WHY YOU NEED SCIENCE

THE BEGINNING AND THE END

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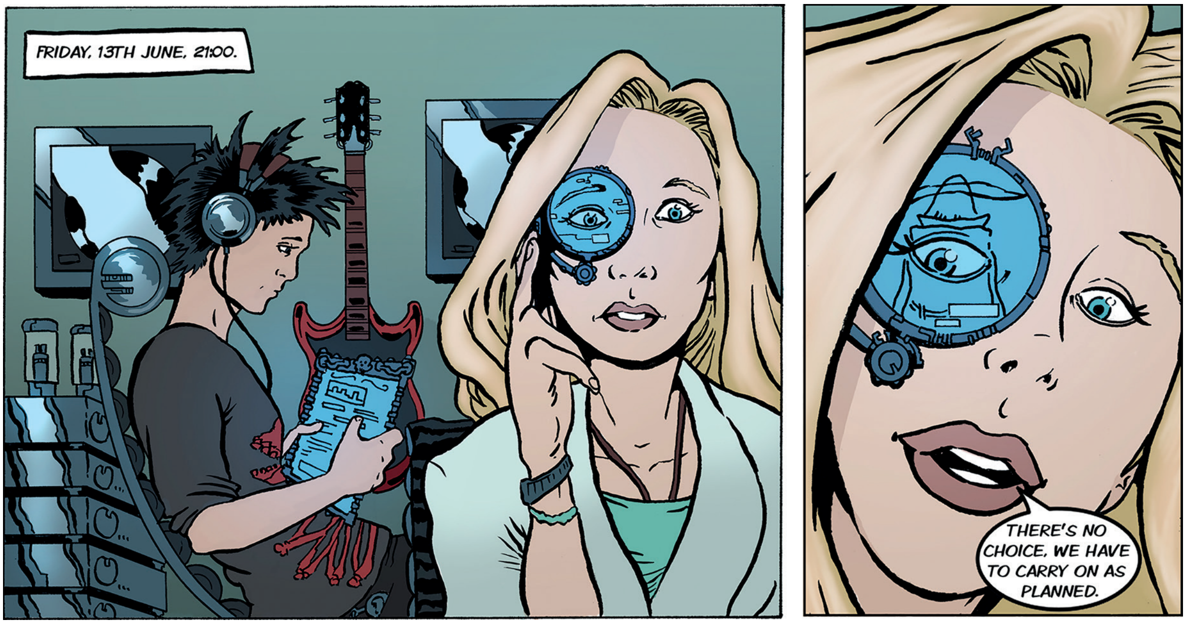

Alice had been acting strangely all night. I had returned from band practice to make dinner before she got in from work, but she was already home. Alice never left work early. She was on edge, and had been for weeks, as though she was hiding something. She was playing music too. Nothing strange about that, you might think, and, sure, when we first hooked up music was our shared passion, but Alice had lost interest. She would come to my gigs, but otherwise she seemed to live and work in silence. I worried sometimes that there was too much silence in her life – that she was too disconnected. Tonight, though, our apartment was full of the sound of an album we used to listen to back in the day, an album that transported me back to a time of staying up with her all night talking and avoiding sleep because it meant being apart. The riffs hit me as soon as I opened the door. It was strange not to return to an empty, silent apartment – it made me a little uneasy. I smiled when I registered that Alice was home and recognized the album she was playing: perhaps her world wasn't as silent as I feared, and maybe these songs still meant something to her? These hopes faded as I saw her nervous and distant expression. She barely registered that I was back, and I felt stupid for thinking that the music might be anything other than a random decision. Alice was a scientist, and that seemed to rule out being sentimental. I cooked, we ate, and Alice spoke only to snap at me. This was normal in recent weeks: things between us had become strained; I wasn't sure how we'd got to this place, or how to leave it.

Alice and I are Clocktorians, but I cling to the pre-revolution more than she does. I wish I had lived through those times; the turn of the 21st century sat in the middle of a golden era for music. People would gather in their thousands at events called 'festivals' to watch bands perform, not in virtual reality but in the flesh. Bands travelled the world, had a real, physical connection to their fans. Of course, my band plays gigs too, but only in our home city. For the rest of the world we are an image in an oculus riff: a multisensory headset for experiencing virtual gigs. For me, the world did so much right a century ago, I couldn't understand how it went so wrong, but people like me were doing our bit to bring back the old ways.

Before the ID chips came in everybody had a Proteus – a device made from programmable matter,[1] which means that it can transform shape and function. In the pre-revolution people had iWatches, iPods, iPhones and the like. The Proteus replaced them all with a single device: it could transform into a touch screen to type text messages, become an earpiece for streamed music, and would happily become a visual screen or project a 3-D image for a video. A Proteus could become whatever you wanted it to be: the owner had only to think of what they wanted it to look like and it would become that thought. You could wear it as a ring, a bracelet, or any design in your imagination. I mainly kept mine in the shape of a slim tombstone, across the top of which was inscribed 'In loving memory of your memory'. I called it my diePad. It was a joke to myself because I think everyone relies so much on technology that our memories have died. Of course Chippers not only don't need a memory, they don't need a Proteus: the chips in their heads relay their thoughts to others via *memoryBank*. This connectivity has made Clocktorians like us outsiders: it's difficult for us to connect to Chippers and they have to resort to a Proteus to get hold of a Clocktorian. It's a pain.

Alice had been on her Proteus most of the evening. She liked to wear hers as an earpiece with a small microphone to pick up her voice and a monocle to see the caller. This meant that I couldn't see who she was talking to or hear the conversation, but I could tell that something wasn't right. I wanted to help, but Alice didn't seem in the mood to talk to me. Fed up with her spiky mood, I put on my headphones to listen back to our rehearsal recordings and picked up my diePad to look at the news. Wearing headphones said a lot about me: Chippers had music transmitted directly to their brains, and even most Clocktorians used their Proteus for listening, but I liked the space and warmth created by dedicated headphones.

1.1 WILL YOU LOVE ME NOW?

As I listened, I found myself distracted by a news story about the Proteus. It claimed that some of the technology in the Proteus had its roots in pre-revolution mobile phones: primitive, inflexible blocks that people used to communicate before the first Proteus, they couldn't change shape or function. They were basically useless. The news story looked at some data from before the revolution that claimed that these old phones caused brain tumours. The journalist argued that the same was likely to be true of the Proteus. Alice spent a lot of time with her Proteus stuck in her ear, and this article worried me: what if she was harming herself? She'd been talking for ages while I'd been engrossed in the story. Now she was pacing around like she was looking for somewhere to offload the weight on her shoulders. I couldn't bear it any more; I took my headphones off and asked her if everything was level. She looked at the floor and reassured me that everything was fine. She always looked at the floor when she was lying.

'Maybe I can help?' I offered.

Alice sighed. It was one of those sighs that made her seem as though she'd become suddenly aware of how little of her lung capacity she normally used. In the Venn diagram of Alice and me there was a beautiful ellipse containing music, films, literature and a general belief in the goodness of humanity, but outside of it we were poles apart. At times like this Alice made me think the ellipse was shrinking. Her facial expression was a window into our growing differences.

She looked at me as though I'd said something ridiculous. 'It's work stuff, you wouldn't understand,' she said dismissively.

Alice did this a lot since she started working at the Beimeni Centre of Genetics: she assumes I'm stupid and uninterested in her research. She has a point. I don't understand maths and science and I never have. Science is dull, unemotional, uninspiring. It can't break your heart like a good resolution in a song. The mistake she makes is assuming that because I'm not interested in science, I am not interested in *her*. She couldn't be more wrong: I'm in awe of her ability to analyse and evaluate situations. She is the most intelligent person I know, and even other scientists think that she is brilliant: she won the World Science Federation's prestigious Einstein medal when she was 21 for her genetics research. She is a genius, of that I'm certain. I know exactly how brilliant she is, and every day I see a passion for knowledge burning in her every bit as strong as the one I have for music.

For real, the vibe was spooks tonight; I didn't know why, but I felt sure that Alice needed someone, and I wanted that person to be me. She had always taken an interest in my music, perhaps it was time I took an interest in science; it might be enough for her to let me in on whatever was going on.

'Maybe I *could* understand,' I said. 'Try me.'

Alice gave an exasperated sigh. 'It's too late for that, Zach; you can't just make everything better by suddenly showing an interest in me.'

Her directness hurt me, but it also seemed at odds with her vibe. The same album was still playing in the background, as though it comforted her to hear the songs that once were the glue that bonded us. Her eyes too; I couldn't explain, but in her eyes was *something*, the tiniest glint of something, that said 'It's *not* too late Zach, please help me.' Maybe it was nothing, but there was only one way to find out.

'I've been reading this,' I said passing my diePad to her. 'This guy believes that the Proteus might cause brain tumours – for real. It's based on pre-revolution science. He quotes newspaper headlines from last century: the *Daily Express* says "Just a few minutes a day on a mobile phone 'raises cancer risk'";[2] the *Daily Mail*, "Mobile phones may cause cancer, warn world health chiefs";[3] and *US News and World Report*, "Cellphone Use and Cancer: New Study Suggests a Link".[4] Even the BBC and CBS News report "Mobiles 'may cause brain cancer'".[5, 6] Seems scary to me. You're a scientist, tell me how *you* would know if the cancer thing was true.'

Alice eyed me suspiciously. 'The headlines are there to grab your attention. I'd look at the *evidence*,' she said curtly.

Alice was trying to shut down the conversation, but I wasn't going to give in. I pulled a silver hunter-cased pocket watch from my jacket. On the silver cover was etched 'Be still, and know'. I pressed the winding mechanism to spring open the cover. Laying the watch flat on my palm, we looked at the familiar clockwork mechanism: a beautiful configuration of cogs, hairsprings, and red, yellow and blue jewels positioned equidistant inside the circular edge. The cogs accelerated into a blur of motion, and at the point of critical velocity the three jewels projected each of their colours upwards into a central mist that quickly settled into the shape of an opaque human head. Clockwork fusion never ceased to impress me: how could self-winding springs create the kind of power needed to generate a fully functional artificially intelligent head? The device was a 'reality checker' and the head within was linked to everything. Of course, you could find things out using a Proteus, or even an ID chip if you had one, but the reality checkers added something that none of these devices could: a brain much better than your own. A reality checker would assimilate data from everywhere, evaluate it, and give you the best answer it could to any question. Gone were the days of believing any nonsense that you uncovered on the internet; a reality checker would filter it all for you. Every head had a personality: for a price you could customize it, or choose one modelled on a favourite celebrity, but at the cheaper end the personalities were randomly generated. If you were as skint as me you bought one of the factory rejects, the ones with such quirky personalities that the manufacturers assumed nobody would want them. Mine was a nice dude, but he certainly was quirky. He refused to respond to any name except for 'The Head', as though he was the definitive model, and he kind of answered questions if he felt like it, and liked to wind me up with false information. Not what you want in a reality checker, but mine was more like an electronic friend. I didn't care about how straight his facts were, I just liked the banter and his beaming smile and deep, hearty laugh. He was pretty handsome too, with a chiselled face, perfect dark skin, an Afro and shades. As vapour-based dudes went, the guy was sick.

'What you got for me, Z?' he said in his cheerful, lispy, North Carolina accent. He was the only person in the world I'd allow to call me *Zee*.

'I was discussing with Alice whether the Proteus causes brain tumours. She told me to look at the evidence. Can you help me out?'

'Hmm, does the Proteus create brain tumours? Let me see … .' The corner of The Head's mouth curled up in a knowing smile. He span around as he checked his database. 'They do … ' he smiled before spinning some more, 'or maybe they don't.' There was more spinning. 'Wait up … looks like they do … or don't … or they *might* … or not … but possibly.' He span some more, and when he returned to a static state he had an overly arched, furrowed brow as though he was about to relay some terrible news. 'Bad news, *Z*. The evidence is contradictory,' he said. He pouted at me to convey the severity of the matter.

'OK … and the answer is?' I raised my tone expectantly to let him know that his answer didn't fulfil his duty as a reality checker.

'Hmm,' he sulked. 'I *could* assimilate this contradictory evidence for you, but you don't like science, so I'll tell you a story instead. That's more your level.' Like I said, he answered questions when he felt like it.

REALITY CHECK 1.1

This was typical of The Head, it was rarely clear if he was being helpful, so I closed his lid, effectively trapping him in a watch. I paused to take in Marcolini's story. Was this evidence the kind that Alice meant? Alice had been flitting nervously around the room, but I suspected she'd heard the story too, so I asked whether Marcolini's story showed that phones gave you cancer. She sat next to me. This *was* a small breakthrough.

'Even if we put aside how old this story is, Zach, it tells us nothing. I feel for Mr Marcolini, but his experience could be unique; in itself, it doesn't prove anything. There could have been a thousand other people back then who used their phones just as often as Mr Marcolini and *didn't* get cancer.'

'But the judge agreed, and judges know what they're talking about.'

'Perhaps, but they are not scientists. Science isn't perfect, and it's not the only way to view the world, but it does give us a system for trying to find answers to questions. You asked me to explain science to you, and I've tried, lots of times, but the trouble is that you're scared of it and you refuse to engage with it.'

'Way back in the day,' The Head began, 'before the revolution, in October 2012, Italy's highest civil court supported Innocente Marcolini's claim that a brain tumour he had developed was caused by long-term use of his mobile phone. Marcolini was a commerce manager and he spent up to 6 hours a day on his mobile phone over a 12-year period. The guy developed a non-cancerous tumour of the trigeminal ganglion – that's in his head. They removed it, but he was in pain. So, he asked INAIL – that's an agency that insures work-related health risks – for money. They rejected the claim and Marcolini went to the Appeal Court. Do you know what happens at an appeal court? It's where people appeal things. The judge agreed that phone use had caused his cancer. This story went around the world:

- Italian court rules man's tumour caused by mobile phone (CBS News, USA)
- Mobiles can give you a tumour, court rules (*Sun*, UK)
- Mobile phones *can* cause brain tumours, court rules in landmark case (*Daily Mail*, UK)
- Mobile phones can cause brain tumours, court rules (*Telegraph*, UK)
- Cell phones can cause brain tumours, Italy's top court rules in landmark case (*National Post*, Canada)
- L'Italie reconnaît le lien entre mobile et tumeur crânienne (*Le Monde*, France)

In an interview with a UK newspaper, the *Sun*, Marcolini said: "This is significant for very many people. I wanted this problem to become public because many people still do not know the risks ... I wanted it recognised that there was a link between my illness and the use of mobile and cordless phones. Parents need to know their children are at risk of this illness."'

Reality Check 1.1 *A case study of subjective beliefs becoming 'facts'*

I felt the breakthrough slipping away. We'd been here many times before, and she was right, I was scared that if she explained her world to me it would reveal to her how stupid I am. When I couldn't understand maths and science at school, it made me feel inferior and frustrated, like I wanted to throw my desk out of the window. I was the rad kid with the guitar, so I couldn't ask for help; I just kept telling myself that music was my thing, and you don't need maths and science to do music. She *had* tried to explain it before, and I *had* refused to engage. Tonight was different, though. Alice looked desperate, and maybe the soundtrack in the background was making me too emotionally charged, but I felt overwhelmed by a need to protect her. I didn't know what to protect her from, but I sensed that, for some reason, she needed me to understand her life, to understand why science was important. I reached for her hand, fixed her gaze and promised that if she tried one more time then I would listen.

1.2 HOW SCIENCE WORKS

1.2.1 The research process

Alice looked sceptical, but her relief was obvious. He eyes darted as she tried to think of a way to capitalize on my interest. Suddenly her expression changed, and I saw the first smile of the evening. 'I've got it!' she said, looking pleased with herself. 'Do you remember at your last Reality Enigma gig, you gave away a free wristband with every T-shirt? After the show you told me that you'd sold more shirts than the previous gig and you thought it was because of the free wristband. How do you *know* that it was because of the wristbands?' she asked.

I shrugged. 'I don't, it was just a hunch.'

'Exactly – and this is a question that science can answer for you,' she said. 'Do you always sell exactly the same number of T-shirts at concerts?'

'No – it's different at each gig.'

'Which means it could have been the wristband offer that made the difference, or perhaps it was just one of those nights where you happen to sell a lot of T-shirts?' She had a point. 'That's why it's useful to have a system, like science, for trying to find out the true answer to questions.'

Alice took her Proteus and stretched it into a large flat screen. Then she sketched a diagram on

FIGURE 1.1

it. 'This diagram shows the process of science,' she said. 'Scientists begin with an observation in the real world that they want to understand, and this observation could be based on data, like when you notice more T-shirts sold when you give away a free wristband, or it could be anecdotal, such as Mr Marcolini believing that his tumour was caused by phone use. These "data" could be an isolated observation such as noticing that one person was persuaded into buying a shirt when you offered them a wristband, or based on several, such as you noticing that nine out of ten people who you offered a wristband ended up buying a shirt. From these initial observations, you can generate a research question, such as "Do free gifts help to sell T-shirts?" or "Can a Proteus give you brain cancer?" Having a research question implies that you are trying to generate a **theory**, which is a principle or set of general principles to explain what you have observed. For example, you observed more T-shirt sales at one gig compared to another, and your theory might be that offering a free gift increases T-shirt sales. Although you might care only what happens with your band, The Reality Enigma, normally scientists are interested in theories that apply very generally – they want their theories to apply to all entities or situations. An entire set of entities is known as a **population**. A population can be quite diverse (for example, you might want to draw conclusions about the T-shirt sales of every band on the planet) but can also be more specific (you might be interested in drawing conclusions only about bands who play a certain style of music, like heavy metal). Different

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types of scientists might focus on different populations. I work in genetics, so I want my theories to generalize to the population of humans, and this population would also be interesting to psychologists, and epidemiologists too. However, an economist might be interested in the population of "small businesses" or "workers" or "managers", and biologists might be interested in the population of "cells". We want theories to be general and apply to the entire population rather than applying only to a specific case within that population; using the T-shirt example, it's more interesting to be able to say that free gifts, in general, will help any band (the population) to sell T-shirts than it is to conclude that free gifts are effective at increasing T-shirt sales if you happen to be in the band called The Reality Enigma, fronted by Zach Slade.'

Alice smiled affectionately at me, and I loved seeing her relax a little. 'A theory should enable you to generate a scientific **hypothesis** or several hypotheses, which are testable predictions about what will happen ➡. You might, for example, hypothesize that "if a band offers a free gift, they will sell more T-shirts". A hypothesis should be a scientific statement: a statement that can be verified (or not) using data. That means that you can break the statement down into things that you can

FIGURE 1.1

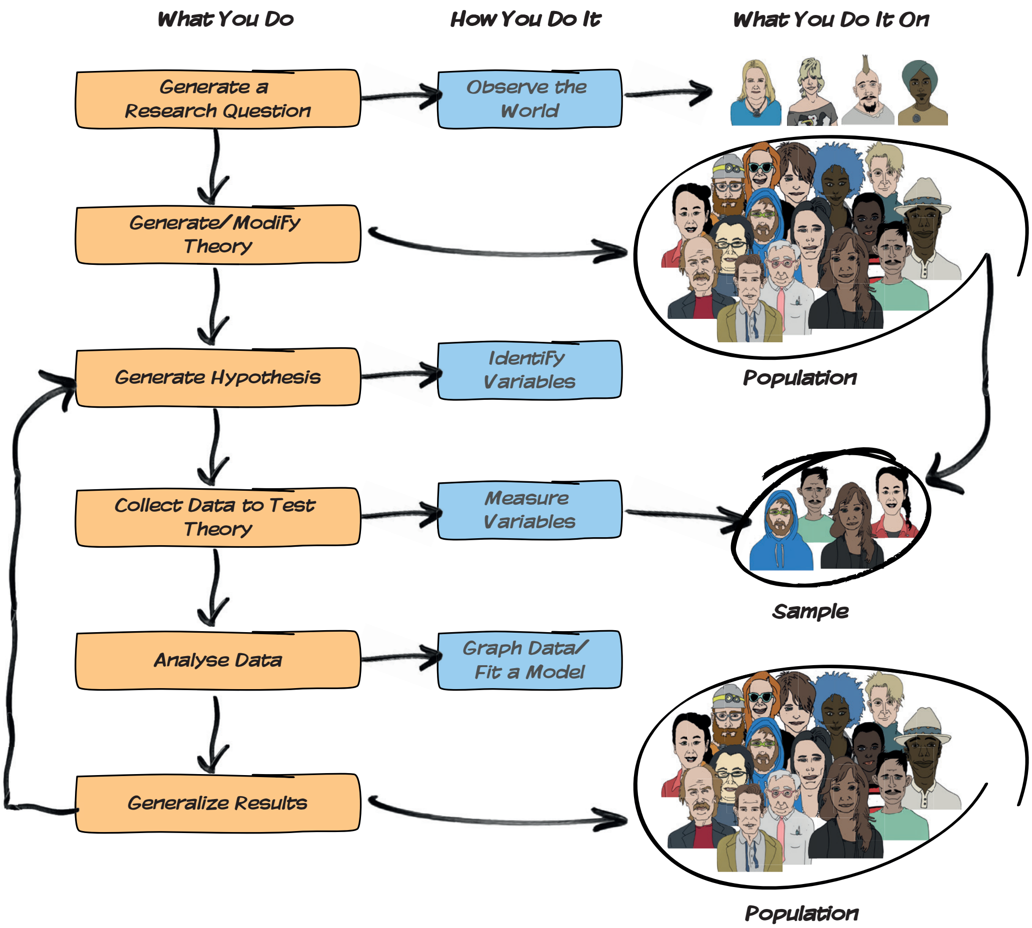


Figure 1.1 *The research process*

measure, known as **variables**. Just now you told me that the number of T-shirts you sold varied from one concert to the next, so "T-shirt sales" is a variable.'

'You mean that I can count how many T-shirts we sell? I suppose I could also note down whether or not we gave away a free gift with the T-shirt at that gig?'

'Yes. You can test the hypothesis about free gifts with two variables: how many shirts were sold, and whether or not a free gift was offered with the T-shirt. You will often come across non-scientific statements, though, and these are statements that cannot be verified, often because they refer to things that can't be measured. For example, "Alice is the best girlfriend in the world"' – she threw me a cheeky smile – 'is not a scientific statement because you probably couldn't get anyone to agree on a definition of "best": different people will value different facets of people (some value looks highly, some intelligence, and others kindness or sociability – who's to say what is "best"?). However, you could turn it into a scientific statement by changing "best" to something that could be measured, such as intelligence. So, "Alice is the cleverest girlfriend" is a scientific statement because we could, in theory, get all of the girlfriends on the planet and measure their intelligence to evaluate this statement.'

'Right, so "The Reality Enigma are the most influential band in Elpis" would be non-scientific because it would be impossible to measure "influence" but "The Reality Enigma are the most popular band in Elpis" would be scientific because we could measure popularity by, for example, measuring how many nodes on *memoryBank* each band in Elpis has?'

'Exactly.'

I unrolled my diePad, touched the screen to activate it and, as Alice continued, I typed what I thought were the important bits.

ZACH'S FACTS 1.1

In Loving Memory ...Of Your Memory

- *Scientific statements* are ones that can be verified with reference to evidence. For example, 'Alice and I will stay together longer than the average couple' is testable: we can measure the average length of time a couple stays together, and we can (eventually) measure the amount of time that Alice and I stay together (it will be forever!).
- *Non-scientific statements* are ones that cannot be tested empirically. For example, 'Alice and I are the perfect couple' would be non-scientific because it is probably impossible to define what a 'perfect couple' is, so we couldn't measure it.

Zach's Facts 1.1 Scientific statements

Alice looked impressed that I made notes. 'The next step of the process is to collect some data [FIGURE 1.1]. The problem here is that you want to draw conclusions about the entire population, but it's usually impractical to collect data from every entity in the population. It would be quite difficult to get T-shirt sales and information about free gifts from all of the bands in our city, so instead we use a **sample**, which is a smaller set of entities from our population. We want the entities that we choose for our sample to be representative of the wider population, and we can do that by selecting them randomly. In doing so, we should get a group of bands that represent all of the bands in the city. We can use the data in the sample to compute **statistics**, which are values that describe the sample. So, the average number of T-shirts sold in our sample is a statistic. However, we can use this value to estimate what the value would have been if we had collected data from the entire population. The value in the population is known as a **parameter**.'

'So, the average number of T-shirts in the sample is called a statistic, but the average number in the population is called a parameter? That's really confusing, why not call them the same thing – they're both the average?'

'The different names remind us that statistics can be computed directly from the actual data we collect, whereas the equivalent "statistic" in the population is something that we can only estimate based on the sample data.'

Alice sensed that I was still confused, and changed tack.

'It boils down to two things that you might want to do with data. The first is to describe what happened in the sample that you collected. You might draw a graph of the data, or calculate some summary information such as the average T-shirt sales. This is known as **descriptive statistics**. However, because scientists usually want to generalize their findings beyond the data they collected to the entire population, they use the sample data to estimate what the likely values are in the population. This is known as **inferential statistics**. Inferential statistics help us to make generalizations about what is going on in the real world, based on a sample of data that we have collected.'

Something clicked in me. 'Sweet, so you see whether offering free gifts increases T-shirt sales for, like, 20 bands and then, based on that, you can say whether it will work for every band. That's sick. *How* can you do that?'

'Let's imagine we could get together the whole population of rock bands.' Alice grabbed my diePad and began to draw. 'I'll draw the population as an ellipse and we'll put some band names in there. Obviously there's your band, The Reality Enigma, and you play with Chamber of the Damned and Zombie Wrath all the time.'

'Yeah, those guys are sick! There's also Hollow, Brain of Morbius, Forest of Trees …'

'… and that band with the amazing woman singing,' Alice added, struggling to think of their name.

'Ten Plagues,' I said.

'Of course … oh, and Kings of Archea,' Alice said, getting into the swing of the game.

Before long we'd listed all the bands we could think of. It was great to see Alice dropping her guard a little.

'Let's pretend that's all the bands that exist. That's our population [FIGURE 1.2]. Let's also say that on average across all of those bands, you expect to sell 35 T-shirts at a show. That's the magic number that we'd like to find out – the population parameter – but we can't ordinarily find it out directly because we don't have information from the entire population. However, we can estimate it by taking samples. Imagine we took a sample of three bands: Zombie Wrath, The Reality Enigma and Scansion. We work out the average number of T-shirts sold across those three bands and it's 37. This is the sample statistic. This value is slightly different from the population parameter: it is 2 T-shirts bigger. This difference is known as **sampling error**, which is the difference between what the population parameter actually is, and the value estimated from the sample. Imagine we put these bands back into the population and took a different sample; this time we get Odin's Law, Forest of Trees and Habit of Hate. For these bands the average T-shirt sales are 42, which is not only different from the population parameter, but also different from the previous sample. The sampling error is bigger than for the first sample (the sample average is 7 T-shirts more than the population average in the second sample, but it was only 2 T-shirts more for the first). Finally, again pretend we put these bands back and randomly select another three to make up a third sample. In this sample the average T-shirt sales are 28, which underestimates the population value and is again different from the other sample values. This illustrates two important things: (1) statistics vary across different samples, which is known as **sampling variation**; and (2) the sampling error differs across samples.'

FIGURE 1.2

Amazingly, this made sense to me. You can't get data from everyone, so you take a random sample instead, and use the data in the sample to estimate the value in the population, but the estimate might be wrong because samples will be different from one another, and might be slightly different from the population too. I was feeling pleased with myself. Normally Alice talking about science is a cue for my brain to start thinking about a song I was working on; today,

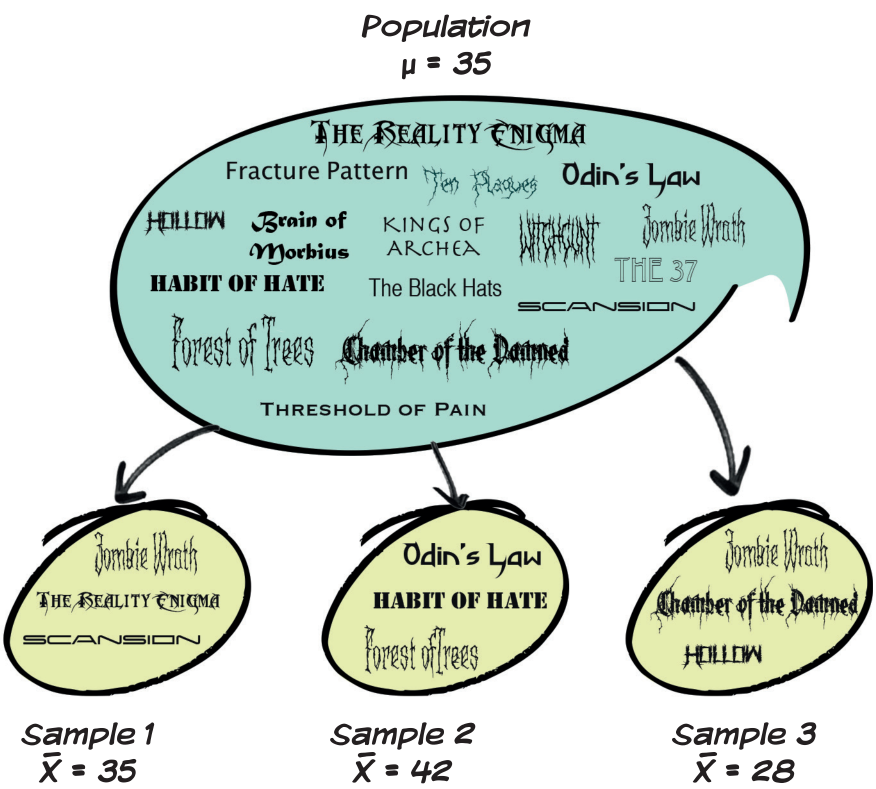


Figure 1.2 *Sampling variation*

though, she needed me, and I'd listened, and although I did get momentarily side-tracked by remembering that I hadn't seen the guys in Zombie Wrath for ages, I more or less understood ➡. ZACH'S FACTS 1.2 I was still missing something, though. How did this help us to find out whether a free wristband sells T-shirts?

In Loving Memory ...Of Your Memory

- Scientists begin with an observation in the real world that they want to understand. They generate a *theory* (a principle or set of general principles to explain what's been observed).
- They want this theory to apply to a *population* (a collection of units – be they people, plankton, plants, cities, suicidal authors, etc. – to which we want to generalize a set of findings).
- To test the theory they generate predictions about what will happen (*hypotheses*) that can be tested by measuring *variables* (e.g., the number of T-shirts sold).
- However, because they can't usually measure these variables in the whole population they measure them in a random *sample* (a smaller representative set of entities from the population).
- They can compute *statistics* from the sample data to test the hypotheses (e.g., the average number of T-shirts sold), and use these to estimate the corresponding *parameter* of the population.
- These statistics sometimes differ from the population parameter (*sampling error*) and also vary from one sample to the next (*sampling variation*).
- The theory is updated based on the degree to which the hypotheses were supported.

Zach's Facts 1.2 The scientific process

Alice looked pleased at my question. 'That's the next step. We have to look at how descriptive and inferential statistics work together.' Alice drew me another picture ➡, and I was reminded of FIGURE 1.3 how she'd looked when I used to admire her in our college library. She had that same intensity and purpose right now. 'Imagine we take two samples of bands from the population of bands in Elpis. The bands in one sample we tell to offer a free wristband with every T-shirt, but the other sample of bands we tell not to. After the concert, we count how many T-shirts each band sold. We can then use descriptive statistics to quantify what has happened in each sample. For example, we could calculate the average T-shirts sales. Perhaps we find that the average sales are 37 for those bands that offered a free wristband, and 35 for those that did not. We know that two random samples will differ anyway because of sampling variation, so the question is whether our sample averages differ because of sampling variation, or because one sample offered a free wristband with every T-shirt. Inferential statistics helps us to distinguish which explanation is most likely.'

FIGURE 1.1

'Right, so to use the scientific process to find out whether wristbands help T-shirts sales, you start with a theory that that they do improve sales. From that you generate a hypothesis that when you offer a free wristband more T-shirts will sell than when you don't, you test that by collecting data – you measured T-shirt sales and whether free gifts were offered in the two samples – then using statistics to compare the samples, you can see whether offering a free wristband, in general, will help

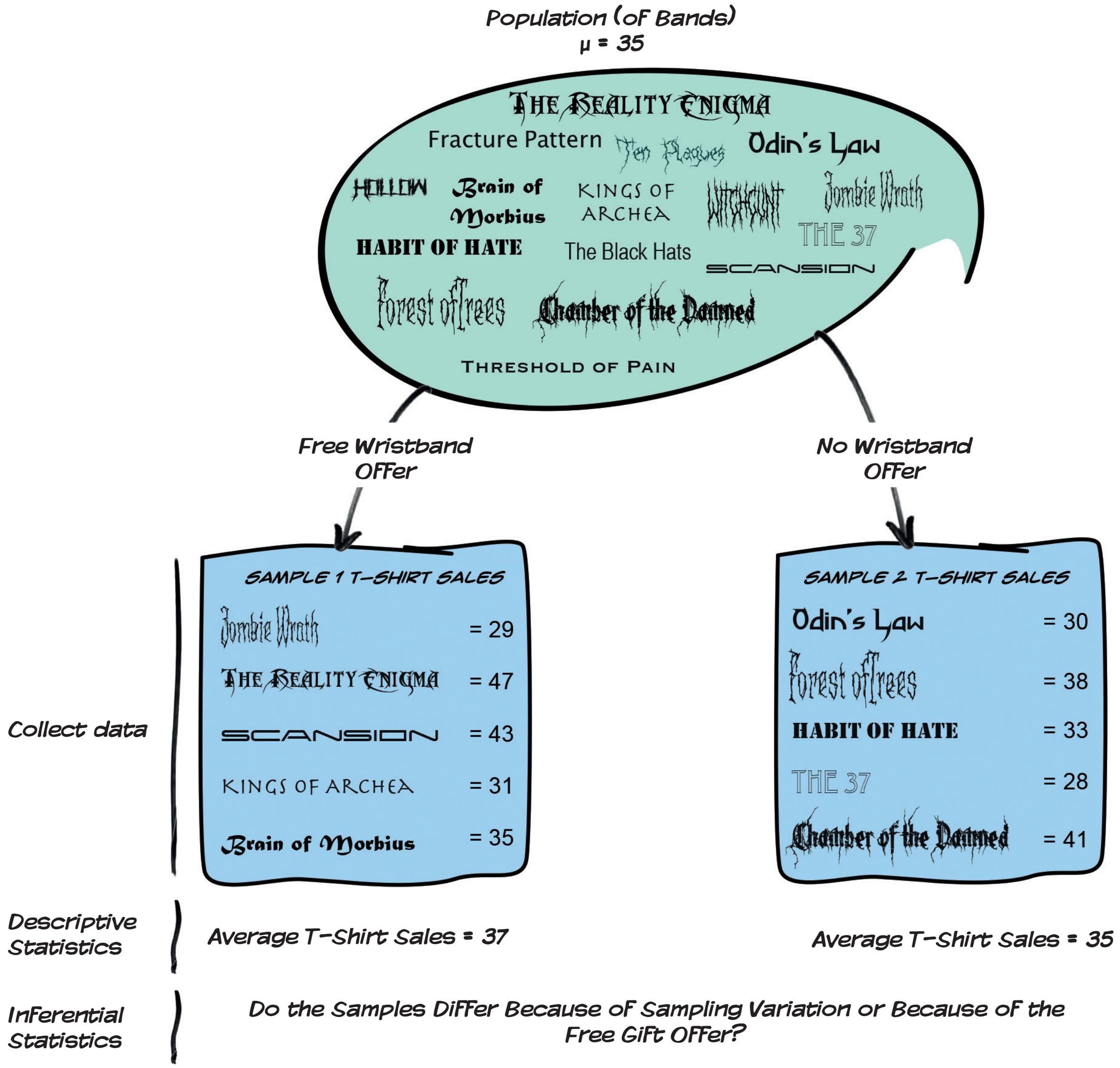


Figure 1.3 Using statistics to answer empirical questions

to sell band T-shirts.' For the first time, I understood the use of science. I was impressed, but not as much as Alice was that I'd paid attention.

1.2.2 Science as a life skill

All this talk of T-shirts had got us away from my original question, which was how a scientist would know whether the Proteus device caused cancer. Remembering the article I felt panicky at the possibility that something bad could happen to Alice. I'd say that the thought of life without her was unthinkable, but that would be a lie because I constantly thought about it and it felt like imagining my last breath. I reminded her of our original purpose.

'You can apply everything I have just told you to addressing the question of whether using a Proteus increases your risk of a brain tumour. Rather than rely on the subjective opinion of Mr Marcolini about his phone, or believing a newspaper headline, or what a politician tells you, you can evaluate the objective evidence. Good science should attempt to be objective, and by agreeing a system of discovery like the one I described, we establish standards that promote objectivity. However, scientists are humans and you can never fully get away from some subjectivity. There will always be subjectivity in how data are interpreted, for example. This is why understanding the system of science empowers you, because it enables you to make your own judgements about the evidence. You don't have to believe everything you read in the paper, or what a scientist tells you. You can look at the science for yourself. In this case, you could look at the studies before the revolution that investigated links between mobile phone use and brain tumours, then look at studies that address the same question about the Proteus (if they existed), and make your own judgement about the risk. You won't be relying on a journalist, who might want to spin the data to make a good story, or a politician, who might want to spin the data to make him or herself look better, or a Proteus salesman, who it might suit to play down the risks. You will be using your knowledge and skills to make an informed decision.'

'Wow, so, like, if I was ill and my doctor gave me some pills, rather than just take them I could find out how likely they are to help me first?'

'Yes.'

'Sick. So, how *would* a scientist know if a Proteus causes brain tumours?'

1.3 RESEARCH METHODS

Alice seemed conflicted. Her furrowed brow suggested that she desperately wished that I'd decided to ask her about science at a different time and place, but she also had softness in her face that hadn't been there earlier in the evening. Perhaps I *had* seen something in her that wanted me to help, or perhaps she knew this was a chance to shrink the space that had been growing between us. All that mattered was that she was talking to me rather than shutting me out.

'There are different ways to collect data,' she said, 'and different types of data that we can collect. Broadly speaking, we can test a hypothesis in one of two ways: by observing what naturally happens, or by manipulating some aspect of the environment and observing the effect it has on the variable that interests us.'

'So, just observing what happens to T-shirt sales when bands decided to give away wristbands, or actually making some bands give away wristbands, and preventing others from doing it.'

1.3.1 Correlational research methods

Alice nodded. 'When you observe what naturally happens in the world without directly interfering with it, it is known as **correlational research**. There are different ways to do this: we could take a snapshot of many variables at a single point in time (a **cross-sectional study**), or measure variables repeatedly at different time points (a **longitudinal study**). To look at the Proteus and cancer, we could measure how often a cross-section of people use the Proteus and how many of them have brain tumours, or we could take a sample of people, follow them over a long period of time and measure their Proteus use and whether they develop tumours over that period. Correlational research gives us a very natural view of the question we're researching because we're not influencing what happens and the measures of the variables should not be biased by the researcher being there. This makes it more likely that the study will have **ecological validity**, which means that the results of the study can be applied to real-life situations. There is a price to pay, which is that correlational research tells us nothing about whether one variable causes another. For example, even if we find an association between Proteus use and brain tumours, we cannot conclude that Proteus use causes brain tumours. This is particularly true of cross-sectional research because the variables are measured at the same point in time, so it would be equally valid to conclude that brain tumours cause Proteus use.'

'Get real! How can a brain tumour cause more Proteus use?'

'Well, perhaps having a tumour means that you call people more because you need social support, but you're right that sometimes explaining associations between variables does make more sense one way around than the other. For example, imagine that you discovered that popular people tend to be more attractive.[7] Although it makes more sense to assume that there's something about being attractive that makes you popular than it does to conclude that popularity changes your physical appearance, statistically both interpretations are equally valid. With longitudinal research you can make a slightly stronger statement about cause and effect if one variable predicts the other in the future, but not versa; for example, if attractiveness predicted your popularity in two years' time, but your popularity did not predict your attractiveness in two years' time. Even here though, you cannot be sure of cause and effect.'

'Why not?'

Alice sighed – a long, drawn-out sigh that was punctuated by her Proteus ringing. She jumped at the noise and was transported back into a state of tension. She felt inside my pocket and emerged with my reality checker. Her perfectly manicured finger pressed gently on the winder to release the front cover and again the crystals glowed, the cogs whirred and the mist appeared.

'Doc Nightingale,' The Head said with a chuckle, 'this is the most pleasant surprise. We should spend more time together … two geniuses, just hanging out, talking about genetics.' He turned to me and feigned surprise. 'Oh, you're still on the scene?' he asked cheekily.

'I need to take this call, so I need you to give Zach the lowdown on cause and effect please.' She kissed the top of The Head and he span. Alice's Proteus fizzed into a vaporous cloud and emerged looking like a strange alien brain. She twisted it into her ear and headed into the next room.

'Anything for you,' The Head shouted after her. I didn't like it when he flirted with Alice.

'Cause and effect, eh? That's gonna *cause* me to delve into my database and hope to have an

REALITY CHECK 1.2 *effect* on your brain.' The Head chuckled a deep, throaty laugh.

Having finished his chuckle, The Head explained: 'Most scientific questions imply a causal link between variables. The causal link can be obvious, such as "being physically attractive makes you more popular", but it can be, you know, subtle, like "physically attractive people are more popular", which implies that being attractive causes you to be more popular. It doesn't matter, though: regardless of whether the question mentions cause, most scientific questions break down into a proposed cause (in this case attractiveness) and a proposed outcome (popularity).

'The cause and the outcome are both variables: they vary. For the cause, some people will be more physically attractive than others. You know, like Alice has a pretty face and you have a … less pretty one. For the outcome, some people will have more friends than others. You answer the research question by uncovering the relationship between the proposed cause and the proposed outcome: are the more attractive people the more popular ones?

'Let's get philosophical. Hume[8,9] said that to know about cause and effect: (1) cause and effect must happen at a similar time (which is called contiguity); (2) the cause should happen before the effect; and (3) the effect should never happen without the cause. Let me put it like this: causality can be inferred through *corroborating evidence*. To know that physical attractiveness caused you to be more popular, you would have to show that whenever someone was physically attractive they were also popular, that the physical attractiveness emerged before the popularity, and that someone should never be popular if they are not physically attractive.

'Sounds rad. But it isn't rad enough, because what happens if we find people who are attractive but also unpopular? This finding doesn't violate Hume's rules because he doesn't say anything about the cause happening *without* the effect. We need something else, and Mill[10] gave it to us: all other explanations of the cause–effect relationship must be ruled out. To do this, an effect should be present when the cause is present and absent when the cause is absent. The only way to show causality is to compare two controlled situations: one in which the cause is present and one in which the cause is absent.'

Reality Check 1.2 *Cause and effect*

I was distracted by Alice's conversation in the next room. I couldn't make out what Alice was saying over the voice of the jabbering Head, but she was becoming more animated and stressed. As The Head was finishing his jibber-jabber, Alice cut the call, and returned looking worried and distracted. I asked if she was level.

'I'm not sure … well, it'll all be fine.'

She wasn't making any sense and I wasn't used to seeing her so indecisive – it made my guts churn.

‘Tell me what’s up.’

‘It’s work stuff. … I’ve got a big decision to make – it’s hard to explain. Don’t worry.’

I held her hands in mine. ‘I’d do anything for you, Alice. Look, it’s a Friday night and I’m talking to you about science. I’m *trying* really hard to understand. Give me a chance.’

Alice was looking right through me as though I was missing the point, but she squeezed my hands. ‘Maybe you’re right, maybe it might help you one day to understand this stuff.’

What an odd thing to say: I couldn’t imagine any situation between now and my death when I would need to know about statistics, but this was the first time in weeks that Alice was letting me into whatever was going on with her, and I wasn’t going to blow the opportunity. She still looked distracted, so I reminded her what we’d been talking about.

‘Of course … yes … the problem with correlational research … cross-sectional research tells us nothing about the contiguity between different variables: we might find from a questionnaire study that attractive people are also popular, but we wouldn’t know whether the popularity or attractiveness came first. Longitudinal research addresses this issue to some extent, but there is still the problem that other variables that you haven’t measured, called **confounding variables**, might be influencing both variables. For example, perhaps personality affects both how physically attractive a person is perceived to be and also their popularity. People with a nice personality have more friends (because they are nice) but they are also perceived to be more attractive. In this example, a person’s personality would be known as a third variable, or **tertium quid**, which is a variable that explains the apparent relationship between two other variables.’

‘That’s what The Head was talking about: when you do correlational research you can’t know that one variable has caused the other because you haven’t compared a situation where the cause is present and the cause is absent.’ Alice broke into a smile that came across as hiding sadness, and I continued with my epiphany. ‘When we were talking about whether a free wristband would help to sell T-shirts, you used an example of comparing a sample that had been allowed to offer a free wristband with one that had not. Wouldn’t this be comparing when the cause is there (the free

FIGURE 1.3

gift) and when it is not (no free gift)?’.

1.3.2 Experimental research methods

Alice’s smile transformed into a more genuine one. ‘Zach, that is perfect – *you* are perfect.’ Alice fixed her watery gaze onto my eyes. I wasn’t sure whether it was the call that had made her so emotional, or that I had set the baseline of my ability so low that any vaguely intelligent thing that I said was cause for her to break down. ‘See, you can understand this stuff when you try. I don’t know why you always underestimate yourself.’

‘Come on, we all know who the brains in this relationship is, and it’s not the guy with spiky hair.’

‘True enough,’ said The Head.

Alice ignored him. ‘Look, just because I’ve made some of the most important genetic discoveries of the past 100 years doesn’t mean I don’t struggle with things. Remember what happened when you tried to teach me the guitar?’

That reminded me, I needed to pick my guitar up from the repair shop.

‘I would never have dated you if I didn’t think you were a clever guy.’ Her use of the past tense unnerved me. ‘The trouble is that you play the fool because you’re scared that you will fail; but you’re spot on with this. Comparing two conditions in a controlled way is at the heart of **experimental methods**: they provide a comparison of situations (usually called *treatments* or *conditions*) in which the proposed cause is present or absent, while controlling for all other variables that might influence the effect in which we're interested. This scenario is an **experiment**. The T-shirt sales example is a good one. Imagine we randomly select some bands, and half of them we asked to give away free gifts with every T-shirt, and the other half gave away nothing. The thing that we have manipulated is the incentive to buy a shirt (the free gift or no gift). This is known as an **independent variable** because it is not affected by the other variables in the experiment. More generally, it is known as a **predictor variable**, because it can be used to predict **scores** of another variable (i.e., we predict T-shirt sales based on whether or not a gift was offered). In this situation it is said to have two *levels*, because it has been manipulated in two ways (i.e., free gift or no free gift). The outcome in which we are interested is T-shirt sales. This variable is called the **dependent variable** because we assume that its value will depend upon whether or not a free gift was offered (the independent variable). More generally, we can refer to it as an **outcome variable**, because it is the variable that we're trying to predict the values of (i.e., we want to know how many T-shirt sales there are). The critical thing is the inclusion of the no-gift group because this is a group in which our proposed cause (an incentive to buy) is absent, and we can compare the outcome in this group against the situation in which the proposed cause is present (a free gift was offered). If the T-shirt sales are different when the free gift is offered (cause is present) compared to when it is not (cause is absent) then this difference can be attributed to the free gift. In other words, the free gift caused a difference in T-shirt sales.'

1.3.2.1 Two methods of data collection

'OK, that makes sense. So, you can infer cause only in experiments where you manipulate the thing that you think is the cause, and not in experiments where you just measure variables cross-sectionally.'

'Sort of, but be careful with your terminology. You can only call something an *experiment* if you have manipulated one variable and looked at the effect it has on another. If you measure variables without manipulating any of them then it is not an experiment, it is a correlational study. Lots of people make that mistake, but it's worth getting it right.'

'What would happen if the same sample of bands wanted to look at their T-shirt sales from one gig to the next when sometimes they use free gifts and sometimes not? Could that tell you anything about cause?'

'Actually it can: we can manipulate variables in experiments in two ways. The first is to manipulate the independent variable using different entities. This is the method we've been discussing – we allocate different bands, or entities, to two different groups – and it's known as a **between-groups**, **between-subjects**, or **independent design**.'

'Seriously? Three terms for the same thing? No wonder this stuff is confusing. Whose stupid idea was it to give the same idea three different names?'

'According to one ancient statistics text,[11] it was a character called Confusius who invented a confusion machine, but that story has never been verified. In any case, the second method is to manipulate the independent variable using the *same* entities. This would be similar to what you were suggesting: we tell a group of bands to give out a free gift with every T-shirt sold at one of their concerts and ask them not to use the free gift at the next concert (or vice versa). This is known as a **within-subject**, **related** or **repeated-measures design**.'

'Does everything in science have three different names?' I quipped.

1.3.2.2 Two types of variation

The conversation was going better than I had expected. I found myself becoming really interested in how I could sell more T-shirts. Our T-shirt designs were totally sick, some would say better than our music. I liked seeing people in them because it made me feel like I was doing some good in the world. After the Reality Revolution real music died out, and instead everyone looked to the great bands of the pre-revolution. Bands like mine were trying to recreate that old-school vibe, where music brought people together. There wasn't a soundtrack to the post-revolution, but my generation were trying to create one. When I listen to those old bands it's how I imagine it was for our parents when they wore a reality prism: it brings home how ordinary you are. Maybe you don't need a reality prism to be a victim of reality.

My mind was wandering, and Alice had noticed and stopped talking. She shot me the look that she gives me when I'm ignoring her and tersely suggested that it might be time to stop. I didn't want to stop, because I'd seen glimpses of the old Alice this evening. There had been cracks in her emotional armour that gave me hope that the past few weeks were an aberration. The key was to stay interested and keep her talking. I apologized and tried to reopen the conversation.

'I get that manipulating whether or not bands give away free gifts tells us about cause and effect, but if we do that experiment, and the T-shirt sales are more for the group that gave away gifts than for the group that didn't, then how do we know that is because of the free gift? I mean, earlier on you said that if you took different samples and measured their T-shirt sales they would be slightly different … erm, look, it's in my notes … sampling variation … so how do we know that the difference in the groups' T-shirt sales isn't just because of that?'

ZACH'S FACTS 1.2

'That's a brilliant question,' she said, and she was hooked in again. 'The answer is that you compare different types of variation in scores or T-shirt sales. Let's take a step back and think what would happen if we did *not* introduce an experimental manipulation. Imagine we have a sample of bands and we measure their T-shirt sales at two gigs (i.e., they never give away free gifts). If there is no experimental manipulation then we expect T-shirt sales to be similar in both conditions. In other words, their sales at the first gig should be similar to those at the second. We expect this because external factors such as the T-shirt designs, the price, the music played by the bands, and characteristics of the people at the gigs and what T-shirt designs appeal to them will be the same for both conditions (The Reality Enigma won't play heavy metal one week and break into some improvised jazz the next). A band's T-shirt sales at one concert should be very highly related to their sales at the other. Bands who sell a lot of T-shirts at one concert are likely to sell a lot at the next, and those that have low sales at the first concert are likely to have low sales at the next. However, sales won't be *identical*; there will be small differences in sales created by unmeasured or unknown factors. This variation is known as **unsystematic variation**. If we introduce an experimental manipulation (i.e., provide a free gift at one of the concerts), then we do something different to participants in one condition compared to what we do to them in the other. The *only* difference between the conditions (or concerts) is the manipulation that the experimenter has made (in this case that fans at one concert get a free gift if they buy a T-shirt). Therefore, any difference between the average of the two conditions is probably due to the experimental manipulation. If T-shirt sales are higher at one concert compared to the other then this *has* to be due to the fact that a free gift was offered with every T-shirt at one concert but not the other. Differences in performance created by a specific experimental manipulation are known as **systematic variation**.'

'But what if you had used different bands in the two samples?'

'In an independent design there are still two conditions, but different bands participate in each condition. Imagine again that we didn't have an experimental manipulation. If we did nothing to the groups, then we would still find some variation in sales between the groups because they contain different bands that will vary the shirt designs that they have on offer, their prices and other things that might affect sales. The factors that were held constant in the repeated-measures design are free to vary in the independent design. So, the unsystematic variation will be bigger than for a repeated-measures design. As before, if we introduce a manipulation (i.e., a free gift) then we would hope to see additional variation created by this manipulation. As such, in both the repeated-measures design and the independent design there is always systematic and unsystematic variance, it's just that, other things being equal, the unsystematic variance will be greater in independent designs. We can use statistical models to compare the size of the systematic variance to the unsystematic variance. In effect, we're looking at the effect of our experimental manipulation against a background of "noise" caused by random, uncontrollable differences between our conditions. In a repeated-measures design this "noise" is kept to a minimum and so the effect of the experiment is more likely to show up. This means that, other things being equal, repeated-measures designs have more power to detect effects than independent designs.'

1.3.3 Practice, order and randomization

'You said that if we didn't include an experimental manipulation then we'd expect the two samples to have similar T-shirt sales, but if we were using a, what was it called, you know, the same bands but tested twice …'

'A repeated-measured design,' Alice replied.

'Yeah, if you were using a repeated-measures design, you might expect fewer T-shirts to be sold at the second gig because if people had bought a shirt at the first gig and then also come to the next one, they won't buy another shirt.'

'That's true, and in reality you would counterbalance the order in which the samples complete each condition. For our example that means that half of the bands would give away a free gift at the first concert and not at the second, but the others would give away the free gift at the second concert but not the first. **Counterbalancing** is a technique used to eliminate sources of systematic variation. One source of systematic variance is **practice effects**. Let's imagine that you wanted to see whether you could help people to overcome their fear of statistics by getting them to pretend to be someone else.[12] You give participants two comparable statistics tests. One of them they complete as themselves, but the other they complete while pretending to be someone who is really good at statistics. When the same entities participate in more than one experimental condition they are naive during the first experimental condition, but they come to the second experimental condition with prior experience of what is expected of them. For example, when they take the second statistics test they have had some practice at the types of questions that might be asked, they're familiar with the format of the test and so on. A second source of systematic variation is **boredom effects**, that is, when participants take part in several experimental conditions they are likely to become fatigued. Imagine we asked people to take statistics tests while pretending to be themselves, a student good at statistics, a statistics professor, someone who had never done statistics, and as a watermelon (as a control). They would have to complete five statistics tests. By the fifth test they'd be quite bored …'

'Or by the first …'

Alice gave me a disapproving look. 'The point is, the more tests they do, the more their attention is likely to wander as they get bored with the task. If every participant does the tests in the same order then we introduce a systematic bias because by the time they do the test as a watermelon, they are more bored and more practised than when they did it as themselves. So, we can combat these effects by counterbalancing the order in which people complete the tasks, or by having them complete the tasks in a random order. Sometimes people use a **Latin square** counterbalancing method. This is easy to visualize with a drawing.' Alice started to sketch.

FIGURE 1.4

'Imagine we just had three conditions to our experiment: we asked 30 people to complete the statistics test as a statistics professor (A), as themselves (B), and as an arts professor (C). In a Latin square design with three conditions we'd split the 30 people into three equal groups. The first group would complete the tasks in order A, B, C (i.e., as the statistics professor, as themselves, then as the arts professor). However, the second group would complete it in order C, A, B (i.e., as the arts professor, as the statistics professor, then as themselves). The final group would complete the tasks in order B, C, A (i.e., as themselves, then as the arts professor, and finally as the statistics professor). The important thing is that across the participants each task or condition appears equally as the first task, the second task and the last task. So, a third of the participants do the task as themselves first, a third of them take that task second, and for the final third it is the last task. Therefore, the order of tasks is balanced. You can do the same type of arrangement with more tasks. With 4 tasks you'd need 4 groups who complete the tasks in 4 different orders, and with 5 tasks you'd need 5 groups who complete the tasks in one of 5 different orders. In all cases, though, across all of the groups a particular task is done at every different position in the order of tasks.'

'That's mind-blowing. I totally get it.' I was partly lying: I didn't get it, but staring at grids of As, Bs and Cs was making me want to blow up my mind.

Alice eyed me suspiciously. 'You understood all of that perfectly? You're not just saying that because you're bored with staring at As and Bs?'

It was frightening how well she knew me. 'Not at all. Crystal clear.'

'I'd understand if it's not – it's quite confusing, and that's why sometimes people randomize the order of tasks instead – it does much the same thing. So, we'd choose the first task randomly out of the three, then choose the second task randomly from the remaining two, and that would also leave a task as the final one.'

'And you do this to minimize the – what did you call it – unsystematic variance?'

'Yes.'

'What happens if you have one of those designs in which *different* people do different tasks?'

'In an independent design you follow a similar logic, it's just that you don't need to worry about practice or order effects. Instead you worry about differences in the natural composition of the groups. If we asked different groups of people to take statistics tests with each group pretending to be someone different, then differences between their scores will be caused by us manipulating who they are pretending to be (a professor or themselves) but also by natural variation between the groups. It might be convenient to take students from two different lecturers' stats classes, and one of these groups completes the test as themselves, and the other as their lecturer. If we find a difference between the groups can we conclude that who the student was pretending to be affected the test?'

'Yeah, because you're comparing groups where the cause is present (pretending to be a statistics lecturer) and where it is absent (taking the test as yourself).'

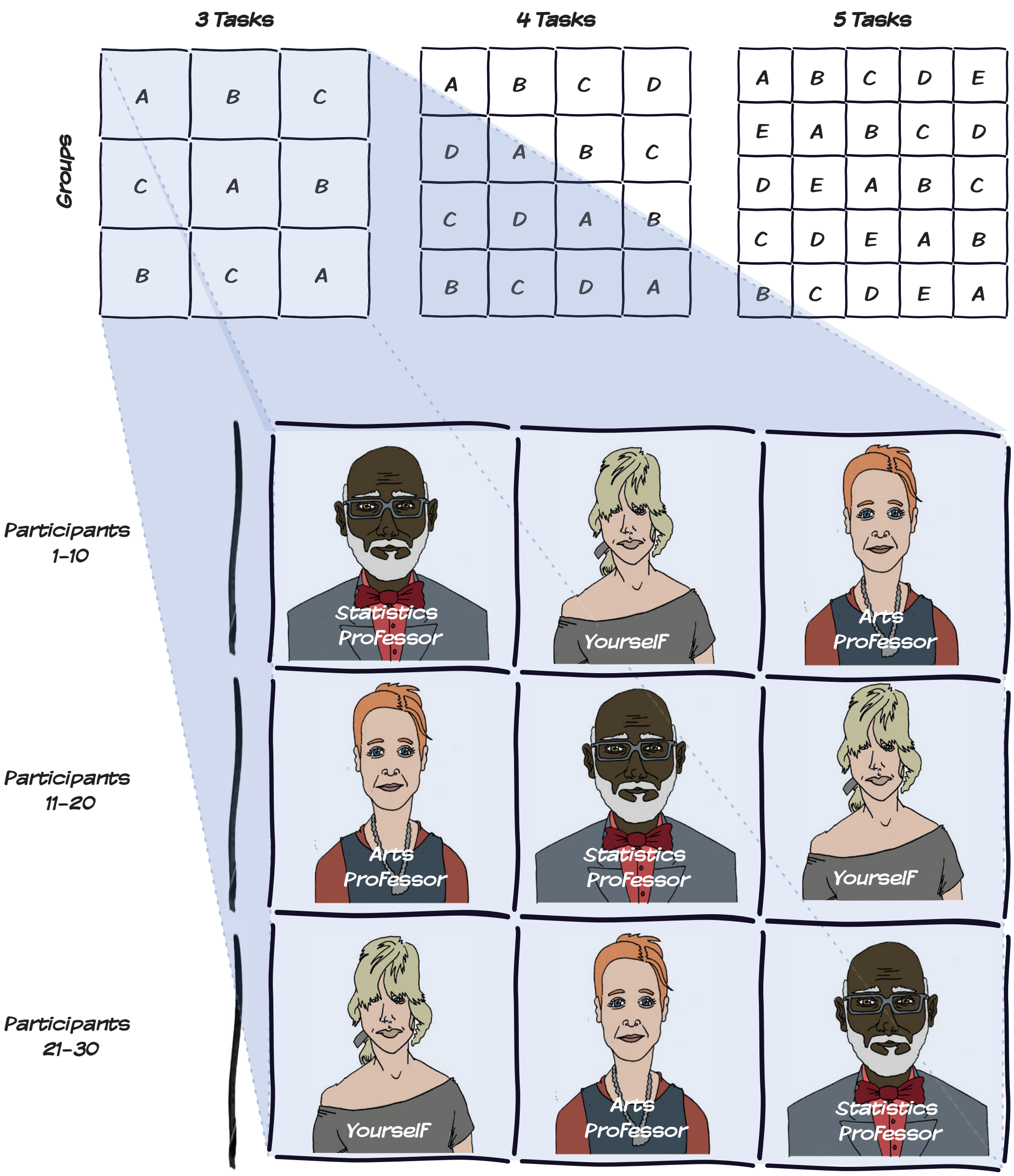


Figure 1.4 *Latin square counterbalancing orders*

'No, because the groups have different lecturers, so not only does our manipulation vary across the groups, but so does each group's background knowledge in statistics. Perhaps one lecturer is much better than the other and produces students better able to do the test?'

'Maybe, but we don't know that for sure.'

'That's exactly my point. We don't know whether the group differences are due to the systematic variation created by our manipulation, or the systematic variation created by the lecturers in their teaching. This is why **randomization** is absolutely crucial in experimental research. If we randomize participants to different conditions, then, providing the randomization works, we should start the study with two groups who are comparable in age, sex and, most important in this example, statistical ability. If we do this randomization then we can be confident that any differences between groups can only have been created by the manipulation that we carried out. Without randomization we can't be sure from where the group differences come. Sometimes though you can't randomize; for example, imagine we wanted to look at the effect of horror movies on children. It wouldn't be ethical to randomize some children into a group that watches a horror movie and others into a group that does not, because some of the children might be very disturbed by the movie. Instead, we would have to compare children who naturally decide to watch horror movies to those who do not. When you don't randomize participants into different groups it is known as a **quasi-experimental design**.'

CHECK YOUR BRAIN: *Why is randomization important?*

In Loving Memory ... Of Your Memory

- Collect data using *correlational methods*, in which you observe what naturally goes on in the world without directly interfering with it, or *experimental methods*, in which you systematically manipulate certain variables (*independent variables*) to look at their effect on the so-called *dependent variables*.
- Experimental methods usually enable you to draw conclusions about cause and effect, correlational methods mostly do not.
- In correlational research the relationships between variables can sometimes be explained by a third variable (a *tertium quid*).
- In experimental research you manipulate the independent variable by having different treatment conditions that represent different levels of it. You can either assign different entities to each condition (an *independent design*) or have the same entities take part in all conditions (a *repeated-measures design*).
- In repeated-measures designs, make sure that conditions are completed in different orders by different entities, by using *counterbalancing* or *randomization*. In independent designs, randomize entities to the different conditions so that conditions are comparable on all variables except the one you want to measure.
- The effect of the independent variable is evaluated by comparing how much variation it creates in the outcome variable (*systematic variation*) against the variance created by unknown or unmeasured variables (*unsystematic variation*).

Zach's Facts 1.3 Research methods

1.3.4 Piecing it all together

'That's more or less all there is to know about how science works,' Alice said. 'Now you know it, how *would* you use science to discover whether Proteus use causes brain tumours?'

CHECK YOUR BRAIN: *What are the different ways you could test Alice's hypothesis? What are the pros and cons?*

I felt a wave of nausea. I thought I'd been paying attention, I really did, but now that Alice had put me on the spot I could feel my mind emptying. I stuttered, I ummed and ahed, and I caught the growing disappointment in Alice's eyes. She swayed her head from side to side, moving almost imperceptibly as though questioning why she'd believed I was capable of understanding what she'd said. I'd found hope of reaching the old Alice, but that hope drained as I fumbled around in my mind. I needed to get a grip, to find a hook to get me started. I remembered the T-shirts – I'd been interested in the T-shirts. Then the answer hit me.

'You'd want to compare the people who had used a Proteus to those who hadn't and see how many people in each group had tumours … erm, oh, yes, but you'd have to randomize people to the groups.'

Alice looked pleased, but she wasn't going to let me off easily. 'What's the problem with doing that?' she asked.

'I guess it's pretty mean to force people to use a Proteus if it might give them a brain tumour.'

'Yes!' she exclaimed. 'It's unethical, but you're right that it would theoretically be the right thing to do. How else could you do it?'

I racked my brain. 'You could let people decide for themselves whether or not they use a Proteus.'

'Would it be easy to find people who have never ever used a Proteus?'

'I guess not … but you could look at *how much* they use their Proteus.'

'Could you still draw conclusions about cause and effect?'

I thought Alice was being a bit negative. I was trying my best, but every suggestion she came back with a problem. I guess that's why she is a genius. I thought about the problem some more. The answer could either be yes or no, so I picked one hoping it would be the right choice.

'No,' I said.

'Why?' she enquired.

'Batticks!' I thought. I concentrated more. 'We're not comparing a situation where the cause, the Proteus use, is absent to one where it is present.' I felt deflated; she had defeated me because I couldn't think of another way to do it. I was surprised when she smiled warmly at me.

'Zach, you're brilliant. Everything you've said is right, but I want you to see that research is complicated: there are always trade-offs and compromises. You're right, we can't do a controlled experiment on Proteus use and brain tumours because it's unethical. We can measure Proteus use and tumours longitudinally and see whether Proteus use predicts tumours over time, but we sacrifice the conclusions we can make about cause and effect. However, we gain ecological validity.

So, what some scientists who have researched this have done is to look at cohorts of people, that is, people born at the same time, and followed them over time, making notes of their Proteus use, and using hospital records to see whether they end up with tumours that might be related to Proteus use.'

Alice opened up the reality checker and unleashed The Head.

'Twice in one day, Doc? I am honoured, let me take you on the information highway to knowledge paradise,' he said flirtatiously.

'Sorry, I already booked my ticket for that particular trip, and I'm not allowed to take pets,' she said, cruelly. 'Get me the summary statistics of all the studies that were done on phone use and brain tumours before the revolution. I want point estimates and intervals around the effect sizes.'

'Now you're talking my language', said The Head with a chuckle.

She certainly wasn't talking *my* language, all I had heard was 'Get me the blah, blah, blah'. Alice and The Head had a weird dynamic where he would flirt with her, she would put him in his place, and yet he carried on flirting. My relationship with him was different: he liked to insult me. I think he just enjoyed any banter he could provoke from people. With Alice he knew that the best way to push her buttons was with sexism, whereas with me it was pretending to think I was an idiot. I wasn't sure Alice liked The Head at all, but despite his goading I did: he liked to talk nonsense, and I liked to fill up hours trying to think up questions that he couldn't answer. I never succeeded. The Head was spewing numbers and names at Alice; she made notes and then started sketching.

FIGURE 1.5

'Zach, here are 23 studies from the pre-revolution that looked at whether mobile phone use is related to brain tumours.[13] There are no studies that have looked at the Proteus, so this is all we have to go on. I've listed the studies down the side of the picture. For each study, the scientists computed a statistic in the sample that represents the size of the effect that phone use had on brain tumours. This statistic is represented by the dots. Remember that we're interested in the effect of phone use on tumours in the whole population, not just in that particular sample. We could use this statistic as the estimate of the effect in the population. If we do this we are using a **point estimate** because we're using a single value, or point, to estimate the effect in the population. However, we know that there will be sampling error.'

'You mean that the value in the sample won't always be the same as the value in the population?'

'Yes, exactly, so we can instead compute an **interval estimate**, which is a range of values between which we think the population value is likely to fall, based on the amount of sampling error we expect for that sample. Notice for each study that there is a point estimate of the effect of phone use on brain tumours, but I have also drawn a horizontal line sticking out of each side of the point. These are limits: for each study we are estimating the limits between which the population value falls.'

'Every study has different limits, so is every study giving us a different answer?'

'Yes, because of sampling variation. The important thing is that when you have lots of studies that have looked at the same question you can look for consistency in the pattern of results. For example, I have drawn a red dotted line at the value that represents "no effect". If the population value is the same as the red line then phone use had no effect whatsoever on brain tumours. Anything to the left of the dotted line means that phone use *decreased* brain tumours, and anything to the right means that phone use *increased* brain tumours. What do you notice about the dots?'

CHECK YOUR BRAIN: *Based on the dots (point estimates), how many studies in Figure 1.5 suggest that phone use increases the risk of cancer, and how many suggest it decreases the risk?*

I quickly counted the dots on each side of the line. 'About 11 dots are above the dotted line, which means phone use increases cancer, and 12 are below the line suggesting it decreases the risk. That's like half of the studies say one thing and half say the other, and actually a lot of the dots are close to the dotted line that shows no effect.'

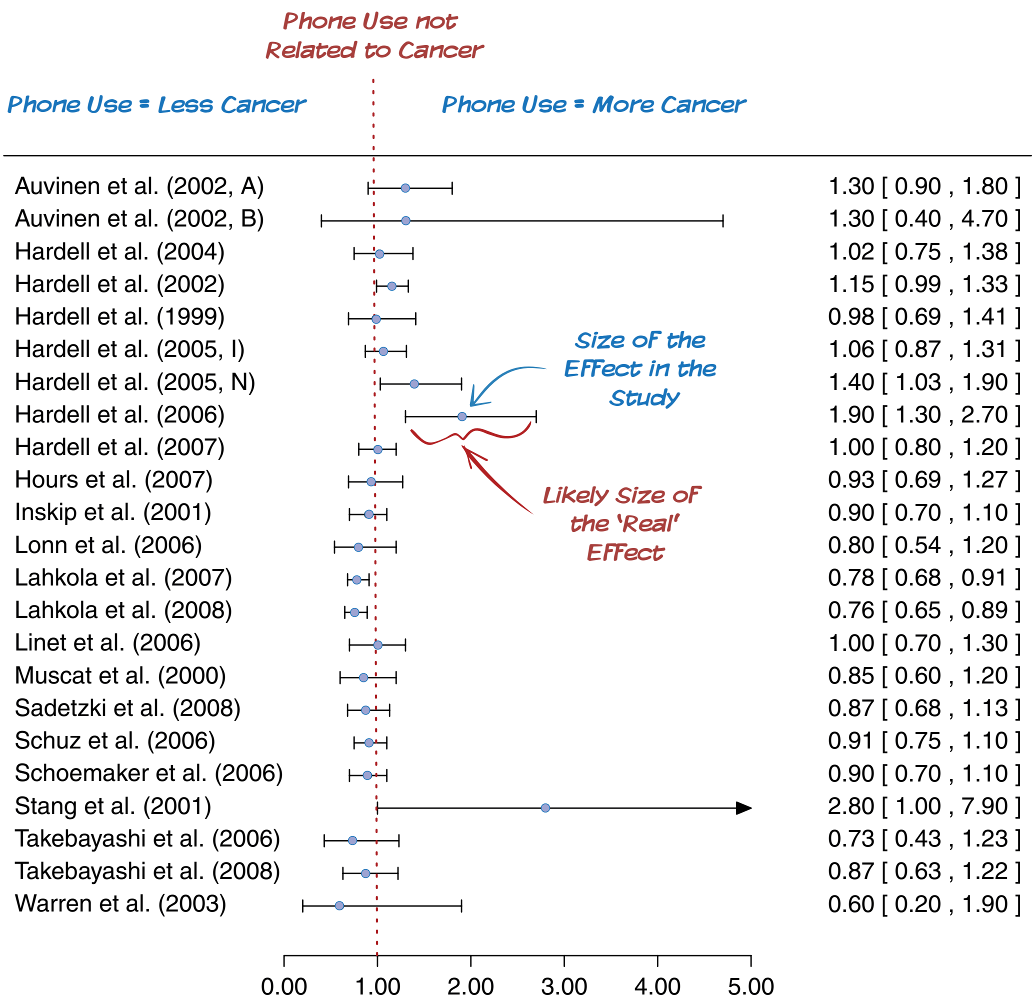


Figure 1.5 *Does your mobile phone cause cancer?*

'Let's look at the interval estimates,' Alice said. 'The horizontal bars estimate a range of values that the population value could be, based on the data in each study. If this bar crosses the dotted line, then what do you think that means?'

'That the population value could be "no effect"?'

'Exactly. It also means that the population value could be either an increased risk of cancer, or a decreased risk of cancer. In other words, if the bar contains the dotted line it means that there isn't a lot of evidence one way or another that phone use does anything to cancer risk. What about if the bar is completely on the right of the dotted line?'

'Would that mean the population value is definitely showing an effect of phone use increasing cancer?'

'We can't say "definitely", because these are estimates and there is a chance they are wrong, but we can say "likely". What about if the horizontal bars are completely on the left of the dotted line?'

'The population is *likely* showing an effect of phone use decreasing cancer.'

'Yes. Based on the interval estimates, how many studies show a likely effect of phone use on cancer and how many show that it likely has no effect?'

CHECK YOUR BRAIN: Based on the horizontal bars (interval estimates), how many studies in Figure 1.5 suggest that phone use increases the risk of cancer (bars are fully to the right of the dotted line), how many suggest it decreases the risk (bars are fully to the left of the dotted line), and how many suggest there is no effect (the bars cross the dotted line)?

'There are about 4 studies where the bars are fully to the right, suggesting that phone use increases cancer, 2 studies where the bars are fully to the left, suggesting that phone use decreases cancer, but most of them – 17, to be exact – contain the dotted line and so suggest that no effect of phone use on cancer is plausible. That's unreal: if you look at a particular study you might believe one thing, but then a different study might tell you the opposite, but if you look at them together then you can see a pattern.'

'Yes, and pulling together the results of lots of studies on the same question is known as a **meta-analysis**. It helps us to get more conclusive answers to questions from a range of studies on the same topic.'

'Basically, I should ignore the headlines and stop worrying about you getting a brain tumour from using your Proteus,' I said.

Alice pressed her palm to my cheek and smiled a sad smile.

1.4 WHY WE NEED SCIENCE

As our conversation ended I was struck by why Alice was so 'scientific'. It gave her power. She was always interested in the news and she always questioned what she read and saw. The news and politics made me feel helpless and depressed, but it made Alice want to change things. We are constantly bombarded with 'facts and figures' from politicians, journalists, and advertisements. Alice would say that throughout history the media would try to sell us remedies for which there's no evidence, or advise us not to protect our children from diseases based on flawed science.[14] When she heard these claims she would dispute them and find out more, whereas I accepted it all. The media could tell me I'm an intergalactic space frog and I'd probably believe it, but not Alice. It made sense, Alice understood the rules of science, she knew the system for evaluating evidence, and sometimes the jerks in power didn't play by the rules: they twist the evidence to suit their own needs, or line their own pockets. Science gave Alice the power to see through it all; in a way, she held her own reality prism to the truth.

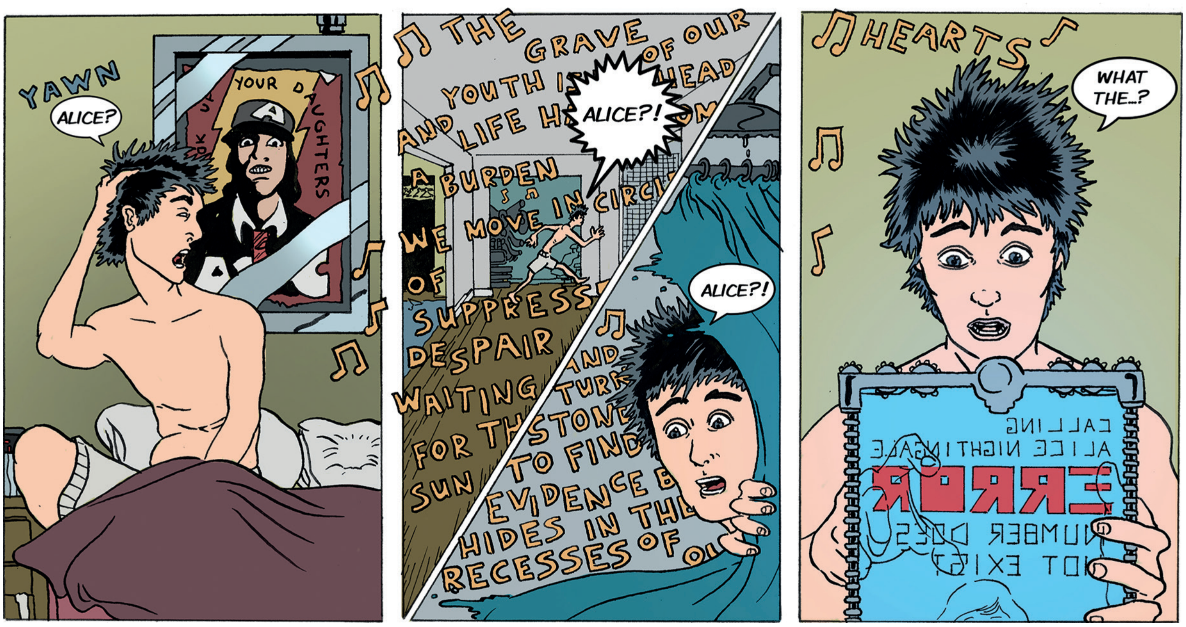
I was reminded of when we first dated, so I told Alice how when we first got together I really admired her passion for the truth, her humanity, and the way that she always wanted to do the right thing. I told her how I now understand that science is a part of that; it's a system to help us to know what 'the right thing' is. It made total sense to me now.

Alice sucked the air out of the room before releasing it in an almighty sigh. Her breath wavered and she trembled as she exhaled. 'Thank you', she finally said, '... for listening, and for understanding. It makes everything easier.'

What did she mean by everything? Before I could ask she smiled beneath her distracted eyes, announced that she was going to bed, and headed towards the bathroom. That was my cue that the conversation was over.

'You said you had a big decision to make. ... Can I help?' I shouted after her.

'You already have,' came her reply.



KEY TERMS

Between-groups design
Between-subjects design
Boredom effect
Confounding variables
Correlational research
Counterbalancing
Cross-sectional study
Dependent variable
Descriptive statistics
Ecological validity
Experiment (research)
Experimental methods
Hypothesis (hypotheses)
Independent design
Independent variable
Inferential statistics
Interval estimate
Latin square design
Longitudinal study
Meta-analysis
Outcome variable
Parameter
Point estimate
Population
Practice effect
Predictor variable
Quasi-experimental design
Randomization
Related design
Repeated-measures design
Sample
Sampling error
Sampling variation
Scores
Statistics
Systematic variation
Tertium quid
Theory
Unsystematic variation
Variable
Within-subject design

JIG:SAW'S PUZZLES

1. Zach wanted to impress Alice, so he asked The Head to find him some famous scientific theories. For each one, can you help him to try to generate a hypothesis that might arise from the theory.
   a. Galton[15] suggested that intelligence is hereditary (runs in families).
   b. Bandura[16] suggested that people learn their behaviours from watching others (observational learning).
   c. Paivio[17] suggested that things are easier to remember if you visualize them (dual-coding theory).
   d. Piaget[18] suggested that children develop logical thinking skills as they grow older.
2. What is the difference between descriptive and inferential statistics?
3. What is the difference between a statistic and a parameter?
4. What is the difference between sampling variation and sampling error?
5. What is the difference between a point and an interval estimate?
6. What is the difference between correlational and experimental research?
7. What is the difference between systematic and unsystematic variation?
8. Zach takes a group of fans of his band and gets them to rate each of five successive gigs according to how good they thought the band were.
   a. What kind of design has Zach used?
   b. What is the independent variable?
   c. What is the dependent variable?
9. Zach wants to know which musical instrument makes you the most popular. He looks at the *memoryBank* pages of a random selection of guitarists, drummers, bassists and singers and counts how many 'Hails' they have.
   a. What kind of design is this?
   b. What is the outcome variable?
   c. What is the predictor variable?

10 Alice wanted to see what methods were best for getting boyfriends to take an interest in your life. She got her girlfriends to try different techniques on their boyfriends: giving the boyfriends affection whenever they showed an interest in their lives, giving their boyfriends chocolate when they showed an interest, or nagging them when they did not pay attention. Every woman tried each method for one week and counted how often her boyfriend listened to her.

11 How would you implement a Latin square counterbalancing for this study?

a. What is the outcome variable?
b. What is the independent variable?
c. What is the predictor variable?
d. What is the dependent variable?

IN THE NEXT CHAPTER, ZACH DISCOVERS ...

That his girlfriend doesn't exist
How to report research
Statistical notation
The mysteries of BODMAS
Levels of measurement
Measurement error
Validity and reliability
Never to corner a man who has his sausage out