 1718, 1722, 1725, 1733, 1734, 1735, 1745, 1763, 1773, 1778, 1817.

The median is the middle value, which is 1733 mm.

(d) The answer to this part will depend on your own height. The example answer given below is based on a height of 1690 mm.

The mean is 1734 mm, making the difference 1734 mm − 1690 mm = 44 mm.

The median is 1733 mm, making the difference 1733 mm − 1690 mm = 45 mm.

Before you move on from this activity, it is important to realise that this is not just a theoretical exercise. The example height used in part (d) of the answer to Activity 10 produces a real value (44 mm) that can be used practically. As you saw in Activity 8, small differences (even smaller than 44 mm) can have a significant effect. It is important to be aware of what the values used actually represent when you use any mathematical methods in design engineering.

4.4 Using numbers to design

To move forward with the desk problem, you needed to know how many other people might be your height. You found a certain desk height acceptable and might reasonably assume this is a good size for everyone of the same height. But how might you find out how many other people are your height?

There are many sources of data on sizes, from the very general (such as people's heights) to the exceptionally specific (such as NASA's guide to the sizes of things in space). Two key sources where a range of human data and information can be found are the British Standards Institute (BSI) and the Health and Safety Executive (HSE). The data they provide about the size and shape of people is called anthropometric data, which consists mainly of physical characteristics and measurements. These data values are derived using statistical methods that allow generalisations to be made about human characteristics, which can be used to inform the design process.

Making use of these datasets and applying knowledge of how people interact physically with objects can be a complex process and is a discipline in its own right. Ergonomics is the study of physical aspects of the human body, such as size and mechanical performance, and how these can be applied to the real world. For example, in car design and manufacture, the design of a car interior has to take account of significant variation of human shape and size, and hence the range of adjustments that can be made to a car seat, seatbelt, steering wheel, etc. And that's before you consider how these adjustments relate to one another, or are operated mechanically.

One useful way of presenting data, which is particularly useful for anthropometric data, is to create a histogram. Histograms offer a convenient way of presenting data to make it easier to read for a particular purpose. Instead of using a continuous spread of data, you divide it up into 'buckets' (often referred to as 'bins' or intervals) and sort items into them. For example, you could think of it as a way of sorting people into height ranges and then working out what proportion of people are in each range. Bar charts are similar, but can be used to represent categories of things that aren't necessarily numerical.

4.5 Visualising numbers

Histograms are used to plot quantitative data, with ranges of data grouped into intervals. For instance, Figure 15 shows a histogram of 200 people using height ranges of 20 mm, with heights measured to the nearest 1 mm. Notice that the values on the horizontal axis are continuous – the first bucket goes from 1600 mm to 1619 mm, the second from 1620 mm to 1639 mm, and so on. The vertical axis shows percentages. The area of each bar represents the percentage of people whose height falls in that range, and the sum of all the areas would equal 100%.

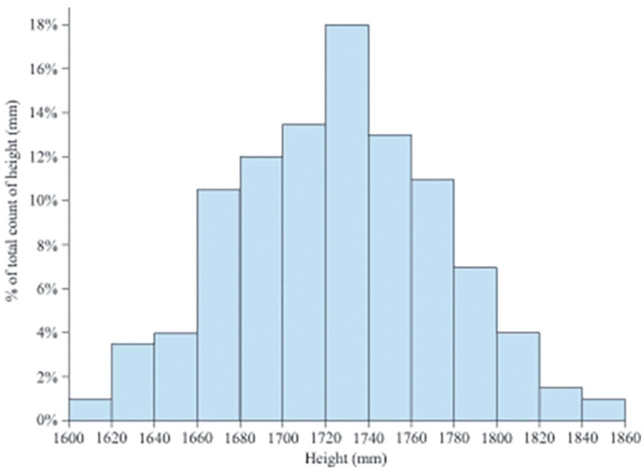


Figure 15 Histogram of heights (mm) of 200 people in 20 mm buckets

Bar charts can be used to group and count the frequency of anything, using categories that are not necessarily numerical. Figure 16 shows a bar chart representing a packet of sweets – sorting and counting the sweets according to flavour makes it possible to say something useful about how those flavours are distributed.

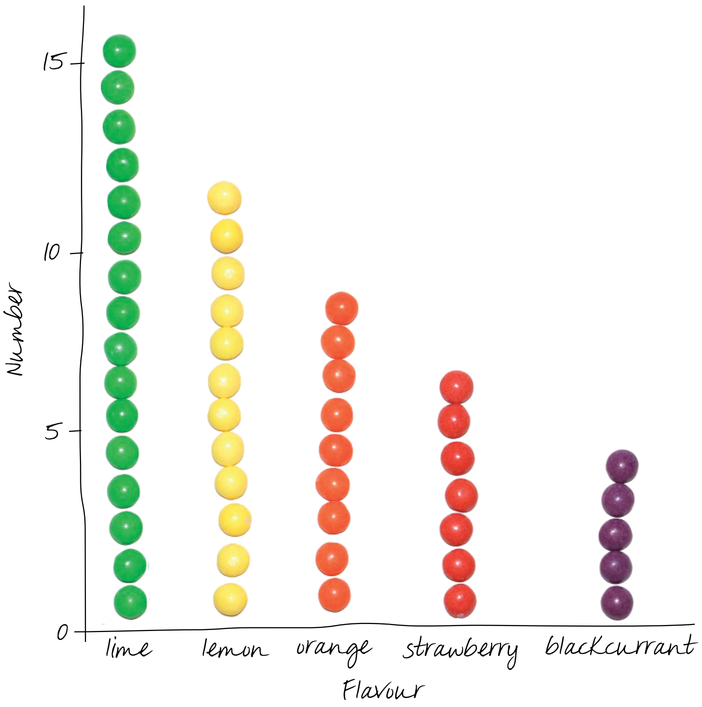


Figure 16 The distribution of sweet flavours in a single packet shown as a bar chart. Clearly the author's favourite flavours appear least often!

In Figure 16 the values on the horizontal axis (*x*-axis) represent a category − flavour in this case − and the vertical axis (*y*-axis) states how many sweets fell into that category. The bars could have been drawn in any order, but ordering them by size as in this case is often most informative.

Histograms and bar charts

The following section provides further information about histograms and bar charts.

Box 6 Histograms and bar charts

Histograms:

- are used to show distributions of variables
- plot quantitative data, grouped into intervals, i.e. a number, or a range of numbers.

In a histogram:

- the bars appear in numerical order
- there are no spaces between the bars (unless the number of occurrences in a particular range is zero)
- the area of each bar represents a proportion, or percentage, of the total.

Bar charts:

- are used to compare variables
- plot categorical data, e.g. colour, flavour, gender, occupation.

In a bar chart:

- the bars can appear in any order
- there are spaces between the bars
- the height of each bar represents the quantity of interest.

Activity 11 Other people's data

Allow 20 minutes to complete this activity

To make sense of what this histogram is showing, do the following:

- Look over the whole graph to get a sense of the information.
- Look at the horizontal and vertical axes to understand what units are being displayed (and how they are displayed).
- Roll your cursor over the vertical bars to get detailed data on each 'bin'.
- Click on the 'Male', 'Female' and 'Combined' (total) labels at the bottom of the figure to switch these values on or off.

Interactive content is not available in this format.

Discussion

On the horizontal axis, there are a series of 'bins'. Each bin represents a short range of a continuous measurement – in this case, height – and each bin represents 0.1 metres. For each bin, there is a frequency (vertical axis) which tells you how many data points are in each bin.

The height of each bar represents the number of people who are in a particular height range. This information has been further divided by gender.

Now make use of this histogram in the following activity.

Activity 12 Finding data ranges

Allow 20 minutes to complete this activity

Using the histogram in Activity 11, find which data range you are in.

1. How many people in total are in the same data range as you?
2. How many men and women are in the same data range as you?

Discussion

The answer to this will depend on your height! To find the correct answer you have to first identify which data range you are in. For example, if you are 1.68 m tall you will be in the range 1.6–1.7 m.

Once you have the appropriate data range you can roll your cursor over the vertical bars (coloured blue, black and green) to get the numbers of male, female and combined (total) in that range.

In Activity 12 you identified which range your own height was in, as well as how many other people were in that same range from the sample data.

For this data to be really useful you need a few more data points, and the ranges would be more useful if they were smaller, as in Figure 15. Based on the data in Figure 15, 18% of the population are in the 1720–1739 mm bucket. This means that 18% of people are between 1720 mm and 1739 mm tall. Another way to write this is by using a tolerance symbol (±), so in this case the tolerance is (to a good approximation) 10 mm above or below 1730 mm. This can be written as 1730 (±10) mm.

Activity 13 Percentages and populations

Allow 20 minutes to complete this activity

In Activity 8 you worked out your new perfect desk height. Now assume that this desk height is directly related to your own height.

Use the data in Figure 15 to work out:

(a) Which bucket does your height fall into? Write this bucket as a value with a tolerance.

(b) What percentage of the population is in that same bucket (i.e. what percentage might be satisfied with your desk height)?

(c) What percentage of the population of 200 people is outside that bucket (i.e. what percentage might not be satisfied with your desk height)?

Discussion

The answers to this will depend on your own height. In these example answers a person of 1762 mm height has been used.

(a) 1770 (±10) mm bucket (because 1762 mm is within the 1760–1779 mm range).

(b) 11% (estimated from the vertical axis (*y*-axis) on the histogram in Figure 15).

(c) The percentage outside this range can be found by either adding up all the other percentages (a very slow process) or subtracting 11% from 100%, to give 89%.

From this activity it seems that quite a few people might not be entirely happy with your specific desk height. A next step might be to work out a bit more accurately what sort of height ranges would be acceptable to suit as many people as possible.

But there are a few big assumptions in what you have just done.

Firstly, it was assumed that there is a link between a person's height and their preferred desk height. This might not be a valid correlation – arm length or sitting height might give a more appropriate relationship. Or there might not be a reliable human measure to use in this instance.

Secondly, it was assumed that 20 mm is a suitable division for the buckets in Figure 15. It is possible that people in both the 1720–1739 mm and 1740–1759 mm buckets have exactly the same preference, and that 40 mm buckets would be appropriate. However, since Activity 8 showed that anything less than a 20 mm change didn't make a noticeable difference, a 20 mm range in height seems quite reasonable.

4.6 Designing for people using numbers

Designing for people can be a complex process for some very simple reasons. Designing the height of a desk for one person might be relatively straightforward, but making that same desk suit lots of people is quite difficult because of the variation in human sizes.

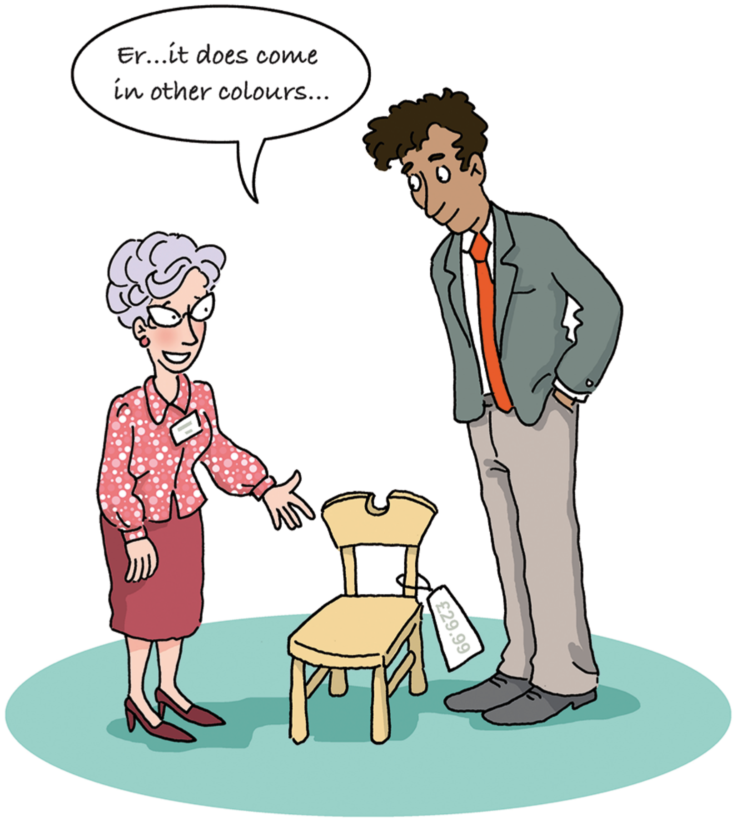


Figure 17 There are many variations to consider in any design and different variations matter to different people

Playing with data

The data you have just been looking at could now be added to hundreds, thousands and even millions of additional data points. In fact, some of the anthropometric data used in the British Standards is collected from entire country populations.

Each time another point is added, the shape of the histogram will change slightly. If we had enough data points we could even imagine the histogram being quite a smooth shape (Figure 18).

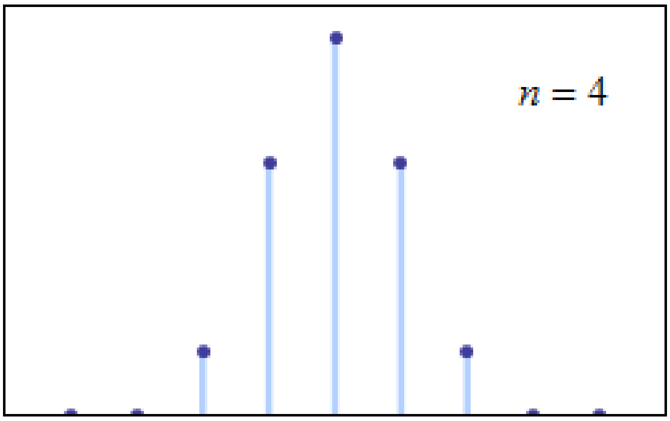


Figure 18 Dynamic illustration of a smoother shape emerging with enough data points

The smooth curve in Figure 18 is called a distribution curve. This is one of a number of different types of representation of data that is useful to be aware of. It's different to the histogram in Activity 11 because it is smooth (continuous) and is not divided into individual (discrete) ranges of data.

It is simply useful to see the *shape* of this data and to realise that a visual representation of information can be just as useful as a mathematical one.

Now you will explore this in the final activity.

Activity 14 Playing with UK height data

Allow 20 minutes to complete this activity

In the interactive graph below you can see the distribution of male and female heights in the UK population. The horizontal axis shows heights (in metres) and the vertical direction represents the number of people in the population.

Interactive content is not available in this format.

1 First, select either the 'Male' or 'Female' population. Next, adjust the left and right vertical bars (labelled 'A' and 'B') and place them in an approximately symmetrical position in the middle of the graph. Then use the adjustment arrows to nudge the numbers (shown above the graph) and get them to show around 50% of the population (pay attention to the dynamic percentage information immediately above the graph).

   (a) What is the height range of roughly 50% of the male population?

   (b) What is the height range of roughly 50% of the female population?

2 In Activity 12, you identified the range (data bin) within which your own height is situated. Use this range to place the vertical lines at the lower and upper values of this range. Note down what percentage of both male and female populations would be in this same range.

Discussion

1 Note that your own answers may vary slightly because the activity relies on a visual judgement to locate the lines. But your figures should be close to these.

   (a) For the male population the range is approximately 1.72–1.82 m (roughly 50% of the male population).

(b) For the female population the range is approximately 1.57–1.67 m (roughly 50% of the female population).

2 If you used the example of the height range 1.6–1.7 m (Activity 12), you would have found that roughly 49% (48.59%) of the female population and 16% (16.36%) of the male population is in this range.

By playing with this data visually, you have learned some useful things about the desk height problem. In particular, you may now be able to visualise just how exclusive some design decisions can be; the decision to use a particular height might exclude a whole section of a population from that product. The example answer given in Activity 14 (Question 2), demonstrated a sizeable population difference between male and female heights.

Clearly, seeing the world from a range of different users' perspectives can have a dramatic effect on the design process.

4.7 Summary of Section 4

It is no trivial matter to physically design something for people to use. The ergonomics of design engineering can be a very complex aspect of design, but simply being aware of people's sensitivity to physical variation can be useful as a designer. Even better, perhaps, is to realise that placing people at the centre of any design process can help you to tackle difficult 'human' design problems.

As you have seen, designing for the 'average' or majority in a population means you often ignore other large parts of the population. This can have a particularly significant effect on population groups that lie outside the average groupings, such as children, older people or wheelchair users. One way of approaching this is to design in order to suit as many people as possible, or even for *all* people in any population. This is known as inclusive or universal design.

Taking this approach for the desk example, the challenge is to create a surface that is suitable for as much of the population as possible. This then becomes the new design driver – to solve the problem of a desk that is adjustable to suit a wide range of users. This changes the original design question, but it also expands the potential user market. Remember, you started considering only your own height and preference (a market of 1 person) – designing for a wider range of the population automatically means creating a more accessible product for *all* users of that design. In fact, most desks attempt to do precisely this and have adjustable feet to ensure that they are adaptable to as wide a range of people as is reasonably possible.

But physical variation is not the only human issue a designer must consider – the attitude and thinking of people is also a hugely important area of study. Like ergonomics, this is almost a whole discipline in itself, called human factors. It deals with how people think, react and interact with products, systems and services. As with ergonomics, it is essential to recognise how important this can be for the success of any design. Research shows that the way people *feel* about a design has a huge impact on how they use that design – whether they persist with it, use it correctly or simply ignore it.

Take your desk height as an example. If the desk were to be fully prototyped using different materials, you might feel very differently about each height depending only on the material. Some research even shows that your very posture changes depending on how much you like your desk!

Similarly, the design of instrument and control panels for complex systems has to consider how people read, use and interact with them – the design cannot only consider functional requirements. Modern cockpits in large commercial aeroplanes, for example, are designed specifically to take account of how people use and interact with the instruments; Figure 19 shows an example. Designing with the user in mind throughout the process is known as user-centred design.

Figure 19 The cockpit of a large aeroplane, demonstrating the complex interfaces between the instruments, controls and people

By placing the user of a design at the centre of the design process, the focus of the project shifts from what is often a static perspective (considering certain aspects only) to a more active view of design (how certain aspects work in the real world). Unfortunately, changes in aeroplane design came only after a series of major failures, where it was recognised that changing the way information was presented to pilots would allow them to make better decisions. The lesson from this is simple – never ignore the user in any design project.

This section has guided you through a short design process. It started with a general exploration of desk height; you then made use of direct knowledge, then tried something to test your ideas and finally checked what you did. If you were to repeat this process and improve the starting question, you would be able to repeat and improve what you did each time. This repetition and improvement is known as iteration, and it is the essence of design – starting somewhere, thinking about it, doing something, then checking it, and repeating the whole cycle until it works the way it needs to.

At each stage you also used a range of types of thinking and processes, both analytical and creative, to 'think through' the problem one step at a time. Each time you did this, what you found informed the next stage in the process – all with the overarching aim of responding to the original question posed. Design is not simply doing one thing or applying one kind of approach – it is a process that incorporates a range of skills, attitudes and approaches.

Conclusion

This completes the free course, *An introduction to design engineering*. Hopefully your existing ideas of what design is have been challenged so you now think of design in other ways too. You have seen that design is more than simply choosing the shape and appearance – it's a fundamental human ability to take existing conditions and change them with a clear purpose.

Design responds to real world situations and challenges, most of which are driven by human needs and desires. These design drivers are major factors in motivating designers but designing for humans is still unquestionably a difficult task.

You have also been introduced to some numerical methods that can be applied in design, showing that it's not only creative thinking that's necessary – good analytical thinking is needed too.

The key to good design is knowing when to apply each of these to best effect in the design process. As a design engineer, you make use of both creative and analytical thinking, taking human imagination and creativity and making it a working reality.

This OpenLearn course is an adapted extract from the Open University course T192 *Engineering: origins, methods, context*.

References

Cross, N. (2011) *Design Thinking*, London, Bloomsbury.

Acknowledgements

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Figures

Course image: © Steve Jackson / https://www.flickr.com/photos_user.gne?path=&nsid=74593159%40N05&page=&details=1

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Figure 4 (a): Taken from: www.criticalgamers.com/archives/cat_blogpire_news.php

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