2. What is Science?

Sections 2.1 - 2.5

Brian Abbott

2.1 Introduction

Humans are innately curious, so it seems natural to pursue knowledge that improves our daily existence and advances the species. Each breakthrough, on balance, serves to improve subsequent generations' lives and livelihoods. The result is a more stable, democratic society that yields dividends from the competition, cooperation, and achievements that are rooted in the scientific process.

The scientific process is often misunderstood by the layperson and misrepresented in the media. Science cannot often be distilled down to sound bites that media voraciously consume. The process is far subtler, and the cost of concealing the evolution of ideas and the thought processes of scientists is a general lack of scientific literacy. This results in statements like, "It's only a theory," downplaying the strongest expression of reality that we have.

A fundamental tenet of science is that facts and truth do not exist. Scientists look at evidence, perform experiments, and analyze data to understand how the universe works. In the purest sense, we cannot definitively "close the book" on anything and say it is a known fact. All we can do is find an equation that works and continue to test it under varying conditions.

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The classic example of this is the theory of gravitation. Since antiquity, philosophers like Aristotle, the scientists of their time, conjectured that motion did not occur without cause. Centuries passed, when, in 1687, Isaac Newton brilliantly quantified this notion in an equation. Subsequent tests of this theory supported Newton's hypotheses, the most profound of which was the deduction of the existence of a planet beyond Uranus (based on the fact that Uranus's motion did not agree with Newton's theory). In 1846, scientists used Uranus's anomalous motion and Newton's theory to accurately predict where the planet causing this motion should be, and subsequently discovered Neptune a month later to great accolade.

However, over time, discrepancies began to appear, including the unexplained drag on Mercury's orbital motion. By the Twentieth Century, it was evident that the theory needed more work. The general theory of relativity, developed by Einstein and published in 1915, was the remedy. General relativity describes the warping of space and time due to gravity, and this small effect was the necessary addition that shored up Newton's theory of gravity. Is today's theory of gravity in its final form? Do we now know everything about gravity? For scientists, it's not possible to say. The theory will continue to be tested and if discrepancies emerge, they will be investigated.

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2.2 The Scientific Method

This, in a nutshell, tells the never-ending story of science. But let's examine each step with more precision. Scientists have many tools at their disposal to investigate the world. They rely on experimentation and their own intellectual set of tools to investigate the unfamiliar. The fate of the scientist is to exist in a continual state of ignorance—their work lies just beyond the forefront of knowledge. A scientist must be comfortable steeped in the unknown, where creativity, confidence, and resolve decode problems and move the intellectual vanguard forward.

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Data are collected via experiment, then analyzed for trends and consistency. Astrophysics, my field, is predominantly divided into two categories: observational (or, experimental) and theoretical. The observational astronomer gathers data from telescopes, be they on the ground or in space, and returns with data perhaps in the form of an image, a measure of brightness, or a spectrum of an object. After analyzing these data, conclusions may be drawn, and the project is written up for publication.

The theoretical astrophysicist writes computer codes to explain the universe using only the laws of physics. The job of the theoretician is to reproduce what one observes in nature. If the output of one's code matches what we observe, then there's a good chance that code reflects what's actually happening. The theoretician relies on the language of science—mathematics—to explain phenomena. This is not so dissimilar from medical, biological, or any other form of research, that also have experimental and theoretical undertakings.

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2.3 The Peer Review Process

Peer review starts in the proposal process, where scientists compete for particular grants in their field. Each grant will have a committee of scientists in the related subfield who review proposals and choose those they deem most likely to succeed. Through this process, proposals with unfounded or specious reasoning, it is assumed, are culled and will be declined. This initial "weeding out" establishes a level of competency among those projects that are funded.

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Peer review enters into the process again at the end of the project. Upon submission to a scientific journal, each paper will be assigned to another scientist in the field who may choose to remain anonymous and shall review the work and judge it for competence, worthiness, and its scientific rigor. This is the final opportunity to judge the work before it is added to the annals, and to confirm that it will indeed further our understanding of the world.

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If others cannot reproduce the work, it will be called into question and discussion will ensue. These discussions can take place face-to-face, or in the journals themselves, where papers may appear countering its results.

2.4 The Myth of Scientific Objectivity

These discussions are not always free of bias, including bias for one's own work, or even politically motivated bias. However, it is the duty of the scientist to be hyper-aware of these biases and to doggedly question them. Of course, it is impossible to completely remove bias, but it is possible to operate ethically in the process. As it is in life, part of understanding a colleague's motivation is to understand their potential biases. Scientists often develop emotional attachments to their work—it can be difficult to abandon an idea. Regardless of bias, the strongest intellectual argument, based on accepted scientific hypotheses, will always prevail, but the road to that conclusion may be fraught with scholarly cul-de-sacs.

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All of these biases and beliefs play into the process of weighing data, a critical aspect of science. Placing weight on a result is the process of assigning a probability to an outcome. Everything in the universe can be expressed in probabilities. While extremely unlikely, it is plausible for all the air molecules to move to one side of a room; however, one would not place too much weight on that outcome. The weight we apply to a scientific notion is proportional to the strength of the foundation that the notion rests upon. While it is judicious to question everything, scientists push forward based on established scientific theories. Those established theories resemble the closest thing we have to fact and are used to build new theories.

Because the forefront of science is rarely encountered in court, much of the science mentioned there shall be considered established, and therefore carries significant weight. These encounters often flow through experts, who attest to scientific relevance and authenticity. Expertise, however, hinges on one's involvement in science and unbiased interest. Involvement begins with the proper training, but, more importantly, it is maintained by remaining active in science and publishing peer-reviewed papers. Terminating one's involvement after training diminishes one's expertise. If someone receives a doctorate and subsequently works out of their field, their knowledge will wither, and their expertise will erode over the years. The highest form of expertise is achieved when one remains immersed in their field and continues to publish in peer-reviewed journals.

The evolution of ideas alludes to the balance of cooperation and competition within the scientific community. Cooperation is essential now more than at any time in history, with dozen-, hundred- or even thousand-member collaborations appearing as authors on one paper. However, competition drives innovation. Intellectual competition inspires one to be the first to discover something new. When balanced, cooperation and competition ensure the steady flow of ideas and a healthy rate of growth, pushing the frontier of understanding perpetually further.

2.5 Science is Acquiring Knowledge

Science is the process of acquiring knowledge. Using empirical methods, with a healthy dose of skepticism, leads to the formulation of hypotheses and their refinement via experimental testing. Cogent hypotheses will yield predictions that may be tested, altered, or expanded, thereby strengthening their validity. With an abundance of experimental support, a hypothesis may become a general theory—a much stronger statement of reality. While our current theories may not be perfect, they are the strongest statements we have for expressing how the universe works.

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Science's self-regulated nature ensures that ideas maintain a standard which rest upon the foundation of thought and theory that precede them. This constant evolution enables scientists to credibly weigh evidence and assign probabilities to particular scenarios in the real world. Peer review helps reduce potential biases, and promotes a self-corrective process, where rejection of ideas also contributes toward understanding. Those who remain active in science and publish in peer-reviewed journals, will inherently be experts in their field of study.

Fact and truth are words that we conveniently apply to our notions of how the universe operates. We use these words because we place our faith in science and its ability to describe and predict the physical world accurately. What we forget is that we live in a world that cares not for our theorems, and, at times, reminds us just how ignorant we remain.