

6 Report

“Beauty is truth” What’s beauty got to do with science?

Nick Spencer



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Nick Spencer

“Beauty is truth”

“It is... the search for this special beauty, the sense of the harmony of the world, that makes us select the facts best suited to contribute to this harmony.”

Henri Poincaré

“There’s important emotion in science. It’s not just aesthetic reflection. It is a desperate, urgent energy-releasing desire to get to the beautiful, even when the beautiful is hidden, that keeps us at work at the coalface of experience.”

“Matthew”, UK physicist



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Executive Summary

Beauty matters to scientists. They find it in the subject of their research, their experiments, and their teaching. It serves not only as a motivator but also as an indicator of truth. Only 3% claim not to find it at all.

The research for this report was conducted among physicists and biologists in four countries (UK, Italy, USA, India) and involved a substantial quantitative questionnaire and in-depth qualitative interviews.

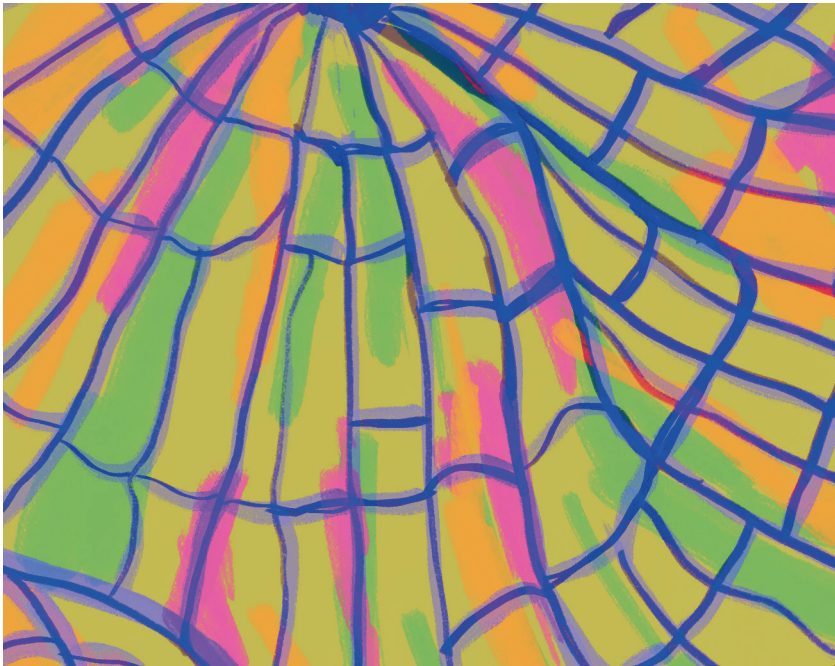
It found that among UK scientists, 76% reported encountering beauty most commonly in the phenomena they studied, whereas 62% found it in scientific theories. Other areas included teaching (46%) and the process of scientific research (44%).

Scientists in India tended to be more likely to encounter beauty in their work, with, for example, 40% saying they “felt a sense of clarity as I saw how things fit together”, compared to 32% of UK scientists surveyed.

Physicists and biologists tended to have slightly differing conceptions of beauty. Biologists tended to cite “complexity” more often, whereas physicists cited “symmetry” and “simplicity”. However, they concurred on the salience of “elegance”, “hidden order or patterns”, and the “inner logic of systems” for the idea of beauty.

While it is too simplistic to say that beauty was straightforwardly or necessarily interpreted as a guide to truth in science, it is nonetheless true that it could be and was used as an indicator or guide in the pursuit of truth. For some, beauty was the reason they started doing science in the first place. For others, it is a reason to continue when things are tough.

Above all, however, beauty plays a role in the connection between the human mind and the world that it is investigating. The fact there is such a connection often strikes scientists as remarkable itself, as does the fact that science reveals a deep coherence within nature that matches this comprehension. The fact that that connection, coherence, and comprehension often reveals itself in simple, elegant, parsimonious – ‘beautiful’ – form is important.





Foreword

Beauty is not a word that typically comes to mind when most of us think about science. Indeed, we usually associate science with words such as rational, methodical, and analytical. We see beauty as subjective and emotional, and science as objective and unemotional.

Indeed, the longstanding critique of science is that it reduces and even strips away the beauty and mystery from reality. Keats famously complained how “cold” scientific philosophy would “clip an Angel’s wings / Conquer all mysteries by rule and line / Empty the haunted air / and gnomèd mine— / Unweave a rainbow...”

But scientists in recent years have been pushing back against this caricature. Richard Dawkins, for example, in his book *Unweaving the Rainbow*, argues, “The feeling of awed wonder that science can give us is one of the highest experiences of which the human psyche is capable. It is a deep aesthetic passion to rank with the finest that music and poetry can deliver.”

Numerous other scientists, such as Paul Dirac, Richard Feynman, Murray Gell-Mann, Frank Wilczek, and others have waxed eloquent about the importance of beauty in science.

A few years ago, I would have dismissed their words as the special privilege of geniuses – of course Nobel Prize winners would find their work beautiful! But while I was part of a team conducting an eight-country study on scientists’ views on religion, I encountered something surprising. In several interviews, when scientists recounted the many sacrifices they made for the sake of their work – long hours in the lab, forsaking more lucrative careers, even sacrificing their family lives – the justification they gave us for doing so was: “Because it is beautiful.”

It was clear to me that this topic warranted further inquiry. What do scientists mean by beauty? Where and how does it matter in their work? Nobody had empirically measured the extent to which such encounters with beauty were prevalent in the day-to-day work of ordinary scientists.

This led me to develop the first international social-scientific study of the role of beauty in science. We decided to focus on scientists in physics and biology departments in four countries: India, Italy, the UK, and the US. To prevent our study from being biased in favour of only those scientists who care about beauty or aesthetics, we branded our project as a study of “Work and Well-Being in Science.” This approach also allowed us to examine the relationship between aesthetic experience and well-being among scientists.

The project was made possible by a generous grant by the Templeton Religion Trust (Grant #TRT0296). Nearly 3,500 scientists completed our survey. We also conducted in-depth interviews with 215 scientists. Our results have convinced us that science itself is a quest for beauty – not unlike music or poetry – although this beauty can be fragile and even misleading. This argument is being fleshed out in a book that is currently in process.

In this report, Dr. Nick Spencer, who conducted a number of interviews with UK scientists for our project, summarizes our key findings on where scientists encounter beauty in their work, what difference it makes to them, differences in what beauty means across scientific disciplines, and what some of the broader implications of our work might be.

This report is especially instructive because it highlights, for one, how ubiquitous beauty is across the scientific process. Drawing on rich interview data from UK scientists, Dr. Spencer

also illustrates what these encounters with beauty look like and how scientists make sense of them. At the same time, he also takes care to identify the various ways in which science is not perceived as beautiful.

The report's careful analysis also demonstrates how scientists perceive beauty as both a motivation and a source of bias. It shows that aesthetic experiences associated with coherence and comprehension are at the heart of scientific work for most scientists – and yet, makes clear why a facile equation of beauty with truth will not do. And finally, the report raises important questions about the relationship between science and theology that flow from our findings.

Dr. Spencer's report does an exceptional job summarizing both the highlights and nuances in the results of our pioneering study of beauty in science. I trust that readers will find it enjoyable and thought-provoking.

More information on the *Work and Well-Being in Science* study, including summaries of our data and methodology, as well as videos and a podcast about beauty in science, can be found at www.workandwellbeingstudy.com

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Introduction

Despite the idea that the modern world is allegedly divided into “two cultures”, in which the sciences and the humanities stare at each other across an intellectual chasm in mutual incomprehension, scientists are very interested in and highly attuned to the idea of beauty.

Natural philosophy, the discipline from which modern science emerged, was never indifferent to (and sometime hardly distinguishable from) a concern with aesthetics (not to mention ethics and metaphysics). Even after the invention of the word ‘scientist’ in 1834 and the slow professionalisation of the role over the following half century, beauty continued to play an important role in science.

The association is strongest – or at least best known – among physicists. “It is... the search for this special beauty, the sense of the harmony of the world, that makes us select the facts best suited to contribute to this harmony,” wrote the French mathematician and theoretical physicist, Henri Poincaré.¹ “If nature leads us to mathematical forms of great simplicity and beauty... that no one has previously encountered,” Werner Heisenberg remarked to Einstein, “we cannot help thinking that they are ‘true,’ that they reveal a genuine feature of nature.”² Or, most bullishly, in the words of British physicist Paul Dirac, “it is more important to have beauty in one’s equations than to have them fit experiment.”³

“

Despite the idea that the modern world is allegedly divided into “two cultures”, in which the sciences and the humanities stare at each other across an intellectual chasm in mutual incomprehension, scientists are very interested in and highly attuned to the idea of beauty.

The aesthetic aphorisms of physicists may be best known but a concern for beauty goes beyond physics. But how far, and to what effect? What proportion of working physicists identify with the concern for beauty expressed by some of their discipline’s greatest figures? How far do other, perhaps ‘messier’, scientific disciplines, such as those within the life sciences, share the same interest and concern? To what extent is this interest in beauty a culturally specific, even culturally conditioned, phenomenon? And what, if any, impact does this attention to beauty have? In particular, is it (understood to be) a guide to truth itself – as the physicists above seemed to think – or is that to load it with more weight than beauty can bear?

Underlying these questions there lie deeper ones, insoluble in themselves but perhaps amenable to the clarification that comes from examining scientists’ engagement with beauty. What actually is beauty in science? Where does it reside? Is it more than a ‘merely subjective’ aesthetic preference? And what, if anything, should one take away from this inquiry with relation to human thought, nature, and the material universe we share and study?

These questions were among many addressed in the study, *Work and Well-Being in Science*. This project, conducted in 2021-23, was a large, international research programme exploring the role of key factors that affect the well-being of scientists. The study focused on physicists and biologists from four countries – India, Italy, the UK, and the US – and examined a wide range of topics, including meaning and identity in work, scientists’ assessments of their workplace cultures, and – the focus of this essay – the significance and the role of aesthetics in scientific work.

The research involved a quantitative study of scientists' views. Abt Associates initially surveyed 22,840 scientists from 233 universities and research institutes between May-September 2021, which yielded a total of 3,442 completed surveys (AAPOR Response Rate of 15.2%). The project research team then conducted a further 215 in-depth interviews with scientists in these countries, exploring the issues in greater depth. This report draws on both data sets although focuses primarily on the in-depth answers from the qualitative interviews conducted in the UK. More details of the project can be found at www.workandwellbeingstudy.com

This essay looks at the question of the role of beauty in science. Chapter 1 examines the extent to which scientists talk about beauty in science and reports that the answer is a great deal: a concern with aesthetics is not simply limited to first-rank physicists, or indeed physicists in general. Chapter 2 then looks at where scientists (specifically physicists and biologists) find beauty in science, and chapter 3 examines what difference it makes to them: is beauty essentially an epiphenomenon, an incidental 'nice-to-have' in the scientific process, or does it play a more substantive role in the task of determining truth? Chapter 4 builds on these findings to tackle the underlying question of what, in the light of what scientists say about it, *is* beauty? The conclusion then draws the camera back and offers a few thoughts on what the perceived relationship between science and beauty might *mean*.

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A concern with aesthetics is not simply limited to first-rank physicists, or indeed physicists in general.

It was the novelist and chemist C.P. Snow who famously observed, over 60 years ago now, that Western intellectual

life had become painfully divided between science and the humanities, in such a way as damaged our ability to navigate the world successfully. Today, as then, there is evidence to support his thesis. Many of those whose home lies in the humanities know next to nothing about science, and some are proud of their ignorance. Conversely, few scientists have any training in aesthetics or hermeneutics, many disparage post-modernity out of hand, and some articulate opinions on the nature of truth that wouldn't pass muster in an A-level lesson.

In a sense, there is no need for guilt here. Academic specialisation has been underway for centuries and it would be obtuse to damn academics for failing to keep abreast of all relevant disciplines. But if not a cause for guilt, it is one for regret, because the compartmentalisation of knowledge and thought is a human artefact and, as the interviews for this project showed, the ideas of truth and beauty are, in fact, closely and perhaps even necessarily linked. And if ‘two cultures’ is a cause for regret, it is also one for humility, in which those who work in the sciences and the humanities forcibly recognise not only the incompleteness of their knowledge (that is easily done) but also their need to learn from others.

Nick Spencer
Theos, December 2022

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- 1 Henri Poincaré, *Science and Method* (London : T. Nelson, 1914), pp. 22-23
 - 2 Quoted in Subrahmanyan Chandrasekhar, 'The Perception of Beauty and the Pursuit of Science', *Bulletin of the American Academy of Arts and Sciences* Vol. 43, No. 3 (Dec. 1989), pp. 15
 - 3 Paul Dirac, 'The Evolution of the Physicist's Picture of Nature', *Scientific American*, May 1963





1.

Where do scientists
encounter beauty
in science?

By far the majority of scientists we interviewed – both those polled as part of the quantitative survey and those interviewed as part of the qualitative research – were familiar with and positive about the role of beauty in science. In the words of one:

“There’s important emotion in science. It’s not just aesthetic reflection. It is a desperate, urgent energy-releasing desire to get to the beautiful, even when the beautiful is hidden, that keeps us at work at the coalface of experience.”¹

It was undeniable and obvious to many that beauty played a critically important role in their work. When presented with a range of areas in which they might encounter beauty, only 3% of respondents answered “none of these”. Beauty was common, and commonly very important. In the revealing comment of one interviewee, beauty is “like a religious experience but for scientific people.”²

The variety of terms that were used for beauty could generate an irreducible uncertainty around the concept that made the scientists we spoke to anxious about it. Interviewees would (occasionally prefer to) speak of something being “interesting or quite exciting”,³ “incredibly satisfying”,⁴ fascinating, amazing, inspiring, “powerful, wonderful” – rather than beautiful.⁵

“I’m not sure if beauty is the right word for it... there’s something kind of joyful and intrinsically feel good about understanding things and uncovering things.”⁶

This range of emotive and affective terms underlines how the *lexicon* of beauty could feel alien to that of science, the indeterminacy of term(s) suggesting (to some interviewees at least) that the discussion of beauty was ineradicably subjective

and therefore fundamentally opposed to the objectivity pursued by science.

“I would describe it as something more human-created, more artistic.”

However, such terminological uncertainties duly noted, it was clear that beauty itself was anything but an alien or unwelcome dimension in their work.

In light of this, perhaps the single most striking finding of the research into beauty in science was its ubiquity. Whereas one might, for example, expect scientists to say that they found beauty in what they studied – and, as we shall see, they do – it is also notable that beauty can be found throughout the whole scientific process.

Table 1: Where do scientists encounter beauty at work?

In which of the following aspects of work do you encounter beauty (however you define it)?	%
Phenomena that I study (e.g., cells, particles, etc.)	75
Scientific theories	61
Teaching science	54
The process of scientific research	52
Writings of prominent scientists	36
Scientific journal articles	31
My workplace	31
Scientific conference presentations	29
None of the above	3

Source: Vaidyanathan, B. & Jacobi, C. J. (2022, June 19). *Repository of the Work and Well-Being in Science Study*. Retrieved from <https://osf.io/jp86u/>

Respondents to the quantitative survey (across all four countries) were offered a range of options for the question

about where they encountered beauty. **The phenomena they studied** came out top, with three quarters (75%) of respondents saying they encountered beauty here. (See Table 1) The qualitative research elaborated on this. Physicists might find images, such as from the Hubble space telescope,⁸ or models, such as that of the evolving universe, beautiful.⁹ Biologists naturally cited “the natural beauty of the environment”¹⁰ or specific specimens or images thereof.¹¹ Beauty was frequently mentioned in relation to the objects of science.

“**Scientific theories**” were next most likely to be considered beautiful by respondents, specifically by 61% of people in the quantitative study. This view was voiced by physicists and biologists, but the examples tended to come more often from the former, or from mathematics, and included Euler’s identity¹² and Einstein’s theory of relativity, judged by one interview as “inherently elegant using beautiful mathematics”.¹³ It was, however, the *general principle of theories* – or sometimes “models” – and their ‘fit’ to reality that commonly struck interviewees as beautiful. In the enthusiastic words of one:

“I cannot stop being completely stunned and wondering why those formulas are able to express or at least somehow tell the story about what’s going on in the world, this is completely incredible. Every theory which increases this kind of understanding for me, has this kind of taste which can be called beauty.”¹⁴



Often, this beauty was located specifically in the mathematisation or the equations that were inherent in the model or the theory, although here the word ‘elegant’ was often used instead of beautiful’.¹⁵ We will return to the question of elegance below.

The third most popular area for finding beauty in science lay in **teaching**, mentioned by over half of respondents in the quantitative research. Here the beauty lay in the connection and inspiration that teaching offered – at least in theory (as we shall note below, interviewees recognised that this was not necessarily the case). “There’s a beauty in teaching and there’s a beauty in them learning and getting excited.”¹⁶ Indeed, beauty was often spoken of as not only important but *necessary* to the task of teaching science.

“I think the beauty in that again is the fact that you’re hoping that you’re inspiring the next generation of scientists, and there’s definitely a beauty in that. And also, you’re sharing in their journey of curiosity and their imagination.”¹⁷

The fourth area was “the process of scientific research”, left vaguely defined in the quantitative study but meaning, for many, the process of **experiment**. A number of interviewees elaborated on this point, with some even prepared to call experiments beautiful when they were otherwise sceptical of this whole area of discourse.¹⁸

“An experiment can also be very beautiful. So, by that we mean that it’s something very elegant about how it was designed, something – somebody looked at something, and found a completely different way of thinking about it. It suddenly clarified it.”¹⁹

Next, respondents registered a sense of beauty in **scientific writing**, whether that of popular size or in academic journals.

“A well written sentence, an elegantly written sentence using the minimum number of words, conveying the point very well, succinctly and concisely, and just well written is in a sense beautiful.”²⁰

In a similar communicative vein, it was not uncommon for scientific presentations to be judged beautiful, with interviewees sometimes mentioning the effort put into this.

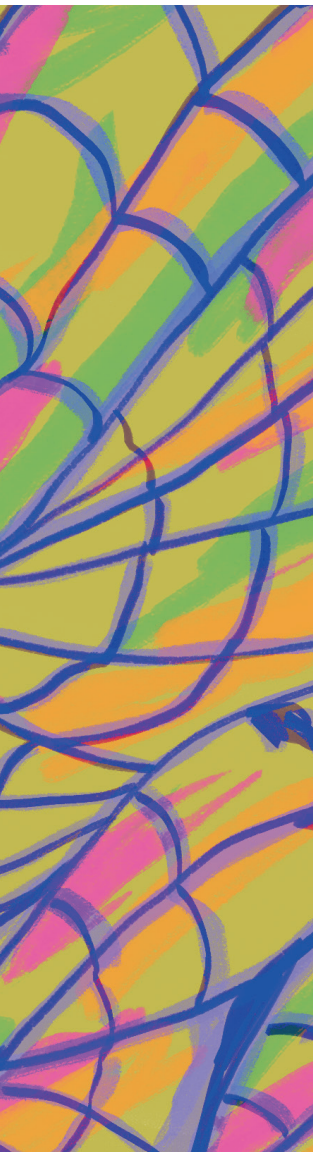
“People love the aesthetics of a great graph or some diagram... very often some of the bigger journals like Cell, Cell Reports, New Phytologist and the ones like that... if you get your paper accepted, they want a diagrammatic representation of what your paper is saying... I get the impression if you go look at journals now, how glossy they are, and that the quality of the figures compared with say 20 years ago.”²¹

Respondents also mentioned their **workplace** as a place where they might encounter beauty – 31% did so.

“When designing the lab, I was definitely thinking about the space, and how to use it, but also about how to make it look nice, be a good place to work.”²²

On this point, however, it is also important to recognise that a number of in-depth interviewees were unusually vocal and forthright about how their workplace (especially their lab) wasn't a place of beauty.

Going beyond the options offered to respondents in the quantitative survey, interviewees also spoke about beauty in science through the simple fact of **understanding**.



“I think one of our driving purposes being human in an inhuman material world is to understand the inhuman material world better and be reconciled to it. And I think that’s what science does. That’s one of the most beautiful and deep and poetic activities one can pursue as a human being.”²³

The beauty here is closely linked to the idea of **correspondence**, that the models, equations, etc. of science correspond so well to the processes of the physical world.

“And as a physicist that elegance it’s partly, it’s mathematical simplicity, but partly if that can say something about the real world, that adds to it because it’s meaningful as well. It’s not just some abstract piece of maths, it’s related to the physical world.”²⁴

And also to the idea of **coherence**, the idea that everything fits together.

“I’m often so astonished and as more I read, as more I learn, and as more I go down into this molecular mechanisms that for everything there seems to be a solution, and that is for me astonishing.”²⁵

Discussion of correspondence and coherence, like simplicity or elegance, nudges us towards the critical question of what beauty actually comprises of, what it actually means, which we shall explore in greater detail below.

In the meantime, it is also worth noting that these scientific experiences of beauty were not

rarities. Although beauty was not always present in science – as we shall note shortly – nor was it anomalously rare. The quantitative survey asked scientists about the *frequency* with which they experienced ‘beauty’ in their work, with the options being “never”, “rarely”, “a few times a year” “a few times a month”, and “weekly or more”. Table 2 below combines the data for “a few times a month” and “weekly or more” for an overall figure meaning, in effect, ‘frequently’. The results show that a sense of beauty is reasonably common among scientists, although for different reasons, and at different levels in different countries.

Table 2: How frequently do scientists encounter beauty in their work?

% who frequently say...	UK	Italy	USA	India
“I felt a sense of clarity as I saw how things fit together”	32	39	37	40
“I felt pleased by the elegance of a scientific object (i.e., equation, model, experiment, etc.)”	28	36	37	43
“I felt pleased by encountering symmetry in scientific equations, models, or data”	20	27	31	36
“I felt surprised by discovering a hidden order or deeper systems underlying the phenomenon I was researching”	14	28	19	36

Source: Vaidyanathan, B. & Jacobi, C. J. (2022, June 19). *Repository of the Work and Well-Being in Science Study*. Retrieved from <https://osf.io/jp86u/>

Scientists in India tended to be most likely to detect or encounter beauty in their work, those in UK the least, and scientists in all four countries were more likely to find beauty

in coherence (“I felt a sense of clarity as I saw how things fit together”) than they were in “encountering symmetry in scientific equations, models, or data” or in “discovering a hidden order”. However, consistently more than a fifth, and sometimes as many as two fifths of scientists polled admitted to finding beauty frequently in their work.

“

Beauty is a salient, widely recognised, sometimes inspiring and sometimes even necessary dimension within scientific work.

In summary, when it comes to the basic questions of whether scientists talk about beauty and in what areas or capacity, the answers are clearly ‘yes’ and ‘in many’. Beauty is a salient, widely recognised, sometimes inspiring and sometimes even necessary dimension within scientific work. On occasion, interviewees even spoke of

the aesthetic quality of the work as transcending its immediate context and claiming recognition in another altogether.

“I’ve got a student at the moment who I’m co-supervising who has done some amazing microscopy with really beautiful, literally beautiful images to the point that I suggest we should maybe submit them to an art exhibition because they’re just so beautiful.”²⁶

Having recognised all this, it is also important to recognise that some scientists do not find and would not talk about beauty in their work at all.

“I might think of it as elegant or neat or kind of cool, but I don’t think beautiful is a word I would ever use.”²⁷

Some found the term too slippery and subjective to be of any real use.

“Some people interpret beauty in different ways, and my logical mind can’t answer something without knowing how they define it.”²⁸

Some thought beauty was a merely affective – rather than in any way a cognitive – quality.

“I would say ‘beautiful’ will be something that doesn’t go through the brain. It goes through the eyes and I just look at it and it appeals.”²⁹

And some even considered it a potential source of bias.

“If we’re looking for beauty or whatever we think of as being a beautiful solution to a problem, then that will bias the science.”³⁰

Moreover, even those who did encounter and discuss beauty in their work were clear that beauty was not an inevitable part of it. Not all natural phenomena were beautiful.

“Usually it’s [the] opposite, in epidemiology, when we talk about the spread of viruses... [it’s] unpredictable, no one knows... basically referring to this system as something not very pleasant, unpredictable.”³¹

Not all scientific images were beautiful.

“Because I’m looking at x-ray data which is often quite noisy... You see those beautiful three-color Hubble Space Telescope images and you go, ‘Wow!’ If you look at one of our images, you’d go, ‘Meh’.”³²

Not all scientific practices or experiments were beautiful.

“To be honest you, if anything, I would describe the real practice of science as ugly or hideous... on the first day of my PhD, my PhD supervisor said to me, ‘ninety-five percent of doing a PhD is redoing what you did yesterday slightly better or slightly

*differently. And when you get really good at it, that goes down to about ninety percent’... There is an awful lot of boring drudge work, frustration, cursing, swearing, like I’m sure there is in any developmental job, and beautiful is not a word, I would use at that point.”*³³

Not all science writing was beautiful.

*“A well written piece of text, a well written paper, which sadly my students never manage... is in a sense beautiful.”*³⁴

And not all scientific presentations were beautiful.

*“If you compare a presentation produced by somebody who’s inexperienced or not a very good presenter in terms of their slides, compared to somebody who is a good presenter, not just in terms of the basic design things but also in terms of the choice of the photos or pictures they use or the choice of example...”*³⁵

In short, beauty appears to be important and arguably intrinsic to the goals and processes of science, and is ubiquitous in the sense of being felt or experienced throughout the scientific process. But it is not *inevitably* present and not ubiquitous in the sense of being sensed by all scientists or being evident in all scientific phenomena, practices, and presentations.

- 1 P-SB-NS-01-UK++Matthew
- 2 P-SV-BR-06-UK-15470++Frey; emphases added.
- 3 P-SV-CK-13-UK-17352++Beverly
- 4 B-SV-NS-19-UK-12692++Thomas
- 5 B-SV-NS-19-UK-12692++Thomas
- 6 P-SV-DJ-10-UK-17973++Katherine
- 7 B-SV-NS-23-UK-12849++Denis
- 8 “I think I spent far too much time looking for new versions of beautiful images to show the students and ways that they can then take some of the raw images and combine them to make their own beautiful images.” (P-SV-BR-10-UK-17984++Colleen)
- 9 “You might have seen some of these computer simulations of how the universe has evolved over time. These are really beautiful, where they show how hot the gas is and how its temperature changed over time and how it... the stars and then you have explosions. So seeing all that stuff going on, seeing all the colors that are involved, I think these are lovely, like visually they’re just amazing.” (P-SB-BR-12-UK++Hili)
- 10 B-SB-NS-12-UK++Ben
- 11 “We still do the aesthetics bit. So I think it’s becoming more and more important along with computational biology, it’s becoming visual biology.” (B-SV-BV-06-UK-13770++George)
- 12 “There’s a lovely equation of mathematics, the Euler equation, e to the i pi plus one equals zero, it’s amazing... all together in one simple equation, that’s beautiful.” (P-SB-NS-04-UK++Arthur)
- 13 P-SV-CK-03-UK-17600++Galilea
- 14 P-SV-NS-20-14727++Patrick. In a similar vein, “When you can match a model to reality, and it doesn’t require massaging it, doesn’t require – what’s the word?... this is the theory, this is the fact, and they match perfectly. That is beautiful.” (P-SV-AU-02-UK-18221++Jim)
- 15 “I know it’s a cliché to say that a mathematical equation could be beautiful, and I don’t think that really sums it up quite right. I would use the word elegant.” (P-SV-AU-08-UK-17344++Lois)
- 16 B-SV-BR-03-UK-12193++Olivia
- 17 B-SV-BR-03-UK-12193++Olivia
- 18 “If I was going to have a sense of wonder, it would be an experiment that hadn’t been done before, somebody had developed some maths, and then

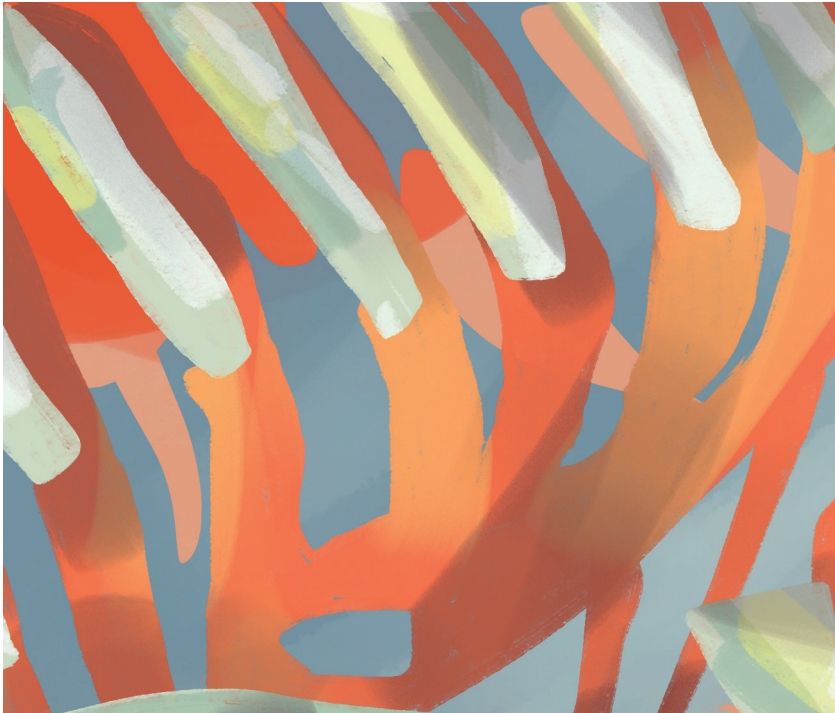
“Beauty is truth”

- they did a simple experiment, which just demonstrated that that was the case unequivocally, that would be the most wondrous and beautiful experiment.” (P-SV-CK-01-UK-15737++Max). In a similar vein: “So in experimental design, certainly in my field, beauty isn’t something I think about or even recognize, I mean aside from you know, a well-designed experiment, you know, you could call it beautiful.” (B-SV-AU-05-UK-12614++Holly)
- 19 P-SB-NS-09-UK++Alan
- 20 B-SB-NS-12-UK++Ben
- 21 B-SV-BV-06-UK-13770++George. In a similar vein: “I spend too much time probably thinking about how I can make a scatter plot as beautiful as possible by using different colour schemes, different points, different axis.” (P-SV-BR-10-UK-17984++Colleen). And: “I always try to make my materials aesthetically pleasing, I think, I’ve definitely spent way too much time in the past...fiddling about with the PowerPoint or something, making it look nice. Because I think that helps too. And I think if you’re communicating something, the more pleasing something is to look at the more your eyes naturally drawn and the more time you’ll spend looking at it.” (B-SV-AU-05-UK-12614++Holly)
- 22 P-SV-AU-02-UK-18221++Jim
- 23 P-SB-NS-01-UK++Matthew. In a similar vein: “understanding what the very fundamental nature of our existence is, which is quite beautiful.” (P-SV-CK-05-UK-14961++Bob)
- 24 P-SV-AU-08-UK-17344++Lois
- 25 B-SV-AU-11-UK-12317++Stefan
- 26 P-SV-AU-08-UK-17344++Lois
- 27 P-SV-NS-21-16506++Peter
- 28 P-SV-AU-15-UK-17944++Parvinder. Also: “Beauty is not defined...the same way between...group of people, because some people will say, this is beautiful, other people will say, nothing really beautiful about that.” (B-SV-NS-22-UK-12297++James)
- 29 P-SV-NS-21-16506++Peter
- 30 P-SV-DJ-10-UK-17973++Katherine
- 31 Interestingly, though, even this interviewee went on immediately to say, “we are trying to make sense of it, but, yeah, kind of beauty is in our results, maybe, if it makes sense.” (SV-AU-10-UK-13333++Dmytro). In a similar vein: “One of the viruses I’ve worked with, tobacco mosaic virus, causes this mosaic effect in the leaf. So it has sort of these patches of dark green and light green, and that can look really beautiful I think as well. Not all viruses are beautiful I suppose.” (B-SV-AU-05-UK-12614++Holly)
- 32 P-SV-NS-21-16506++Peter

33 P-SV-NS-21-16506++Peter

34 B-SB-NS-12-UK++Ben

35 B-SB-NS-12-UK++Ben





2.

What difference
does beauty make
in science?

Scientists talk about beauty in their work. They recognise its significance. They sense or find or aspire to it in a remarkably wide range of their activities. And although they are entirely alert to the fact that not everything in science is beautiful, they still encounter beauty frequently in what they do.

But what difference does it make? What are the consequences of this attention to beauty? Is beauty effectively an epiphenomenon, a secondary factor incidental to the actual practice of science, or does it play a more substantive and formative role?

The quantitative study probed this issue, the results of which are presented in Table 3.

Table 3: What are the consequences of encountering beauty in scientific work?

“Encountering beauty in my scientific work...”	%
Motivates me to share the beauty of science through teaching or mentoring	62
Motivated me to pursue a scientific career	62
Improves scientific understanding	57
Helps me persevere when I experience difficulties or failure in my work	50
Motivates me to communicate science to the public	49
Feels familiar to the beauty I encounter in forms of art (e.g., fine art, music)	47
Gives me more confidence in my results	42
Makes me think that I am on the right road to reach truth in my investigation	35
Has been life-changing for me	22
Suggest to me the existence of a higher power	14

Leads me to think I should re-check my work	13
None of the above	5

Source: Vaidyanathan, B. & Jacobi, C. J. (2022, June 19). *Repository of the Work and Well-Being in Science Study*. Retrieved from <https://osf.io/jp86u/>

The idea that beauty was a **motivation** was the most widespread, and was also commonly mentioned in the in-depth interviews. This could be as a motivation to work in science in the first place.

“I think beauty is what led me into science because I never thought of being a physicist until the dad... of these kids I was babysitting when I was 17 years old said something like a physicist is an artist who can’t draw. It’s this kind of sentence that triggered something in me.”¹

It could be as a motivation to choose a particular scientific discipline, whether within the life sciences:

“Working with plants, I think is hugely beautiful. I mean, obviously flowers are particularly beautiful to the human eye and then, you know, other organisms too... I think that’s also what led me to my research area.”²

Or in the physical sciences:

“I think ultimately people who come into astronomy specifically, I think [for] a lot of them their first exposure to it would have been an interesting image or a beautiful image.”³

It could be as motivation simply to keep going through the times of drudgery and doubt.

“Thinking is hard work. But the hard work is less hard if it’s fuelled by aesthetic loveliness, because there’s an energy in the attraction of beauty that helps the hard work of deep contemplation, if you know what I mean.”⁴

And it could, as we have already noted, be a motivation to encourage others into science.

“I think there’s definitely beauty in teaching because I don’t think that we can really get people on board with the science unless we show them the beauty of science when we teach.”⁵

Does the beauty inherent in science go beyond its motivational significance towards a more substantive role? There was broad agreement that beauty – of objects studied, of theories formulated, of understanding achieved – was a genuine enticement to and encouragement in scientific activity. But was it more than that? Is beauty associated with understanding or with truth? Is it even a *guide* to truth?

The (perceived) answer to this is mixed. Over half (57%) of physicists and biologists say that they thought that encountering beauty in their work “improved their understanding” and 42% say it gave them “more confidence in their results”, while 35% said it made them think that they were “on the right road to reach truth” in their investigation. These statistics were supported in the in-depth interviews. A number of interviewees made comments like:

“I think intuitively I will see the best solution as the most beautiful solution.”⁶

“Some people would say, ‘well, any ultimate theory of nature should have an intrinsic beauty to it. And if it doesn’t, if it’s messy and ugly and ad hoc, that means that you’ve missed something scientifically.’”⁷

These quotes come close to the famous words of Paul Dirac with which we started. However, it is important to underline that many of the interviewees who spoke about beauty and truth positively also did so with a clear qualification. Beauty,

truth and understanding had *some* connection but not one that was necessary or infallible.

*“Beauty can help to get the truth, but ugly also can... it doesn’t need to be beautiful to lead to the truth... In my career, more than 70% of the things we try in the lab, will never be published and still we gain truth in those ugly sides.”*⁸

Moreover, if “it doesn’t need to be beautiful to lead to the truth”, it is equally (and also logically) true that beauty can mislead. One interviewee cited an example from history, where the allegedly self-evident beauty of something did mislead the ‘scientists’ of the time.

*“So [the idea was that] everything orbits in circles, that would be very, very pretty and it’s a very simple solution, but it’s not actually true. The truth is a bit different. Everything orbits in ellipses in slightly different orientations. And even that’s not really quite true because things don’t orbit in ellipses.”*⁹

It was a similar issue with experimentation. In theory, a beautiful experiment might lead you towards the truth, but in reality, it need not at all.

*“You can have really beautiful experimental setups because an experimental setup, if it’s good, is symmetrical, and symmetry is generally perceived as pleasing... you can see when something looks really good, and there’s a perception that this means that the science will be better and work better, but that’s not necessarily true.”*¹⁰

Beauty could be an indicator of truth but that which is true need not be beautiful. On this point, one interviewee directed the ghost of Dirac to the un-beautiful state of truth in contemporary physics.

“[Beauty is] one of the signs of truth, but it’s not... it’s not infallible, and actually what Dirac would have found very ugly about modern physics is... so much arbitrariness.”¹¹

For everyone who cited Dirac here, there was someone who would counter-cite the American physicist, Richard Feynman.

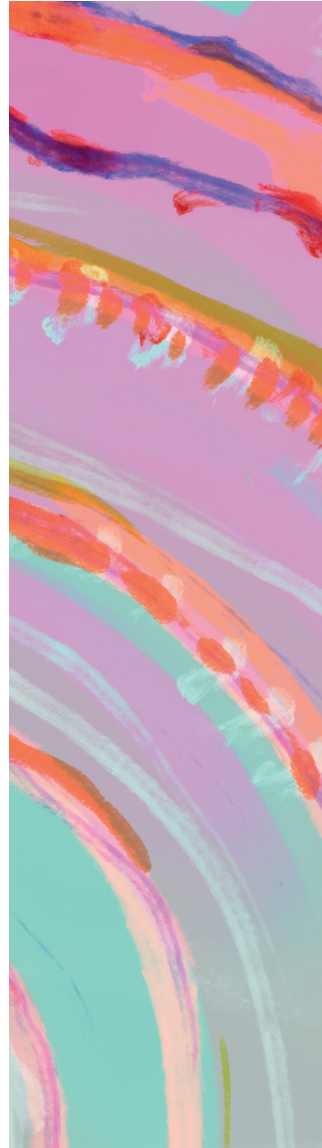
“It’s coming back to the Richard Feynman quote that, it doesn’t matter how beautiful your theory is, if the experiments say it’s wrong then it[’s wrong] – I can’t remember how it goes, but something like that.”¹²

Moreover, while many interviewees were happy entertaining the idea that there was some connection between beauty and truth in science, there were others who warned that it could sometimes be a source of bias.

“I think sometimes the idea of what a beautiful theory is can get a little bit in the way, but by and large, also sometimes beauty is pointing towards the most simplified answer and those are often the best, certainly the best starting points.”¹³

Alternatively, some claimed that there really was no meaningful connection at all.

“When you say that people say that beauty is a guide to scientific truth... [I] think that’s a load of tosh. And that seems to me to be based on a prejudice... I see no a priori reason to believe that at all.”¹⁴





While many interviewees were happy entertaining the idea that there was some connection between beauty and truth in science, there were others who warned that it could sometimes be a source of bias.

For all the vigour of this comment, it was far from unique. The quantitative research shows that when presented with the strong statement “Mathematical beauty is a good indicator of scientific truth”, 34% of scientists disagreed, compared with 27% who agreed. More powerfully still, when testing Dirac’s famous aphorism, “It is more important to have beauty in one’s equations than to have them fit experiment”, fully 70% of physicists disagreed compared with only 9% who agreed.

It was also in this discussion – about the “consequences” of encountering beauty in scientific work and, in particular, whether there was any perceived link with truth here – that an important difference between scientific disciplines emerged. In-depth interviewees mostly worked in biology and physics (both broadly conceived to include, for example, ecology, environmentalism, astronomy, etc), though some also had worked in other fields, like chemistry and mathematics. Across these different disciplines a subtly different approach to beauty, and to its connection with truth, emerged.

Put at its simplest (so to speak), interviewees commonly claimed that simplicity was a fundamental, guiding, heuristic principle within physics. The perceived connection of simplicity with beauty meant that the connection between beauty and truth usually felt tighter in physics.

“Because in physics this heuristic that beauty is a guide to truth is so deeply ingrained, that it’s actually something that people do without realizing that that’s what they’re doing... So, they’re looking for simplicity, for elegance, for beauty, and you could call it many different things. But they’re basically using beauty as a heuristic tool to distinguish between competing theories.”¹⁵

Arguably, this was even more the case with mathematics.¹⁶ Biology, by contrast, was naturally much “messier”, a word that was repeatedly used by interviewees. “In biology, things get very messy, and things get much less predictable.”¹⁷ This gap between simplicity and messiness was not unbridgeable, especially in light of the mathematisation of biology in the neo-Darwinian synthesis.

“I was chatting to a colleague about this who comes from a mathematics background... in her field she does a lot, you know, designing equations to model. And she’s a biologist now, she uses maths to model animal behaviour and stuff. And she was always talking about how actually that – you keep working on the equation until it gets to a really simplistic, beautiful kind of element.”¹⁸

That recognised, the idea of beauty had a less powerful hold, at least as a guide to truth, in biology than in physics, primarily because the concept of beauty in biology was less likely to be instinctively associated with simplicity. As one interviewee pointed out, this did not necessarily mean that the business of biology was itself any less beautiful or that

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Interviewees commonly claimed that simplicity was a fundamental, guiding, heuristic principle within physics.



beauty in biology was any less important. Rather, it simply meant that there were different ideas about what beauty was and, accordingly, what consequences encountering it had.

“I often wonder how things work in biology when people are trying ... it’s a bit messier. I think it’s no less beautiful but it seems to me like it must be a bit messier because I mean, how can you ever boil down a biological process to just one or two things?”¹⁹

In a similar vein, one interviewee who was capable of commenting (very knowledgeably) on chemistry made a related point. Chemists certainly did have a conception of beauty. However, it was less instinctively associated with simplicity than it was for physicists (about whom this interviewee could also speak with authority).

“If you talk to chemists, for example, I think when they talk about a beautiful molecule, or a beautiful reaction, there’s a kind of cleverness to it. It’s a kind of, ‘Ah-ha. Yeah. What a brilliant idea to make something like that, or to get those things to fit together like that.’”²⁰

If this suggests that the chemist’s conception of beauty is closer to the biologist’s than the physicist’s, on account of its appreciation of complexity and intricacy, the interviewee went on to underline a subtle difference with biology too. Chemists’ beauty, according to him, registered a kind of *human* cleverness too, not

dissimilar to the kind of beauty-as-accomplished-experiment that we mentioned earlier.

“There is much more of a craft element. There’s much more of the human element, I suppose, in it. There’s a pleasure in the fact that someone had a particular realization, and you can see the human imprint in what they’ve done.”²¹

He proceeded to give a specific example.

“Chemists... particularly have admiration for the work of people like Robert Woodward, Nobel Laureate, because he just had a fantastic way of figuring out a path, to get from one molecule to another... there was absolutely that human element of creativity and that response. So, I think that that is something... that is to my mind much closer to a classical aesthetic sense of beauty.”²²

What this detour into the differing conceptions of beauty in different scientific disciplines, and their perceived relationship with truth, suggests is that however widespread and significant beauty is within science, both the nature of beauty itself, and its implications for scientific activity are complex, and resist easy summary.

There is no denying the presence, ubiquity, and importance of (the idea of) beauty in science but – in line with the sense of subjectivity that the word had for many – there was no consensus over what significance beauty had for science. 66% of scientists supported the statement that “it is important for scientists to encounter beauty, awe, and wonder in their research”, but knowing precisely why was more elusive. To explore this further, we need to look carefully at what beauty actually means in this context.

- 1 P-SB-CK-15-UK++Edelweiss. In a similar vein: “I think most scientists, myself included, I mean, chose to do this work because we enjoy it, and part of that will be because we think that there’s something, yeah, I guess, beautiful about the scientific method and learning things and discovering things.” (P-SV-DJ-10-UK-17973++Katherine)
- 2 B-SV-AU-05-UK-12614++Holly
- 3 P-SV-ZT-02-UK-17775++Ruby
- 4 P-SB-NS-01-UK++Matthew. In a similar vein: “Science can become extremely dry if you lose the thing you started from. So the wonder, that the sense of beauty that dragged you into it.” (P-SB-CK-15-UK++Edelweiss) And “everyone understands that like huge fraction of our time we just do boring – not boring, but tedious work going through all this unrelated or strange, unexpected, unexplained things. And then later if, well, sometimes, not always, sometimes they kind of pieces fitting together, the puzzle is created, is taught and we see the pattern, and then the beauty appears.” (P-SV-AU-10-UK-13333++Dmytro)
- 5 B-SV-AU-12-UK-11851++Elena. In a similar vein: “I think that is really important for teaching, that when I’m allowed to teach about my things, which I found really beautiful, fascinating and my heart is with it, I give way better lectures.” (B-SV-AU-11-UK-12317++Stefan) Also: “the easiest way to teach children is to teach something beautiful, something unexpected.” (P-SV-AU-10-UK-13333++Dmytro)
- 6 P-SV-CK-01-UK-15737++Max
- 7 P-SV-CK-03-UK-17600++Galilea
- 8 B-SV-NS-22-UK-12297++James
- 9 P-SV-ZT-04-UK-16928++Oscar
- 10 B-SV-AU-06-UK-12596++Iliya. In a similar vein: “I would agree that a more beautiful theory or a more beautiful experiment is a better one, so I think it is important for like, it’s probably the one closer to the truth not necessarily is the truth yet.” (P-SV-CK-01-UK-15737++Max)
- 11 P-SB-NS-04-UK++Arthur
- 12 P-SV-ZJ-03-UK-17778++Sandra. The full quote appears to be “It doesn’t matter how beautiful your theory is, it doesn’t matter how smart you are. If it doesn’t agree with experiment, it’s wrong.” This, at least, is how it is repeated in numerous books and websites. However, I have been unable to track down its source.
- 13 P-SV-BR-10-UK-17984++Colleen

- 14 P-SV-NS-21-16506++Peter. In a similar, if less visceral, vein: "I'm not sure you can make beauty some very good indicator of whether something is correct or not." (P-SV-CK-13-UK-17352++Beverly)
- 15 P-SB-NS-09-UK++Alan. In a similar vein: "I have a slightly difficult relationship with the way beauty is talked about in science, and when you hear it invoked, it's most likely that it will be coming from physicists, even more actually, than you hear from mathematicians. Physicists love this notion of beauty. And many of the greats have said that, that Einstein said, 'We want our theories to be beautiful.' The German mathematician, he was really a mathematical physicist, Hermann Weyl, actually said on one occasion. I'm paraphrasing here, 'I've tried to find things that are both true and beautiful. But if I was forced to make a choice, I go for the beautiful,' which is a really interesting thing for a physicist or a mathematician to say." (N-SB-NS-05-UK++Peter)
- 16 "Because I've changed disciplines, because you start off with math and you have your idea of beauty and then you actually end up looking at like I say the world that's more messy and after you find something that's logical and that is underlying the whole mess, but you haven't done that as a student." (B-SV-AU-12-UK-11851++Elena)
- 17 N-SB-NS-05-UK++Peter
- 18 B-SV-AU-05-UK-12614++Holly
- 19 P-SV-AU-04-UK-15354++Sean
- 20 N-SB-NS-05-UK++Peter
- 21 N-SB-NS-05-UK++Peter
- 22 N-SB-NS-05-UK++Peter



3.

What *is* beauty
in science?

There is an immediate answer, or cluster of answers, to the question of what beauty is understood to be within science. It is clear and simple but arguably also partial and simplistic. It centres on the idea of simplicity itself.

Time and time again, we heard from interviewees that beauty could be characterised by simplicity.

“Usually the best design for an experiment is the simplest one” ... “Typically, more beautiful means simpler” ... “[It] is quite beautiful to take something that’s incredibly complicated, simplify it down so that we can actually understand the equations that are being solved” ... “For me [it’s] simplicity. Since I do a lot with genetics and sometimes you can... do very simple experiments that are very telling” ... “The math is simple, and elegant, and perfectly modifiable, and that’s beautiful”¹

One physicist gave a down-to-earth specific example of this.

“There are these mugs at CERN that have the Lagrangian of the Standard Model... The standard model is the model of elementary particles that describes and unifies all the electromagnetic strong nuclear, weak interaction... these variety of phenomena can be actually written in a single equation that can be written on a mug. For me it’s an image of beauty, of theoretical beauty because behind that there is everything you see in terms of elementary interactions.”²

Simplicity could be parsed in different ways. Simplicity meant parsimony.

“Very often beauty, it means a parsimonious theory. So, if you’ve got one theory that can tie a bunch of things together, that’s considered to be a beautiful theory.”³

It could mean symmetry.

“Things like symmetry, things like having complete numerical, mathematical, elegant mathematical models, that is beautiful.”⁴

It could, as the previous quotation indicates, mean elegance, a frequently deployed term often used a synonym for beauty-as-simplicity.

“When you have a really elegant experiment which just works and it produces the results, that’s pretty beautiful.”⁵

Beauty, therefore, meant simplicity and/or parsimony and/or symmetry and could, in this way, equally be captured by the term elegance.

This, as noted, was a common understanding of beauty but also, arguably a simplistic one. One interviewee, a physicist but who had an unusual professional expertise in a number of other areas, including philosophy, voiced this concern forcefully.

“What puzzles, sometimes frustrates me, is that it’s a very particular notion of beauty that [scientists] have, that doesn’t connect with the theories of aesthetics in art. That it’s a notion that beauty comes from simplicity, from symmetry, from perfection. A very ironically, very Platonic thing, whereas Plato himself was actually quite suspicious of aesthetics and beauty in art.”⁶

He went on to explain.

“You’re not meant to use that word [beauty] in art anymore. But certainly, when it has been used in the past, theories of aesthetics... haven’t really focused on this notion that the beautiful is the simple, in the symmetrical. In fact, sometimes it’s quite the opposite. Even Francis Bacon, the seventeenth century

philosopher, who is considered to have in some ways started the whole modern scientific project... said that... the things we find beautiful always have some strangeness in their proportion. There's always something slightly askew. And certainly, in cognitive terms, what we seem to respond to most strongly from an aesthetic sense, that we find most pleasing if you like - let's leave aside whether we find it most beautiful - are things that hit a sweet spot between simplicity and complexity.”⁷

This is an important point, which is why I have quoted it at length. It is easy to see how scientists' conception of beauty slides into simplicity in an unduly 'simplistic' way, as if beauty just meant something being uncomplicated.

To be fair, for a number of our interviewees it did mean just that. However, crucially, the manner in which many interviewees spoke of beauty gestured beyond the simplistic idea of beauty as simplicity, in the sense of something being plain, uncomplicated, or just easy to understand. Rather, beauty-as-simplicity (or symmetry, parsimony, etc.) was commonly a shorthand for simplicity *as a response to, and in the light of, the complexity (or apparent disorder or messiness) of nature*. Adapting the words from the philosopher-physicist just quoted, beauty was closer to being the “sweet spot” – or, better still, the *interaction* – between simplicity and complexity.

Beauty was discerned in the subtle interplay between simplicity and complexity (or, as we shall note below, order and disorder). This was hinted at by several of the other terms used by interviewees to explain what beauty actually meant.

“The more complicated it is, the better... the more beautiful it would be. It's kind of proportional to the difference between the complexity and simplicity, the more different they are, then the more beautiful it will be.”⁸



Several interviewees gave concrete examples of this, such as from biology.

“A lot of things in biology are interactions between things. It’s the science of interactions and how every single thing is a two-way street... When you realize that both things are benefiting or there’s some concert of interactions, when you realize that, it becomes so much more beautiful.”⁹

Or physics:

“You might know that the Mandelbrot set comes from an extremely simple equation, okay, $z = z+c$ and then basically fell back onto itself. As a physicist or a scientist, knowing that simple equation can manifest such complexity and beauty, it adds an additional layer to the beauty, it sort of like, amplifies it.”¹⁰

Or, to quote the title of a famous article by Eugene Wigner, in “the unreasonable effectiveness of mathematics in the natural sciences.”¹¹

“I was never disappointed because then I always found beauty in the simplicity of the mathematical equation that described complex phenomena.”¹²

One of the terms commonly used for this interplay between simplicity and complexity was “pattern”, which captured the idea that there was a ‘simple’ regularity discernible within a ‘complex’ wider picture.

“I encounter beauty in science when you’re at the point where you take the data and analyse it, and then you see the patterns coming.”¹³

The beauty of science rested in discerning the ordered connections and patterns within the rich, intricate, complex, and *apparently* disordered or even random natural world.

“So, this kind of beauty I’m talking about... the things start to have patterns, connections, relationship, principles, rules.”¹⁴

When science saw order amidst the messiness, and when that order was ‘simple’ in the senses we have been describing it here, then that was a source of beauty.

“Life is messy and so you get a lot less of it. But sometimes when you have this really elegant proof, and it all falls into place, and you get this formula and it’s like so perfect and so clean. If it’s a very elegant proof, every step is very clean, and it follows the rules of whatever the problem is.”¹⁵

“

Interviewees commonly claimed that simplicity was a fundamental, guiding, heuristic principle within physics.

3.1 Deep coherence

Examined more closely, this conception of beauty as the ‘simple’ pattern discerned from with the rich complexity of nature, actually had two linked but distinct elements within it. The first was the idea that the natural world into which scientists peered was itself inherently ordered, and that the patterns scientists discerned there *were there*, and were not just created or imposed by human observers. There were various ways of articulating this. Patterns emerging from apparent randomness was one.

“You see the patterns coming out and the beauty of it is in the apparent randomness that is only apparent randomness. It’s not random at all. Yeah, something is going on behind that you can then uncover and learn about that. That is where I see the beauty.”¹⁶

A second way was through the idea of coherence.

“There’s the beauty in the explanation that it fits together... it fits together, and it has some logical sort of motivation.”¹⁷

A third was self-consistency.

“To me, if something is really chaotic and all over the place or if it’s really neat and beautiful, neither of those make it more likely to be true. What I do think is it ultimately something has to be self-consistent, quite clearly. And so maybe people argue that that naturally implies a beauty because everything ends up adding it all together. You know, you can go in a circle and get back to where you started, kind of thing.”¹⁸

Things just clicked into place:

“There’s some kind of appreciation of how the universe can do that, that it clicks in such a way.”¹⁹

The metaphor of the jigsaw was the obvious one.

“It all fits together. It’s like a jigsaw that just suddenly you turn it one way and it just – and you’re like, oh, and from that point of view, yes, it’s beautiful.”²⁰



There’s a structure out there somewhere that means it must be true, but at the same time it’s completely inexplicable as well.

It is worth noting that this coherence sometimes catalysed further questions that took interviewees beyond the purview of science. Indeed, arguably it opened up more questions than it answered, leaving some at least with

a frustrating sense of *inexplicability* or (ironically, as we shall see) incomprehension.

“So maybe more so than symmetry, there’s a structure out there somewhere that means it must be true, but at the same time it’s completely inexplicable as well. Like nobody can have an intuition for why it’s right, it’s just must be so.”²¹

This could be a dissatisfying place to end, but that did not affect the basic observation about beauty as deep coherence – science’s ability to discern ‘simple’, ‘symmetrical’, ‘parsimonious’ patterns and order within complex, apparently random natural world, which pointed towards an underlying unity, consistency, and rationality within what they were studying.

“When I see a theory or model as elegant, I think of that as slightly analytic, it’s neat, it’s compact, it does the job in a way that you can understand and that you just see the way everything falls together with it.”²²

3.2 Deep comprehension

The second ‘linked but distinct’ dimension to this idea of beauty within the interplay of simplicity and complexity is hinted at in this previous quotation (“in a way that you can understand”). It was the idea – astonishing to many interviewees – that the human mind was capable of discerning and grasping this deep coherence. It was, in effect, the idea of beauty as *comprehension*, or alternatively of beauty as *intelligibility*.

This was part of the experience of science, one of the things that started some interviewees on their scientific career, or that helped others to keep going with it.



There are beautiful relationships between mind and mathematical theory.

“For me, the beauty is that when I look at something very – basically, something that doesn’t make sense, completely unpredictable and I don’t understand how it works, and then I start seeing laws or principles or some rules how this works, and then suddenly all this chaotic picture, which is just, was a complete

mess, it started to have a meaning or some message, so that I find quite beautiful.”²³

This sense of meaning emerging from mess was more than just a powerful source of motivation. Repeatedly, powerfully, interviewees testified to the sense of astonishment that this deep comprehension gave them.

“I think there are beautiful relationships between mind and mathematical theory.”²⁴

“How come certain, some equations that we have, that we were given to think of, because we didn’t even decide to be born with the category of geometry, beauty, symmetry that led us into knowing something that is actually real?”²⁵



This apparent consonance between the material world, the underlying laws of mathematics and the capacity of the human mind was judged beautiful.

Put another way, the fact that science worked, and there was this apparent consonance between the material world, the underlying laws of mathematics, and the capacity of the human mind was judged beautiful.

“It’s the beauty of using the rules of math and problem solving for this particular problem and getting something that behaves

in a way that's very clean and compact and describes the process in a very meaningful way."²⁶

Some, more philosophically inclined interviewees, recognised that deep comprehension, like deep coherence, was a *precondition* for science.

*"In the past, including the twentieth century... it's been a motivation for scientists and natural philosophers, really to have confidence in an intelligible universe. Which in a way, you have to have, in order to do science at all."*²⁷

This did not make it less astonishing, however. Indeed, as with the 'problem' of deep coherence, it made the issue more perplexing.

*"When you can boil things down to a really quite simple equation to describe more than you can comprehend. It blows my mind. I don't really understand how it works or why it works, it just does."*²⁸

In this way, therefore, the perceived beauty of deep comprehension provoked the same challenge as that of deep coherence. Why the natural world under scientific investigation should prove so amenable to the human mind – which, some interviewees pointed out, was itself 'merely' a material, natural, evolved organ selected for survival and reproduction – was a mystery.

In a sense, this discourse was simply a riff on a famous aphorism of Einstein (which was not,



in fact, referenced by a single interviewee). This is popularly quoted as the idea that “the most incomprehensible thing about the universe is that it is comprehensible,” although the true quotation from an article Einstein wrote in 1936 is even more ‘mystical’ in its language.

“The very fact that the totality of our sense experiences is such that by means of thinking...it can be put in order, this fact is one which leaves us in awe, but which we shall never understand. One may say ‘the eternal mystery of the world is its comprehensibility’... It is in this sense that the world of our sense experiences is comprehensible. The fact that it is comprehensible is a miracle.”²⁹

Einstein famously had a propensity towards mystical language in his public pronouncements on science, a language that he also poo-pooed at other times. In this instance, given

the popular understanding of the word ‘miracle’, the use of that word here is unhelpful.



The world of our sense experiences is comprehensible. The fact that it is comprehensible is a miracle.

Nevertheless, the precise terms – which, as we have seen from this research are rarely precise – matter less than the underlying reality to which they give voice. This is that the pervasive sense of beauty, sensed by scientists, springs from their

discerning pleasingly simply and parsimonious patterns from within the rich, complex objects of study, and which points them toward an underlying coherence and intelligibility in the universe.

3.3 Measuring ideas of beauty

How prevalent and how powerful were these deep ideas of beauty? The quantitative element of the research did not permit the same level of probing or granularity as did in-depth interviews, but it did offer some opportunity to measure how widespread certain general conceptions of beauty are.

Perhaps the first thing to reiterate before examining the quantitative data, is that no matter how many interviewees experienced and explained the idea of beauty, for *some* the whole territory was altogether closed, indeed non-existent. We have already noted how some interviewees dismissed the idea of beauty in science altogether as too vague or subjective or as fundamentally irrelevant, and it is important not to lose sight altogether of their views, minority ones as they may have been.

Having recognised this, it is also worth noting that there were measurable differences in opinion here between physicists and biologists. Physicists were more likely to admit to a sense of beauty in their work, but that is simply at a generic level. When asked what characterised their understanding of beauty in their work, biologists were rather more likely to say it was “pleasing colours of shapes” or “complexity” than were physicists (40% vs 21% for pleasing colours of shapes, 54 vs 37% for complexity). Conversely, physicists were more like than biologists to cite “simplicity” (68 vs. 43%) and vastly more likely to cite “symmetry” (61 vs. 29%). These data support the claim made by Ben MacArthur on respective understandings of truth and beauty in physics and biology.³⁰ (See Table 4)

Table 4: Dimensions of beauty, by scientific discipline (1): where physicists and biologists differ

“Which of the following would you ascribe with “beauty” in your scientific work?”	Physics %	Biology %
Pleasing colours of shapes	21	40
Complexity	37	54
Symmetry	61	29
Simplicity	68	43

Source: Vaidyanathan, B. & Jacobi, C. J. (2022, June 19). *Repository of the Work and Well-Being in Science Study*. Retrieved from <https://osf.io/jp86u/>

Intuitively this all makes sense, biologists attracted by and attuned to the complexity aspect of beauty, physicists to the simplicity and, in particular, the symmetry aspect. It further underlines, however, the idea that beauty cannot justifiably be reduced to a single thing or quality, but is wide-ranging, subjectively understood and, if it resides in anything, does so in the interplay between different qualities.

That did not mean that physicists and biologists did not necessarily agree on the different aspects of dimensions of beauty. Indeed, they showed broad agreement as often as they did disagreement. In particular, there were three dimensions that were judged as a characteristic of beauty by more than half of physicists *and* biologists. (See Table 5)

Table 5: Dimensions of beauty, by scientific discipline (2): where physicists and biologists agree

“Which of the following would you ascribe with “beauty” in your scientific work?”	Physics %	Biology %
Asymmetry	16	14
Harmony	36	33
Sense of fit	36	33
Hidden order or patterns	63	57
Inner logic of systems	62	58
Elegance	65	54

Source: Vaidyanathan, B. & Jacobi, C. J. (2022, June 19). *Repository of the Work and Well-Being in Science Study*. Retrieved from <https://osf.io/jp86u/>

As we have seen, elegance is sometimes used as a synonym for beauty, so the frequency of its detection here should surprise us less. But the others – in particular the “hidden order or patterns” and the “inner logic of systems” – are highly resonant with the idea of deep coherence discussed above.

- 1 P-SV-CK-01-UK-15737++Max; P-SB-NS-09-UK++Alan; P-SV-CK-05-UK-14961++Bob; B-SV-AU-11-UK-12317++Stefan; P-SV-AU-02-UK-18221++Jim
- 2 P-SB-CK-15-UK++Edelweiss
- 3 P-SB-NS-09-UK++Alan. In a similar vein: “this kind of beauty to explain certain phenomenon with as few premises as we can.” (P-SV-NS-20-14727++Patrick)
- 4 P-SV-AU-01-UK-15499++Jade. In a similar vein: “There’s so much symmetry in it all. I would say that there’s beauty abound in all of it.” (P-SV-AU-04-UK-15354++Sean)
- 5 B-SB-NS-12-UK++Ben
- 6 N-SB-NS-05-UK++Peter
- 7 N-SB-NS-05-UK++Peter
- 8 P-SV-CK-01-UK-15737++Max; emphases added. In a similar vein: “to me there’s a beauty in the simplicity, but also the complexity of that.” (B-SV-AU-13-UK-12577++Laura). And: “a lot of science is trying to reduce complex real phenomena to these simple or numerical mathematical models, that is kind of trying to understand reality through a lens of beauty and simplicity.” (P-SV-AU-01-UK-15499++Jade)
- 9 B-SV-AU-06-UK-12596++Iliya
- 10 P-SV-CK-09-UK-18114++Duncan
- 11 Eugene Wigner, ‘The unreasonable effectiveness of mathematics in the natural sciences’, *Communications in Pure and Applied Mathematics* 13:1-14 (1960)
- 12 P-SB-CK-15-UK++Edelweiss
- 13 B-SV-AU-06-UK-12596++Iliya
- 14 P-SV-AU-10-UK-13333++Dmytro
- 15 B-SV-AU-12-UK-11851++Elena
- 16 B-SV-AU-06-UK-12596++Iliya. In a similar vein: “There are some examples when sometimes experiments are actually beautiful or this phenomenon in real life are beautiful and that’s when, for me, when we talk about this chain of random events and then somehow we can say that those events were not completely random, but somehow linked, and then that’s kind of surprising, unexpected link.” (P-SV-AU-10-UK-13333++Dmytro)
- 17 P-SV-CK-13-UK-17352++Beverly
- 18 P-SV-NS-21-16506++Peter. Interestingly, this interviewee went on to immediately say that “But that’s a bit of a subjective phrase”

- 19 P-L-BR-01-UK++Kendra. In a similar vein: "Just seeing how things come together is very beautiful as well, I think. People come from an idea or an observation of something and the first image is pretty raw, but then they combine it with a bunch of other information they have about an object and they bring all these different things together and then they come up with something, like some kind of cool scientific theory or explanation or results and things that all individually just don't look that exciting." (P-SV-BR-10-UK-17984++Colleen)
- 20 P-L-BR-02-UK++Mary
- 21 AU-04-UK-15354++Sean
- 22 P-SV-NS-21-16506++Peter
- 23 P-SV-AU-10-UK-13333++Dmytro
- 24 P-SB-NS-01-UK++Matthew
- 25 P-SB-CK-15-UK++Edelweiss
- 26 B-SV-AU-12-UK-11851++Elena
- 27 N-SB-NS-05-UK++Peter
- 28 P-SV-AU-09-UK-15477++Ben
- 29 Albert Einstein, 'Physics and Reality', in *Out of My Later Years* (Philosophical Library of New York, 1950), p. 61
- 30 Ben MacArthur, 'Truth and beauty in physics and biology', *Nature Physics*, Vol. 17, February 2021, pp. 149-151; <https://t.co/Nk7m4Xzmid>

The background is an abstract, vibrant painting with thick, expressive brushstrokes in shades of teal, purple, orange, and blue, creating a sense of movement and depth. A large, light orange shape is visible in the top-left corner. A solid red rectangular box is centered on the page, containing white text.

**Conclusion:
Beauty is truth?**

It is very easy to overlay the connection of beauty and truth in science. With all due respect to John Keats, the idea that beauty is truth and that is all you need to know doesn't work when doing science, notwithstanding some extravagant claims about beauty made by some physicists. Time and time again, interviewees – even those that were generally positive about the significance of beauty – were wary about taking the equation too far, and a good number insisted that being a scientist meant precisely being willing to hear and heed information that could disturb a settled, 'beautiful' picture of reality.

“The world is beautiful by itself, so we will find beauty there. But also again, it's not a dogma, we must be prepared that the world may be ugly... that's a quite an important point. I think scientists should really be open-minded and be ready to adjust their views if new experimental data, new observations appear, and sometimes it means to really throw away very beautiful concepts or theories or experiments... I think that's a much more important skill... it's very important for scientists, for science in general.”¹

“We must be prepared that the world may be ugly” should be carved into any discussion of beauty, truth, and science.

Having acknowledged that, it is equally important to emphasise that beauty does play a real and significant role in science, at almost every level. For many, it is a reason to start doing science in the first place and for some it is a reason to continue when things are tough. It plays a role in

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“We must be prepared that the world may be ugly” should be carved into any discussion of beauty, truth, and science.

science communication and science teaching. It plays a role in the design and practice of science. Alas, it rarely plays a role in the buildings in which much science takes place.

Above all, beauty plays a role in understanding, in the connection between the human mind and the world that it is investigating. The fact there is a connection often strikes scientists as remarkable itself, as does the fact that science reveals a deep coherence within nature that matches this comprehension. The fact that that connection, coherence, and comprehension often reveals itself in simple, elegant, parsimonious – ‘beautiful’ – form is all the more striking.

All this naturally leads some towards metaphysical conclusions that point towards an ultimate confluence of order, truth, and beauty, fathomable (in principle at least) by the human mind. It is a conclusion that resonates with Christian metaphysics. The order of creation reflects something of the truth, beauty, and goodness of God – as the prophet Jeremiah says, “God made the earth by his power; he founded the world by his wisdom and stretched out the heavens by his understanding” – and human beings, made in his image, are capable of grasping that order.

There is certainly a powerful case to be made here but (as with so many conversations about beauty and science) it may be risky to take it too far. One of the (most theologically literate) scientists we interviewed made this point this way.

“You want to go to theology because, is God beautiful? Apparently, yes, he’s supposed to be, and God’s creations can often be beautiful. But, there’s a famous phrase [in the Old Testament book of] Isaiah, ‘No looks to attract our eyes.’ Wow! Yes, that man carrying his cross, beaten, spat upon, wearing a crown of thorns, and that’s not very beautiful, is it? So sometimes

[that] which is really good, what is infinitely good, cannot be attractive at all.”²

This is a profound and important point, which touches on one of the themes cited earlier in this essay, namely that beauty is subjective and is vulnerable to immediate cultural pressures and interpretations. We should be wary of drawing too straight a line from beauty perceived in science to a final, perfect beauty of any metaphysical order.

However far you do take the philosophical conclusion here, what is undeniable is that beauty does have a real, important, and arguably truth-bearing role in the practice of science. Indeed, at times, at its most significant it can have an almost life-giving or revelatory aspect to it.

“As I said, there’s all of the beauty in the whole universe in there if you can find it, and I feel having a pursuit like that in life means that I feel like it fulfills me.”³

“Beauty is truth”

1 P-SV-AU-10-UK-13333++Dmytro

2 P-SB-NS-04-UK++Arthur

3 P-SV-AU-04-UK-15354++Sean



The background features a vibrant, abstract composition of thick, expressive brushstrokes in shades of orange, blue, and light green. A prominent red rectangular box is centered in the upper half of the image, containing the title text in white. The overall style is modern and artistic, suggesting a dynamic and data-driven theme.

Appendix: Background to Quantitative survey

“Beauty is truth”

	UK (N=925)	Italy (N=637)	US (N=535)	India (N=1,345)
Gender	%	%	%	%
Women (%)	30	41	30	39
Discipline	%	%	%	%
Physics	63	46	48	47
Biology	32	44	39	47
Other	5	11	14	7
Position/status	%	%	%	%
Postgraduate student	32	21	28	37
Postdoc	21	20	14	6
Research Scientist	9	n/a	2	19
Junior Faculty	8	16	12	14
Mid-level Faculty	12	29	10	11
Senior Faculty	18	14	34	13

Note: Table displays raw/unweighted proportions. Statistics used in the report have been survey-weighted.



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“Beauty is truth”

“It is more important to have beauty in one’s equations than to have them fit experiment,” the British physicist Paul Dirac once provocatively remarked.

Was he right? What role does beauty play in science? How important is it, and to what ends? And what, if anything, are we to conclude from the relationship between the two?

Drawing on a pioneering cross-national research project, *Work and Well-being in Science*, “*Beauty is truth*” lays out a clear, empirically-grounded, and theoretically-informed exploration of the true relationship between science, beauty and truth.

“[This report] demonstrates how scientists perceive beauty as both a motivation and a source of bias. It shows that aesthetic experiences associated with coherence and comprehension are at the heart of scientific work for most scientists – and yet, makes clear why a facile equation of beauty with truth will not do. And finally, [it] raises important questions about the relationship between science and theology that flow from our findings. Dr. Spencer’s report does an exceptional job summarizing both the highlights and nuances in the results of our pioneering study of beauty in science.”

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