Becoming Scientific

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Developing Science across the Life-Course

By

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Saima dedicates this book to her loving parents as well as to the young sciencey people of her family: Sana, Samia, Haaniya and Arsalaan.

Mike dedicates this book to his truly amazing family:
Ruth, Sian, Rhian, Oscar, Rosie, Lily, Joel, Conor and Dylan.

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CHAPTER 1

SCIENCE AND EVERYDAY LIFE

We begin this book with two examples, Judy and Ibrahim. Judy is mid-thirties, a successful hairdresser and mother of two, she owns her own small business in southeast England. Her husband, Paul, is only slightly older, but already suffers from very painful arthritis—Judy is concerned about his condition and for his mobility, he has always been such an active man and still so young. She is happy to admit she knows little to nothing about arthritis, thought it only 'got to' old people, but feels strongly that she now needs to 'get up to speed fast'. As she talked, cup of coffee in hand at her kitchen table, she also admitted that she had left school biology, all of school science in fact, way behind her many years ago.

> "I was rubbish at science", she sighed, "never any good. I was never part of the sciencey lot, I was into sport in a big way. You might have thought that, with sport, I'd have learned a bit about the body wouldn't you? But I blanked any of that, focussed on the team, on skills and tactics, getting fit, being competitive. And when I left school I needed a job and went into hairdressing".

She stared into her coffee cup for a moment.

> "I'm not sure what good it would have done me anyway. I have picked up bits and pieces of science about diets and chemicals and such like in work; I listen to the news and watch TV programmes, you know, David Attenborough's *Blue Planet* and stuff like that. Oh, and I know quite a bit about difficult childbirth after having the two boys. But that's about it, really. Not much, is it?"

Another thoughtful pause.

> "Someone asked the other day what a 'tonic-and-volumiser' actually did to her hair. I gave her the usual blah-blah you get on the side of the bottle, but I really didn't know. I did come home that night though and looked it up. Alex [her son] helped me".

Ibrahim on the other hand is an engineering student at our West London University. We are alone in our communal departmental kitchen; he is contemplating leaving his undergraduate course to return home to Saudi Arabia. His father died suddenly a few months back and his mother and younger brother are trying valiantly to manage the family farming business in dates and olives. He is standing, arms folded, head down as he talks,

> "Neither of them can drive, you see, and so they are having to hire a driver, even just to get around. Just basic things".

He feels torn; he desperately wants to finish his engineering degree and he sees his qualification as a means of adding significantly to the family's income.

> "I have always wanted to be an engineer, not a farmer. My father knew this about me from a very early time in my life and he always encouraged me to study science. He paid for me to go to a technical school, helped me with my homework".

He grinned sadly,

> "I didn't actually need his help but he gave it to me anyway".

A long pause,

> "Science and engineering are in my blood. There is big money in oil engineering, especially in Saudi. I want to be a project manager for a company I know, I did work placement with them last summer, they will take me, I know. I just love being on site, the smell, the talk, the problems and the challenge. I want to wear a hard hat not garden gloves".

There are several signposts in these two examples to indicate the directions we take in this book. First, we are interested in how people 'come' to science and become engaged with matters scientific. There are often a number of events—large occurrences and small 'nudges'—that can act to catalyse a person's interest and immersion in science, and we explore a number of these in the chapters to come. We know this engagement with science can happen in early childhood, at school or, indeed, much later in life—although there are many people in the world for whom science passes them by entirely. So, if we were cooks or chefs then our starter-question in culinary terms might be: Do some people come 'sciencey-ready flavoured', or is it possible to 'science-marinate' them over time? How can we 'science' them? Our view is, of course, that both of these are possible. A key follow-up question might then be: what exactly is the balance of ingredients—the formula of that 'science marinade' to help people become 'sciencey'?

Throughout the book we ask a number of similar questions, for example, to what extent can people identify with the culture of science? Are there aspects of science with which they can become curious, grow accustomed to, develop an understanding of, and share in a meaningful way? Can some people really begin to 'love' science and, if so, what are the circumstances under which this can happen? In the examples above, Judy is clearly driven to know more about medical science to better understand Paul's arthritis and, given a powerful incentive to help him with this condition, she will no doubt 'come up to speed' very rapidly. Ibrahim, though, has been immersed in science from 'very early in his life' and, through circumstances outside of his control, may have to head the other way and leave it behind. We are interested, too, in the disparities between formal (school, college, university) science education, and that which happens in everyday life—the non-formal or informal learning of science through a variety of media, such as television, magazines, and the Internet. We are captivated, too, by what it means to be 'part of the sciencey lot' or not, as Judy put it; someone who revels in science or who 'blanks' science whenever he or she meets it.

That the conversations with Ibrahim and Judy both took place in kitchens is not wholly coincidental, a major part of our research has been to accumulate peoples' science stories, and we have collected these in ways that are open, informal and as relaxed as possible. Some of these 'kitchen conversations' have been recorded in people's homes, local libraries, cafes, restaurants, school classrooms, university offices and a number of other venues—wherever and whatever suited our respondents best. The great majority of our research has taken place in the southeast of the UK, a relatively affluent part of the country and this, necessarily, sets the cultural context for the work we have been doing. These two stories are quite particular and so now we need to set a broader, less specific, backdrop to the book.

Some of our dilemmas

We are caught on the horns of several dilemmas (or multi-lemmas) and faced with serious contradictions. First, people are consuming more and more popular or lay science and yet moving away from the formal study of science. The fashions in school science—from the drill/rote learning of the 1950s to the 'discovery learning' of the 1960s; and from 'Science for All' in the 1980s to 'Citizen Science' in the 1990s—have all had very mixed results. We are witnessing a movement away from the formal study of science (particularly chemistry and physics) as young people increasingly fall out of love with these subjects. As Michael Matthews (1994) comments on students in science ‘the more they do, the less they like it’, and:

> “When people en-masse abandon science, or science education abandons them, then the world is at a critical juncture. At such a time the role of the science teacher is especially vital, and in need of all the intellectual and material support possible” (5).

Almost two decades later, the situation is much the same. The backdrop to this book concerns some of the reasons why: How is it possible to enjoy some aspects of science yet dislike (even detest) the formal study of science? Why do some people ‘love’ science while others hate and abandon it? And, importantly, has, as Matthews suggests, science abandoned people?

While we have no single answer to each of the questions we ask, we do have a lot to say on these matters. In the chapters ahead we follow a number of paths and, for example, discuss several distinctive approaches to learning science. Our broad views on learning are that it is complex—very rarely is it a simple matter. Teaching is most certainly *not* the same as learning and there are innumerable factors that intervene between what teachers do and exactly what learners make of this teaching. Importantly, for most of the book we are concerned with lifelong learning and not just with formal learning in schools, colleges and universities. We do feature the formal learning of science at various points although, as John Falk and Lynn Dierking (2010) point out, formal learning probably occupies only some 15 % of a person’s whole life. While we do take a look at that 15 %, we primrily focus on the other, informal 85 %.

We see people’s learning, too, as an emotional affair. Between the joy of success and the fear of failure lie a range of affective features of learning that depend on our own sensitivities, the surrounding circumstances, the learning tasks before us and the possible end results of learning. As such, feeling frustrated and bored in a dull classroom, surrounded by unfriendly people, trying to learn something difficult and meaningless for no apparent reason at all, is seldom a good recipe for success. This is a poor motivator to becoming sciencey. Alternatively, if one is surrounded by cheerful and helpful colleagues and friends, intellectually and socially connected with other people, and deeply engaged in learning something interesting and important, one stands a (very) much better chance of learning and ‘getting there’, wherever that ‘sciencey there’ may be. Moreover, the medium of the learning matters. For instance, learning through conversation and discussion is different to learning directly from a video; learning through a website on the Internet is different to learning from a book; learning through practical hands-on activities is different to listening to someone explaining; learning through curiosity and enquiry, and chasing down one's own ideas, is different to following someone else's opinions; and learning through stories and narratives is an essential part of learning throughout all of one's life. We have a particular focus on stories and storytelling because we appreciate just how important a learning medium these can be.

We have a lot to say, too, about 'dispositions'. We do not mean just 'moods' or attitudes, although these do matter in themselves. We are interested in longer-term dispositions that shape our outlooks, our sense of 'being'; dispositions that form and shape directions in life. This has led us to think about what it means to be well-disposed towards science (or, in too many cases, to be ill-disposed and virulently anti-science); what it means to follow one's curiosity into areas of science, to be 'sciencey' or, in our terms, to come to have a positive science identity.

A second dilemma is where does 'me', 'myself', my dispositions, my identity come from? This is a very old philosophical, psychological, social, cultural and sometimes religious question. The background literature on identity formation is enormous and, while it is too vast a field of study for us to do it justice, we do return to it in more detail in Chapter 4. Here it is sufficient to mention just some of the directions we take. In part, the dilemma relates to the age-old nature-nurture debate, i.e., is it the individual or the environment that 'makes' a person? Does it come, for example, from the child or the parents? Deliberations on which of the two holds sway have a long history, are often polarised, and have played out in many ways over time. In our view it is futile to try to separate the two. Nature and nurture are both fundamentally essential for the development of any growing organism, and human beings are no different. As digital scientist Timo Hannay (2015) puts it:

> 'The most elementary error people make in interpreting the effects of genes versus the effects of the environment is to assume you can truly separate one from the other. Donald Hebb, the brilliant Canadian neuropsychologist, when asked whether nature versus nurture contributed more to human personality, reportedly said, "Which contributes more to the area of a rectangle, its length or its width?"' (179).

In our view, rather like Einsteinian space-time, both are deeply intertwined and have complex interactions that give rise to complex outcomes. We suggest an ecological view of science identity—children do not just inherit genes from their parents, they also inherit their environment. A gene's actions and effects can be altered dramatically by both immediate chemistry and more distant factors, for example by other genes and their development, as well as the conditions prevailing within and without the organism as a whole. Moreover, children are not simply passive recipients; they are also driven by their genes to modify the very environment they inherit. Steven Pinker (2004) makes the point that identical twins reared together share all of their genes and most of their environment (home, peers, friends, schools, and neighbourhood) and yet correlations between their personalities are no greater than 50 %: the same genes, a very similar environment, but two different people. He writes of growing up in the Bronx, New York:

> 'Now, one would hardly claim that growing up in the Bronx predisposes a person to a life of exploring nature. More likely, children with a scientific bent seek out nature wherever they find it. The conventional wisdom might have it backward. Rather than childhood experiences causing us to be who we are, who we are causes our childhood experiences' (84).

In his chapter about growing up, Pinker (2004) continues by saying:

> 'So why do people *really* go into science? I suspect the real stories run something like this. Thanks to genes and chance, some people are born with a dose of the requisite talent and temperament: curiosity about the natural world, mechanical and mathematical aptitude, a tilt towards intellectual compared to physical and social forms of amusement. Unless their childhoods are unusually deprived, they will have been exposed to the cafeteria of opportunities provided by modern societies and will have gravitated to a succession of teachers, activities, books, clubs, courses, friends, and hobbies that engage them' (86).

A recent study in *Cognition* (2011) by Claire Cook, Noah Goodman, and Laura Schulz, understands every child to be a *natural* scientist:

> 'Children are born scientists. From the first ball they send flying to the ant they watch carry a crumb, children use science's tools—enthusiasm, hypotheses, tests, conclusions—to uncover the world's mysteries. But somehow students seem to lose what once came naturally' (Parvanno, 1990 quoted in Jirout & Klahr, 2012: 126).

As with Cook et al. (2011), the problem we see is how to remain well disposed towards science as we pass beyond childhood. Pablo Picasso once declared: 'Every child is an artist. The problem is how to remain an artist once we grow up'. Well, something similar can be said about scientists. What Pinker has called the 'scientific bent', that 'dose' of curiosity and aptitude, that 'gravitation' towards science, we have called 'science identity', or Sci-ID. Before we pick up on these key issues in more detail, we return to the dilemma with which we began.

The popularity of science education in life

Data from a report called *Science communication and public attitudes to science in Britain* (2000) identified six attitudinal groups within the general population. That report (now almost twenty years old) argued that the majority of the public falls into the category of 'technophiles', which includes people who are:

> '… pro-science and well educated in science, but sceptical of politicians. They tend to be confident that they know how to get information when they need to, although they need reassuring that the regulatory system exists and works effectively' (Office of Science and Technology, 2000: 6).

That is, people feel able to 'get' scientific information when it is important to them, although they do not always trust the origins of that information. For us, this paints an enormously encouraging picture—one in which people feel confident in their abilities while remaining suitably sceptical and critical of the sources of particular materials. Some researchers have even suggested that scientific advancements and research in technologies have *increased* the public's faith in science (Farias, Newheiser, Kahane & de Toledo, 2013). In their later report in 2016, the Wellcome Trust stated that 77 % of Britons are interested in research on medical advancements and 63 % are interested in hearing about scientific inventions. The main source of information for people on science comes from television, especially news programmes (Ipsos MORI, 2014). For example, sources might include the BBC's science coverage (BBC Trust, 2014); Neal DeGrasse Tyson's Cosmos (Johnson, Ecklund & Matthews, 2018); and TED talks (Caliendo, 2012); in addition to science blogs that can reach wide audiences (Blanchard, 2011). Popular science books also sell well, for example Steven Hawking's *A Brief History of Time* is an international best seller. On the other hand, the majority of Britons also exhibit some mistrust towards media coverage (Gilbert, King, Pettigrew & Wilson, 2016; Gleick et al., 2010; Open Science Collaboration, 2015; Pittinsky, 2015).

But the picture is not always so rosy. Bastiaan Rutjens, Steven Heine, Robbie Sutton, and Frenk van Harreveld (2018), for instance, highlight the fact that 'as science continues to progress, attitudes towards science seem to become ever more polarized' (125). That is, there exist some very 'pro' and some very 'anti-science' people. Whether there is an ever-increasing polarisation between the two is an open question, and is one we consider throughout this book. In our view, people in general certainly do show a higher interest in science (Ipsos MORI, 2014; Wellcome trust, 2016), though this does not always reach down to young people, and definitely does not result in more people actually becoming scientists (MacDonald, 2014; Winterbotham, 2014; UK Commission for Employment Skills (UKCES, 2013). Two decades ago, in a UK national report, Robin Millar and Jonathan Osborne (1998) made the point that:

> 'School science, particularly at secondary level, fails to sustain and develop the sense of wonder and curiosity of many young people about the natural world. This interest and inquisitiveness which characterises many primary school children's response to science diminishes at secondary level to a degree which cannot wholly be accounted for by the onset of adolescence. The apparent lack of relevance of the school curriculum to teenagers' curiosity and interest contributes to too few young people choosing to pursue solely courses in science and mathematics post-16, preferring instead to follow courses in the humanities or a mixed combination from a range of disciplines' (5).

In a nutshell, from what has been said above, this paragraph could be re-written as: while primary school children engage well with science, this engagement wears off at secondary school where many youngsters become wholly disengaged with science. Exactly the same can be said today. In past work we have discussed how affect and feeling, and engagement and disengagement, become manifest in schools (Alsop & Watts, 1997; Pedrosa-de-Jesus, Neri de Souza, Teixeira‒Dias & Watts, 2005). We feature the formal learning of science at various points throughout this book, but, as we have already noted, Falk and Dierking's (2007) 'formal 15 %' of a person's whole life is not really very much—it is amazing just how much pleasure and pain can be crammed into such little time!

Science and technology are embedded in people's lives—socially, culturally and politically—in ways that range from the everyday issues with which people grapple (such as obesity or heart disease), to societal decisions about particular technologies (diesel cars or mobile phones), or revelations about scientific scandals and 'miracle breakthroughs' in the mass media (cures for cancer, Parkinson's or dementia). Scientific literacy is commonly described as the ability to understand and manipulate particular forms of science (Lemke, 2004). For us, scientific literacy comprises a mix of facts, concepts, skills, arguments, 'science stories', expressions, and attitudes necessary to manage people's personal needs. We add, too, a dash of history and philosophy to the mix. *Using* science and *doing* science—what may be called *consuming* science—are clearly different things, although, as we discuss later in the book, there is space for school students and everyday people and non-scientists to do both of these. As we have already mentioned, we see both the formal and the informal learning of science to be a complex affair, drawing on a multitude of sources and, at its best, characterised by a learner's purposive curiosity and meaningful engagement with ideas and processes, and largely driven by their purposive curiosity.

Curiosity is a powerful force in motivating human activity. Over the course of history, humanity's seemingly unquenchable thirst for knowledge and discovery has resulted in countless scientific and cultural advances (Zuss, 2011). Curiosity is not exclusive to science, of course, and our human capacity to be curious spans situational contexts, cultural boundaries and even time itself. Curiosity reflects a need for new information, a desire that is often aroused by novel, complex, or ambiguous events happening in our surroundings. This then motivates exploratory behaviour to tackle such events in ways that allow individuals to seek out, resolve, and adapt to changes in their environment. The philosopher Daniel Dennett described humans as 'informavores' (1993), constantly, restlessly, on the hunt for new information. In this chapter, we are interested in the role of culture and experience in learners' understanding of the physical world. In our case, the events of interest, and the information and understandings that surround them, belong to the broad domain of science, and our own curiosity lies in how people, young and old, come to terms with these.

We believe that the starting points of our enquiry entail making meaning of certain situations related to objects, artefacts, and processes. Making meaning can differ widely between people: it is possible to derive many different connotations and implications from particular occurrences or circumstances. Within this, a distinct tension exists between scientists and non-scientists in terms of accepting or rejecting different forms of meaning-making. A brief story here serves as an example: on a Saturday afternoon we sat for a coffee with colleagues and, as soon as the coffee was served in tall glasses, we three scientists on the table shouted, "Claire, please don't stir the coffee, we just *have* to take a photo". Claire's coffee was special because we 'sciencey' people took particular meaning from the multi-layered coffee in the glass. Claire's (an English lecturer) take on the series of coloured bands was that the milk forms the top layer in the glass, and espresso sits near the bottom, alternating in layers, because milk is lighter than espresso—because the colour is lighter. We scientists (politely) rejected this. We saw the creation of convection cells that resulted from differing temperatures and densities of espresso and warm milk. In our world, the intensity of the colour of a liquid is not a measure of the density of that liquid. The conversation progressed from there: rather than accepting our scientific description of the coloured bands, Claire began light-heartedly to conceive the coffee colours as a metaphor for life: different strands and shades of life, becoming darker at the bottom, which she perceived as one's life coming closer to death and, by stirring the 'ripples of life', one goes under the surface and reflects more deeply on the future. She was only semi-serious, but the conversation illustrates the ways that scientist and non-scientists can use different approaches to making meaning—in this case the meaning of multi-coloured coffee. Claire then drank the coffee before it got cold.

The significant links that connect scientists with everyday people are common sense views, beliefs and languages. 'Common sense' is a catch-all expression, but, in general, it relates to how people understand things through what they see and how they normally express their knowledge about issues and events. For example, the process of day and night is commonly perceived as the sun rising in the morning and setting at night—in Germany people say the sun drowns in the evening. A 'sciencey view' is that the earth spins as it travels around the sun.

Being 'sciencey'

Being 'sciencey', the very nature of being a scientist, is captured by Joseph Schwab (1960) in the figure of a 'man/woman of enquiry'. While people in everyday life might take for granted that the sun rises everyday, an inquisitive scientist would ask why? And what is a sun anyway? While some might admire, and paint, a yellow sunflower, the curious scientist would ask, what exactly do we mean by yellow? Why do plants bother having vibrant colours at all? Scientists 'do' science by employing certain styles of enquiry, practices and positions, and the order of scientific enquiry can differ from one problem to another; from one field to another; and from one subject matter to another. If we accept the definition of a scientist as a person who is an 'enquirer by doing', then why do we find a tension, a divide? Is it the case that scientists live in a scientific world while the general public lives in an 'everyday' world? Why is entering the world of science seen to be a difficult task? If all humans have an inquisitive and enquiry-based nature, can they not all be scientists? Can they not all have a scientific bent?

Before we press on with these ideas, we want to signpost the words 'love of science' and return to emotions. Back in 1964 at the University of Hull, John Bradley was a great admirer of Henry Armstrong's heuristic approach to teaching science. Bradley had a passionate commitment to teaching science—in his case chemistry—in a way that made students 'fall in love' with the subject:

> 'This falling in love with chemistry is the Real Right Thing about learning chemistry; and it is the only item of educational psychology which the teacher of chemistry needs to know' (364).

It might sound odd to talk of 'loving chemistry' or being 'passionate about physics' (not odd for us, by the way!), but we do want to explore a sense of 'loving to learn'. Henry Armstrong was professor of chemistry at Imperial College, London, around the turn of the twentieth century. He forged a campaign against the cold, dull, and didactic teaching that dominated school science at the time. His life's work was dedicated to training students to think and solve problems for themselves, to 'teach them, in fact, to help themselves' (Richmond & Quraishi, 1964: 519). In this way, he aimed to replace the barren transmission of facts from teacher to pupil with an emphasis on practical experimental teaching and a belief in the importance of students learning-by-doing.

Many people, though, dislike the feeling of being hesitant, uncertain or confused. There are positive feelings attached to being 'on top of things', 'clear' and 'sorted'. As Philida Salmon (1988) says:

> 'New understanding is, potentially, threatening ... To be confronted with unfamiliar knowledge can result in a feeling of complete bewilderment. You feel totally at sea, lost, without anchors of any kind, unable to relate what is being offered to personally meaningful interpretations' (27).

Confusion, frustration and doubt can be unsettling, exasperating and disorientating, to the extent that, when we eventually reach a state of clarity, of better understanding, we feel a sense of relief along with the pleasure and satisfaction of having 'got it' and of having 'got there'. There are, though, others (like ourselves) who actively enjoy states of confusion. It is fun to confront challenges, opposing ideas, surprises, anomalies, contrasts, and alternative ways of thinking or doing things. We enjoy the effort that is involved in thinking things through, wrestling with ideas, working at answering questions, deliberating on various situations, and solving problems—we like being in a state of what Jean Piaget (1985) called cognitive disequilibrium. For us, confusion and frustration are essential to optimal learning, for getting into the flow. That is, we enjoy the process of incorporating new ideas, changing the connections between the things we already know, and even in discarding some long-held beliefs about the world.

In a series of classic studies, Mihaly Csikszentmihályi (1990) described an ideal learning state as a state in which learners encounter ideas, resources and learning challenges at just the right level of difficulty to become wholly absorbed in the material. It becomes so totally immersive that time disappears, fatigue vanishes, and one loses all sense of one's surroundings. Csikszentmihályi called this absorbed state 'being in the zone', or being in the flow—the direct opposite of distaste, tedium or boredom. In this form, quality learning becomes both fun and challenging; learning is autotelic—entirely for its own sake—deep, unfettered, free-ranging and highly enjoyable. Just think of those occasions when the last chapters of a book are so enthralling it is impossible to put it down; playing a hard-fought game of five-a-side soccer; climbing a demanding rock-face; being gripped by the drama of a film, play or an opera; being entranced by a piece of music, or being wholly absorbed in a game of bridge, chess or a conversation with friends. It demands our full concentration, time flies as the person is so engaged and engrossed that, for a while, contact is lost with everything else around them. We discuss this later as the 'perfect learning storm'. What follows here is a quote from Eve Curie's (1938) book about her mother, the double Nobel award winner Marie Curie, as she and her husband Pierre worked on radioactive materials:

> 'At this point we were entirely absorbed by the new realm that was, thanks to an unhoped-for discovery, opening before us. In spite of the difficulties of our working conditions, we felt very happy. Our days were spent at the laboratory. In our humble shed there reigned a great tranquillity: sometimes, as we watched over some operation, we would walk up and down, talking about work in the present and in the future; when we were cold a cup of hot tea taken near the stove comforted us. We lived in our single preoccupation as if in a dream' (Marie Curie, quoted from Curie, E. (1938) *Madame Curie*, (trans. Sheean, V), London, Heinemann).

Is it possible for lesser mortals to be absorbed by and in science? Our colleague, Sarah Winwood, is a communications scientist, who uses her knowledge and experience of science to communicate it—sometimes to the public at large; sometimes to business or entrepreneurial communities. She understands science and she understands her audience; she is comfortable with TV and other media; she is also a part-time lecturer at a university department of physics. Sarah, it is true to say, *is* absorbed in science: it is more than her job, it is a significant part of her waking life. She plays badminton, walks a lot and has a large extended family, but her reading time, her study time, her working life and, indeed, her social life is absorbed by science and scientists. Peter Frome, in turn, is starting out on his science career with a degree in geology. He is interested in extra-terrestrial rocks from space, rather than earth-bound ones, and studies some of the many meteorites that fall to Earth every year. Meteorites are fragments of the asteroids that originate between Mars and Jupiter, and Peter is part of a project to analyse their constituent chemicals, looking for clues about the formation of the solar system. He is planning to get married, he plays soccer, rides his bicycle to work, but, when he is at work, he is fully engaged in what he is doing, and in what the answers to his analysis might say about the big questions of science. In talking to them, both Sarah and Peter had very positive early experiences of science, both during school and their university courses. They really appreciated hands-on laboratory activities and experimentation; they enjoyed repeated and direct engagement with scientific enquiry and they valued peer collaboration with friends and colleagues. Both highlighted the importance of warm and welcoming learning environments in their absorption into the world of science. These factors fostered their love of science.

Scientists like Sarah and Peter also see themselves as working towards similar goals, not least of which is to make society and the world a better place in which to be, albeit by different routes. For example, a neuroscientist may work on a biochemical approach to determine the reasons behind depression and violence among traffic officers in under-developed countries. This is actually a real project, where high levels of depression and aggression have been recorded over time. Taking one direction, an environmentalist/geologist might explore the heavy metal elements in air, water and soil that could possibly be responsible for increasing anti-social behaviour. Meanwhile, an artist might bring the societal problem of depression and violence to the canvas, and a musician might create lyrics and music to portray and highlight the plight of the people concerned. All of these people might attend a march to mark a day on dementia. Each of these examples has significance in its own way.

But why do scientists want to push beyond common sense understanding? Some answers can be deduced by re-considering Claire's coffee-story above. There is a kind of cognitive challenge in understanding the science of convection cells, a challenge that seems both conflictual and unnatural (McCauley, 2011). Stefaan Blancke, Johan De Smedt, Helen De Cruz, Maarten Boudry, and Johan Braeckman (2012) contrast "the naturalness of religion with the unnaturalness of science" (1167) and Rutjens et al. (2018) make the point that:

> 'Many scientific theories—including evolutionary theory, spherical earth theory, general relativity, and quantum mechanics—are highly counterintuitive, and this counterintuitive nature impairs science understanding' (128 & 129).

Despite (or maybe because of) these contradictory and 'unnatural' ideas, theories and inventions, there are some (sciencey) people who will continue in a science direction and engage with such conflicts. The research in this area is mixed and muddling: some say that scientists are 'made' through their family, friends, schools and society; while others may argue that scientists are simply born that way. The answers are important for the ways in which we educate people, not just in schools, but in everyday life; and not just in the UK, but across the world. Do we want single-minded specialists or 'cross-border raiders'—as Glen Aikenhead (2007) has called them? Is there not room enough in science to fit everyone? Even for those who might say they detest it?

Science and culture

We are interested in the ways that science percolates into culture. The picture in figure 1.1 expresses the perspectives for much of the book. Science itself is a part of our everyday world—it is part of culture-writ-large. Within this, and as we discuss much more in the following chapters, we are interested in what we call Sci-ID, i.e., being sciencey or non-sciencey.

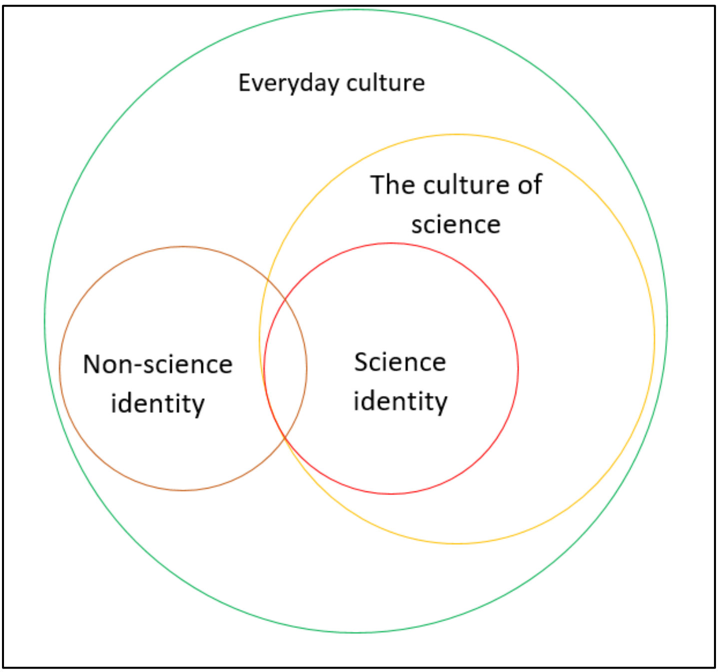

Figure 1.1: overlapping cultures and identities.

Many people seek some understanding of science in everyday life, possibly because it is a part of their working life and, as good professionals, they want to stay up with the field. They may have broad concerns about climate change and carbon dioxide emissions; they may be worried about earthquakes and tectonic plates; or they may be concerned about vaccinations and the possibilities of epidemics. At a more personal level, in terms of everyday science, they may want to think more scientifically about their health or diet; are fascinated by their hobbies; or wish to tackle local issues like, say, the management of toxic waste. What is clear from these matters is that we cannot begin to understand and deal with, for example, climate change without having to think about issues of economic growth and development; we cannot consider economic growth without appreciating population and demographic shifts, and thinking about urbanisation or personal lifestyles. Needless to say, population movements are prone to be influenced by economics, epidemics and earthquakes. Learning science is a complex business and science is a lens through which we can view and tackle complex problems. It does not, though, stand alone, but sits alongside many other fields of enquiry and is thoroughly embedded in everyday culture and all of its value systems.

A further dilemma relates to the fact that a rift is commonly seen between science and culture. Recently in the UK, for instance, a major government funding agency, the Arts and Humanities Research Council (AHRC) (2012), initiated a call for funding bids on Science in Culture. This call aimed to 'develop the reciprocal relationship between the sciences on the one hand, and arts and humanities on the other', a recognition of Charles Snow's (1956) 'two cultures' still alive and well in the West. The relationship between the two domains remains fraught, and debates surrounding the boundaries between culture and science have regularly engaged philosophers and historians of arts and science, as expressed in Thomas Gieryn's 1999 book *Cultural Boundaries of Science* and Adam Bly's *Science IS culture* (2010). For Bly, the term culture applies to the practices, behaviours, expectations, written and unwritten rules of a subset of people, in this case, of scientists. Their practices and rules of good behaviour are fairly general, but are essential to maintaining the quality of science. A report by the Nuffield Council on Bioethics (2014) has described the rules of high quality science as entailing the following important components: rigour, accuracy, originality, honesty, transparency, collaboration, multi-disciplinarity, openness and creativity. This debate opens up questions about the extent to which science is driven by cultural imperatives—and to what extent does science drive art? Certain types of cultural production 'accept' science as a subject for artistic treatment, while others do not. On both the big screen and the small screen, for example, science fiction thrives (*Doctor Who*, *Star Wars*, *Star Trek*, *Dune*, *Alien*, *Blake's 7*, *Blade-runner*, etc.), whilst in other formats, e.g. 'serious' fiction, Wells, Huxley, Conan Doyle, Bulwer-Lytton, etc. it is far less frequently covered.

There are as many varied definitions of science as there are of the term culture. Our intention here is to define neither in any hard and fast way, but simply to enter into a discussion on the relationship between the two—in a manner, of course, that suits our own particular interests. Our principal areas of concern in this book lie in the ways that people identify with science and how they tackle their learning of science—neither of these concerns are 'culture free'. One of the most important responsibilities of science educators is to help empower learners to make defensible judgements about science-based problems—be these problems that exist in a 'theoretical domain' or in a here-and-now, real-life, 'practical domain'. We are not talking about simple quiz-answer questions, but reasonably complex issues that require interpretative arguments and decision-making and which entail real consequences for the learner. Context is all-important on occasions like these, and this commonly relies on the demarcation of the overarching culture, which, in turn, defines the context.

When people talk about science there is often an explicit, though more likely implicit, notion of some hallowed principles that are called the 'scientific method'. Leave aside for the moment that this is a highly contested set of philosophical ideas and that there are many people who argue that no such universal 'method' exists. Imagine, instead, that there are some essential aspects of science that lend it insight and authority. These are usually couched in terms of: observation; hypothesis; experimentation through control of variables; measurements; analysis of outcomes; and some discussion of interpretation and implications. So far so good. Then, a distinction is sometimes made between pure and applied science. In the first of these, the key purpose of the scientific endeavour is to explore and explain natural phenomena, without necessarily much in the way of possible application or exploitation. For us, this lies at one end of a 'spectrum of sciences' that moves from pure science through strategic science (yielding a reservoir of knowledge, out of which as yet unidentified successful products and processes will occur) to applied science (related to a specific project and tied closely to a timetable with a practical outcome often specified by a client). Beyond this lie the domains of 'citizen science' and 'personal science', both of which we discuss in due course.

Rather than a supposed unique method in science, there are actually many different forms of argumentation and logic at play in developing scientific understanding. To give a short example:

> The sign on the beautifully manicured lawn said 'Do not walk on the grass'. The boy, Ben, wondered about this and asked the adult, Anna, 'But why can't I walk on the grass?' Anna responded by telling him that, if *he* can walk on the grass then so can other people. And, if a million other people decided to walk on the grass then it would very quickly be worn away and rapidly loose its green beauty. Ben's puzzled response was that, right here and now, Anna, there are not a million other people ready and waiting to walk on the grass. So, if *he* walked on the grass then it would not actually start an avalanche of grass-walkers and be worn away.

Anna's is an argument by extrapolation, if one can then a million can, and if a million do then the consequences for the lawn would indeed be dire.

Knowledge cannot move forward in the sciences without this kind of extrapolatory argument. In the *Mathematical Principles of Natural Philosophy* (the *Principia*), Isaac Newton described his theory of universal gravitation. It might, in all modesty, have been called a theory of 'solar system gravitation' not least because, by the late seventeenth century, no tests were conceivable beyond the confines of the immediate system. However, Newton assumed that his description of gravitational attraction would extend beyond, indeed, to the whole cosmos:

> 'If it is universally established by experiments and astronomical observations that all bodies on or near the earth gravitate toward the earth, and do so in the proportion of matter in each body ... it will have to be concluded ... that all bodies gravitate toward one another' (Newton, 1999: 811).

Scientists commonly feel justified in making these kinds of arguments given the cumulative power of scientific theories to explain so much of the world. Science often extrapolates a theory or model beyond its tested limits, making a statement such as 'gravity works the same way across the entire universe', or 'the theory of evolution by natural selection applies to all forms of life, including extra-terrestrial ones'. In 1692, the Cambridge theologian Richard Bentley asked Newton, 'if gravity acted equally across a spatially finite universe, why wouldn't all matter be concentrated in a huge ball at the center?' Newton replied, agreeing that this would indeed be the case if the universe were finite in extent. However, he went on to say,

> 'If the matter was evenly diffused through an infinite space, it would never convene into one mass but some of it convenes into one mass and some into another so as to make an infinite number of great masses scattered at great distances from one to another throughout all that infinite space' (no page).

Newton's belief in the universal nature of gravity was strong enough to let him speculate confidently about the spatial extent of the cosmos as a whole. He then used his extrapolation on the nature of the gravitational force to justify why the universe itself should be infinite. As David Deutsch (2011) wrote in *The Beginning of Infinity*, conjectural sources build one's theories and knowledge, alternating with criticism.

We have mentioned here some forms of reasoning and argumentation that are crucial components in constructing scientific knowledge; however, they are neither exclusive to science nor general across all forms of science. Science and scientists are shaped by culture and events: scientists negotiate their priorities, the nature of data, and their results in conversation with each other, with their stake-holders and with communities at large as they work towards outcomes that can then be published. They are kept in check by a sense of persistent enquiry and constrained by rigour, critique and self-criticism. In all this, culture plays an enormous role, not least in setting out what work is valued, and what is an acceptable mode of operation.

Anna's extrapolation about lawn-walkers is an example of just one of these. Scientific problem solving trades on logical analytical rationality—we use observation and evidence as the basis for belief, and we base reasoned explanations and decisions on the merits of discussion, debate and evidential reasoning, just as Bentley and Newton did. Scientists commonly use a range of techniques, for example, they make liberal use of Occam's Razor, the underlying principle that a simple explanation trumps a complex one, which is a principle of intellectual efficiency. They also make use of frames of reference; notions of position; points of view and perspective; judgements; and changes of scale. Added to this is the use of inference; tests and implications of conjecture; the principle of exclusion and of exhaustion ('what if…,' and 'what if not…'); necessary and/but not sufficient conditions; notions of verifiability and solvability; symmetry and invariance; successive approximation; 'guestimation'; particulateness and quantisation; continuity and discontinuity; the exploitation of error; signal-to-noise ratios; coherent interpolation; the use of analogy, metaphor and many, many other procedures. Curiosity and problem-solving in science are used for those problems that are amenable to these kinds of evaluative logic and reasoning. To evaluate something is, literally, to place a value on it, quite commonly to place upon it a numerical value. For example, in order to decide what is and what is not a variable to be controlled in an experiment, we must already have a sense of what it means to vary, how it might vary, what dimensions it might take, the scale of the variance and so on—we have already made numerical value judgements about it before we begin. In this discussion, then, we reserve the workings of science to be relevant to those objects or phenomena that can be the focus of reasoned hypothesis and of subsequent experiment; i.e. reserved for those things that, in general, *can* be explored and measured like this. We exclude from its reach things like feelings, beliefs, magic and miracles.

In our past work (Kanhadilok & Watts, 2016) we proposed an apt analogy: a 'double helix' model of science and culture, where the two are wrapped around each other, inexorably intertwined though held separate from each other. In particular, we have been interested in the 'educative bridges' between the two separate strands of this helix, the 'bonds' that hold science and culture together and yet maintain their separation. For example, evidential arguments depend on value-laden background assumptions, including such things as gender biases, from culture. The geneticist Barbara McClintock was denied recognition until late in her career because the genetics community failed to understand the sort of arguments she was making, or the sort of evidence she was providing. More recently, we have been inspired by Anne Phillips (2010) who presented the idea of a person 'wearing' her or his culture. A person's culture is worn, says Phillips, in a weighted fashion: worn 'heavily' by '...those who are deeply embedded in their cultures' or worn 'more lightly' (10) by those less concerned by their background or heritage. We return to this idea more fully in the chapters to come.

Chapter summary

We have initiated several themes in this first chapter, themes that began with two stories about Judy and Ibrahim and that will now dominate the chapters to follow. Science, in all its different manifestations, is very much a part of our culture and plays an important part in all of our lives. While several reports portray people in the general population as pro-science or as technophiles, we are very conscious that there are also many for whom science is unimportant (at best) and sometimes abhorred, i.e. those who are technophobic. In that sense, we understand that learning science (any learning for that matter) is not just an intellectual activity, but also an emotionally charged affair. We are keen to explore what it means to be 'sciencey', and how it is that people continue to learn science throughout life; we are keenly interested in the ways stories work in relation to science itself and to the learning of science.

In the next chapter, we look at key drivers of science: curiosity and inquisitiveness. We consider, too, the processes involved in questions and questioning.

CHAPTER 2

DEALING WITH FEELINGS

Further on in this book, in Chapter 9, we discuss some of our research and thinking about ‘family science’. During the course of our research into family science, we talked to many family members (mothers, fathers, grandparents, uncle, aunties, nieces, nephews, and family friends) about their ideas of science, and of school science in particular. One father, Tom, sat in a school classroom with us, talking over a glass of school orange juice and confessed that he actually *hated* school and actively hated being inside the school building: even now (“even at my age” Tom exclaimed) it made him feel queasy. He and his wife were there to support their youngest daughter, Sophie, with her project on solar eclipses; but he was really not enjoying the experience, not one single iota. Tom said he had a very poor time at school as a child and this had stayed with him through adulthood:

> “I normally can’t get past the school gates,” he said, “the feelings build up inside me. And even if I get as far as the front door, then I really can’t get any further. It’s the smell, I think. You know that smell? It’s something like … Oh, I don’t know … a mix of wet clothes, boiled cabbage and floor polish. Oh heck, I still shudder, I still hate it”.

We recognise that smell, but our own experiences are radically different to Tom’s. We have visited schools across the world, taking in the nature displays, science tables and school laboratories in the places we have gone. And, yes, there is a characteristic smell about school labs: the dry, dusty ozone aroma of a physics lab; the tangy acidic whiff of a wet chemistry lab; the earthy smell of a biology room. But, for us, these are welcome smells that take us back to our own enjoyment of being classroom teachers and, before that, to our own successes as young science students at school and university. A common factor in these conflicting accounts is the power of smell to evoke past emotions—so negative in Tom’s case, so positive in our own. Nor, more generally, are smells alone in giving us the shudders: thoughts, words, ideas can do the same. As is evident throughout the chapters in the book, we have talked to many people, young and old, who have adored science or otherwise been repelled by it. Their repulsion has