On truth and objectivity

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1. Introduction: What is truth in science?

In my opinion there is absolute truth to physical phenomena and the physical universe. Then, separate from this, there are mathematical, physical, chemical, etc. models designed to represent such truth. That is what science deals with. Whatever the model, the model is not the truth. It is only a mathematical/scientific explanation or description of the truth. So these models have an inbuilt degree of uncertainty, and we mustn't confuse the truth of the nature of the actual phenomenon with the validity or viability of the model.

For our purposes,

1) there is an absolute truth about the essential nature of a physical phenomenon. Such truth is permanent. Here we can say that truth is unrestricted in the sense that there is an essential nature to the phenomenon, and that this truth applies at all times in all places under all conditions;
2) mathematical models or theories are simply conjectures about the physical phenomenon. Science seeks, via mathematics, models, theories, etc., to explain the phenomenon as best as possible with the aim of improving, over time, the understanding, description and explanation towards the actual truth of the phenomena. In this case we can say that truth is restricted or contingent in the sense that the mathematical model or theory is true only under certain assumptions or conditions or time frames.

Furthermore, there is truth and there is falsehood. There is no such thing as relative truth. Instead, there is viability or validity to a given degree. Opinions, ideas, processes, scientific theories, mathematical conjectures, etc., are viable, or valid to a certain degree. In this respect we can say that a viable/valid theory is a theory which represents *to a certain degree of correctness or accuracy* the nature of a particular physical phenomenon.

So we can say that

a model which represents the truth = a model/theory which is valid or viable + uncertainty.

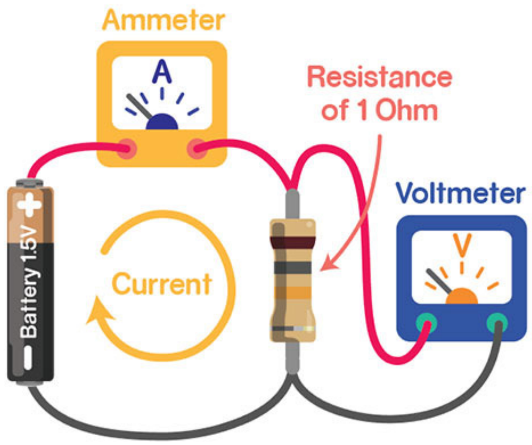
If there was no uncertainty (or error) then the model would be a perfect representation of the truth of the phenomenon. This model would apply in all circumstance at all times. So we can say that such truth is unrestricted truth.

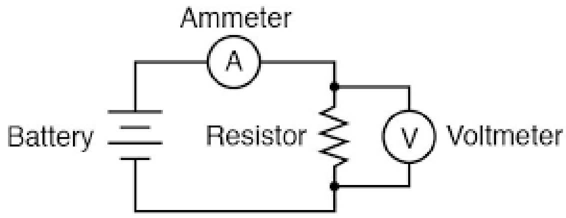
2. Truth in the physical sciences

2.1. Examples of true things in science

The following are examples of restricted or unrestricted truths:

1) the phenomenon of gravity is an unrestricted truth since this applies all over the Earth, at all times, in all conditions. It also applies to all planets, stars, galaxies and the universe as a whole;
2) the phenomenon of aerodynamics is an unrestricted truth since this always works at all times and in all circumstances to lift things off the ground. Aerodynamics is a law of nature which allows us to fly. This assumes the planet has an atmosphere. Mars has an atmosphere so flight is possible, but its atmosphere is much thinner than that of the Earth. This means we would need a greater ground speed to take off and fly;
3) the phenomenon of buoyancy which keeps things afloat is an unrestricted since this works at all times for all liquids. Buoyancy could be considered a form of aerodynamics for water (of other liquid) since it allows lift for heavier-than-water objects;
4) the existence of subatomic particles is a Truth since they exist in all circumstances and at all times since they were first formed at the start of the universe,
5) Ohm's law ($V = IR$): This is a basic law of electric circuits which says that if you have a resistance in a circuit (which all circuits do) then the greater the resistance to electric charge (i.e. electricity) for a given current, the greater the voltage across the resistor. Another way of saying this is that an increase in resistance will cause a decrease in current if we want to keep the voltage across the resistor constant.





Ohm's law is not an unrestricted truth since it does not apply at very low temperatures. It is therefore a restricted truth since it accurately describes the conductivity of the vast majority of electrically conductive materials over many orders of magnitude of current. However, some materials do not obey Ohm's law such as diodes and batteries.

However, Ohm's law has been observed on a wide range of length scales. In the early 20th century, it was thought that Ohm's law would fail at the atomic scale, but experiments have not borne out this expectation. As of 2012, researchers have demonstrated that Ohm's law works for silicon wires as small as four atoms wide and one atom high.

So Ohm's law can be said to be a restricted truth.

6) "Water expands when heated". This is a restricted truth. It is now known that water contracts when heated between 0C and 4C. That is why ice floats on water. That is why we have icebergs on Earth. But it is true that, outside this temperature range, water expands when heated.

7) "The electrical conductivity of metals decreases with decreasing temperature". This is a restricted truth since we have discovered the phenomenon of superconductivity. This means that at ultra-low temperatures certain metals become highly conductive rather than resistive. But it is true that, in certain temperature ranges, the electrical conductivity of metals decreases with decreasing temperature.

2.2. More examples of true things in science

All physical theories in the history of science could be considered valid/viable theories (to a greater or lesser extent) given the state of science and technology at the time. For example,

1) *The truth about planetary motion*

   a) Ptolemy's geocentric model of the planetary systems, namely that everything revolved around the Earth in a circular path, was certainly a viable and rational theory of how the planets, sun and stars moved in the sky.

   b) Then, as a result of further observation and data about the motion of planets, anomalies arose in Ptolemy's model to the point where Copernicus came up with another model (the sun-centred model) which better explained the motion of planetary objects. This was a much more viable model of planetary motion.

   c) Then Kepler came along to describe such motion even more accurately by saying that the motion was not circular but was in fact elliptical.

   d) But the Truth is, and always was, that the Earth and planets revolve around the Sun, and do so according to an elliptical path.

2) *The truth about gravity*

   a) Newton's theory of gravity (developed in the late 1600s) was based on his concept of force. This was an ill-defined concept usually described as "action at a distance". But there was no explanation as to how such action could be performed at a distance, let alone the large distance between planets.

   b) Then came Einstein's theory of relativity (1915). This too was a theory of gravity, but its theoretical conception of gravity was very different to that of Newton's. The idea of gravity changed from an invisible force acting at a distance in some unknown way to the geometric curvature of spacetime.

   c) But the truth is that physical phenomenon of gravity has always remained the same. The essential nature of the phenomenon of gravity is now what it was then.

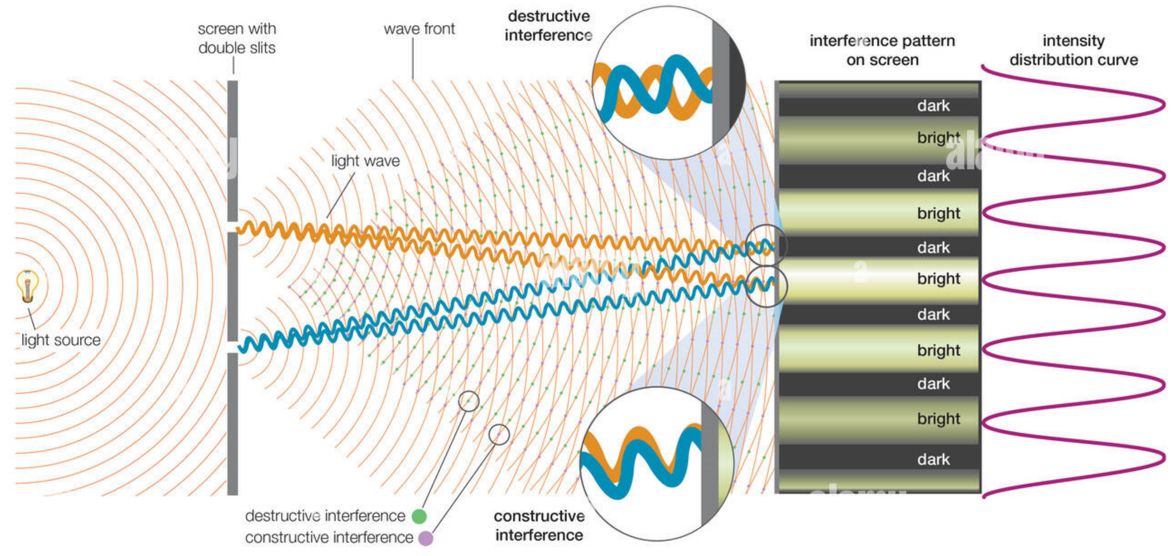
   d) It is also true that gravity has always existed (things have always remained on Earth instead of flying off into space), and will always work without fail to allow us to keep our feet on the ground. In fact, the physical phenomena of gravity is an absolute truth at all places and at all times (planets have always revolved around the sun; the solar system has always revolved around the centre of the galaxy, etc.).

e) What is not absolute truth are the mathematical models which describe gravity. These are mathematical representations of the physical phenomenon of gravity, and such representations/models can improve over time as our understanding of the world and mathematics improves.

3) *The truth of light as both particle and wave phenomenon*

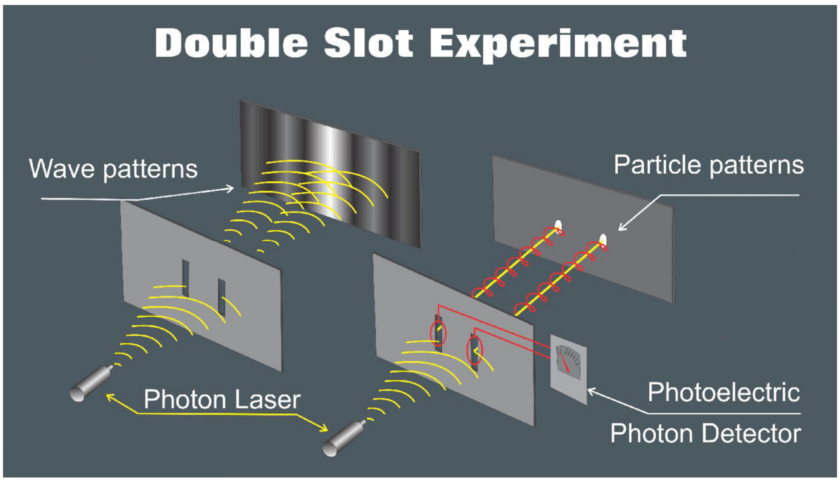
a) The history of the nature of light can be traced back at least Democritus (5th century BC). However, we will start with Isaac Newton (1642 - 1726/27) who, in his studies of the reflection and refraction of light, found that light travelled in a straight line. This could only happen if light was made of discrete particles (not waves, since waves move up and down, not in straight lines).

b) On the other hand, when light moves from a substance with a low refractive index to a higher refractive index (such as from air into glass) it slows down, and when light moves from a substance with a high refractive index to a low refractive index (such as from water into air) it speeds up. So, on the other side of the fence were people such as Robert Hooke and Christiaan Huygens, and later Augustin-Jean Fresnel, who were able to explain refraction as affecting the speed of light only if light travelled as a wave. Then in 1801 Thomas Young (1773 – 10 May 1829) performed his double-slit experiment which showed that light behaved like a wave. The diagram below shows a representation of this experiment and its result (from www.alamy.com).



c) Later Max Planck, in 1901, and Albert Einstein, in 1905, were respectively able to experimentally and mathematically show that light behaved in a particle fashion. Einstein's theory of the particle nature of light was then shown experimentally in 1915 by Robert Millikan (1868 - 1953). Further experiments and mathematical analysis showed the light behaved both in a particle fashion and in a wave manner. (see [Wave–particle duality - Wikipedia] for some animations illustrating the wave-particle duality of light).

d) So by the sheer weight of evidence, the fact that every single (ever improved) experiment (with ever better and more accurate equipment) has confirmed that light can exists both as wave and as particle, without any evidence against this, means that this phenomenon is an absolute truth of physical reality. How can it not be? How can we have a 100% consistent record of confirming this experimentally and it still not be an absolute truth?



On the other hand, the mathematical description/model of the wave-particle duality may be open to improvement. *Remember that the model is not the phenomenon.* Whatever the absolute truth of physical phenomena, the mathematical description are only models which are open to improvement. So the models themselves are not the truths, but the phenomena are the truths.

2.3. Do other forms of truth exists

No. If something is true, it is absolutely true. There is no such thing as pragmatic truth or truth based on consensus (as may have been presented in one of your previous C1 or C2 lessons). To me, this is a distortion of the meaning of the word "Truth". Thousands of years ago people used to think that the Earth was flat. They believed this to be true. So this could be said to be a pragmatic or consensus based truth. But the fact is they were wrong. So we can't call this a truth. All we can say is that they *believed* the Earth was flat based on the available evidence.

We therefore have to be careful about how we use the word "true/truth" and the context in which we use it. Is it used in the context of normal everyday language and conversation (in which case the person using this word is not normally using it scientifically) or is it used in a scientific context?

Another example: The case that there are now only 8 planets in the solar system does not count as a truth. Certainly we speak in the manner of, "It is true that there are only 8 planets in the solar system", but the way in which the word "true" is used here is not the same as the way in which I have been describing it, or the way in which I believe it should be used in science. The normal conversational meaning of the word "true/truth" is much looser and vaguer than the way it needs to be used in science.

In terms of the number of planets in the solar system, up until August 2006 it was said that there were 9 planets. I had grown up for 40 years being told by the astronomical community, and believing, that there were 9 planets in the solar system. But in August 2006 the International Astronomical Union (the organisation which oversees everything astronomical) downgraded Pluto (the 9th planet) to a dwarf planet. This means that there are now only 8 official planets. But this has nothing to do with Truth or truth. This is just an academic argument about how to define what is meant by a planet. And the debate goes on about whether or not Pluto is a planet and whether or not it should be reinstated as so.

Returning to relative truth vs absolute truth, science is a progression of limited truth (truths under certain limited conditions) towards absolute truth by developing new (true) knowledge about phenomena, progressively learning more and more about the phenomena (over decades and centuries), every time expanding, refining and deepening one's understanding of the phenomena. The whole point of this, of doing science and of studying nature is to understand the fundamental aspects of nature. To me this means finding the absolute truths of nature. Otherwise, what's the point.

3. Truth in mathematics

In terms of pure mathematics one can speak of truth in the sense that if one follows prescribed steps of algebra one can get from a starting point to an end point in our maths, and have our mathematics be true.

3.1. An example of truth in maths

It is a truth that an odd number added to an odd number always produces an even number. This can be proved by simple algebra as follows (the proof is optional. It is there for the more mathematically minded):

Theorem

If n and m are odd integers, then $n + m$ is even.

Proof: Let n and m be odd integers. Then $n = 2j + 1$ and $m = 2k + 1$ for some positive integers j and k. Then

$$\begin{aligned} n + m &= (2j + 1) + (2k + 1) \\ &= 2j + 2k + 2 \\ &= 2(j + k + 1). \qquad (*) \end{aligned}$$

Since $j + k + 1$ is integer, and (*) is by definition even, $n + m$ is even.

Q.E.D.

If you understand the generality of this proof it says that an odd number plus an odd number *always produces an even number, for all time*.

So, provided you follow the two fundamental principles of maths which are that your maths should either use axioms (which are a kind of definition) and/or algebra/deductive logic then your conclusion (the thing you are trying to prove) will always follow correctly from your premise (i.e. your initial mathematical statement). this is what is called a theorem. Because of the way mathematics has been developed theorems are always true. There is no such thing as a false theorem. There are things called conjectures, which are mathematical statements we believe to be true but have not yet been proved to be true, but these are not theorems.

Consider now Fermat's last theorem which says that for the following three positive integers *a*, *b*, and *c*, the equation

$$a^n + b^n = c^n$$

(where n is a positive integer also) only works for $n = 1$ and $n = 2$, not for $n > 2$ (note that for *n* = 2 we have Pythagoras' theorem). Pierre de Fermat (1607 - 1665) is the first person as being recorded to have made this statement. He said he had a proof of this but not proof was ever found. So it remained a conjecture (even though it was still called a "theorem"). For over three hundred years the best mathematicians in the world tried to prove this conjecture to no avail. Then in 1995 Andrew Wiles (1953 -) proved this conjecture to be *true for all integer n >= 3 for all time.*

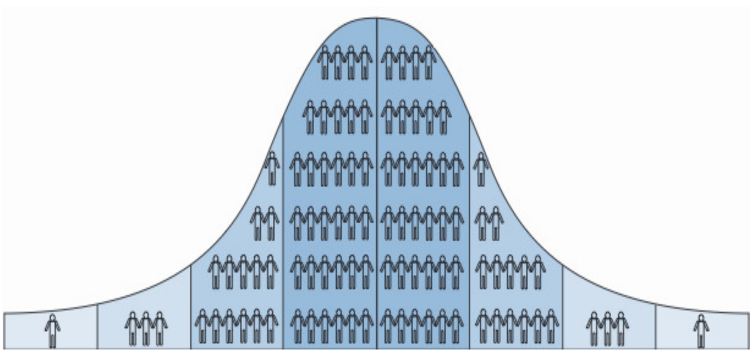
(Optional comment: I will not go into that aspect of mathematics referred to as undecidability. This was discovered and proved by Kurt Godel (Austrian, 1906 - 1978) and presented in his 1931 paper called "On formally undecidable statements in *Principia Mathematica* and related systems" which basically says that in any mathematical systems based on a set of axioms which allows us to perform arithmetic there will be some mathematical statements which cannot be proved true. This doesn't mean to say that that the statements are not true, just that we can't prove whether they are true or not. Godel's theorem is a theorem about the technical limitations of an axiomatic system. But those mathematics which can be proved are then shown to be absolutely true under that axiomatic system).

4. Truth in statistics

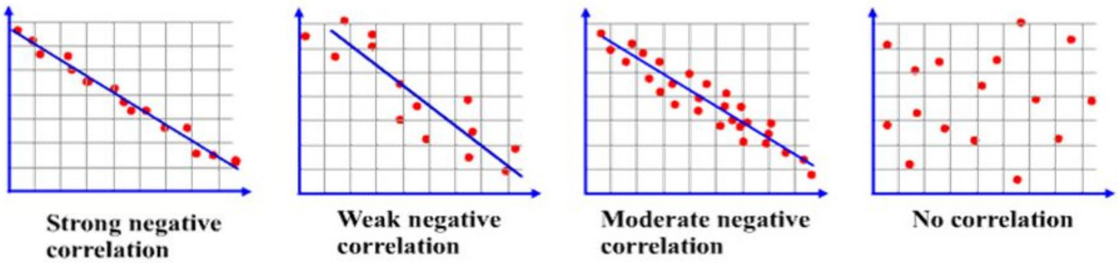
Statistical analysis is the process of collecting and analysing data to identify patterns and trends. What is data? Is it not a collection of numbers which represent a certain phenomenon?

Question: What data does your discipline collect? What does this data represent? What is the data about (in other words, what kind of data does your discipline collect)?

The two basic "patterns" which exemplify statistical distributions or trends are the normal distribution (the bell curve) of data and the line of best fit through data (which allows you to identify the degree to which data is correlated), as illustrated below.



Bell curve (Normal distribution)



Lines of best fit

There are two main types of statistical analysis: i) descriptive statistics, which explains and visualizes the data you have, and ii) while inferential statistics, which relies on finding as representative a sample as possible from which to draw conclusions about a wider population. It allows for extrapolation beyond the data set. As there will always be uncertainty about extrapolating from a limited set of data to a wider population, statistical inference relies upon estimating uncertainty in predictions.

In this case statistics does not allow you to find the truth about an individual “thing”. It only allows you to find out about probabilities and trends, i.e. the likelihood or probability that something will happen, or the overall trend or direction of a set of data. For example,

- knowing the average height or weight of a population of adults does not allow us to say that one particular adult will have that same height or weight.
- showing that aspirin helps reduce the incidence of heart attacks in 950 out of 1000 adults does not mean that we know that aspiring will help reduce the likelihood that this-or-that person’s will get a heart attack.
- knowing that the performance or reliability of 1000 units of a mechanical component lies within a certain range does not mean that we can say that the performance of the next unit will lie within that range.

The more data you have the clearer the trend or the greater the chances are that you will be correct.

4.1. Example: Averages

Let us look at the most simple example used in statistics, one which we all learn right at the beginning of a statistics course. We are told that there are three types of averages, these being the mean, the median and the mode, and all more commonly known under the general heading of *measures of central tendency*.

But already if there are three ways to calculate an average the question is “which one is the true average? Is there such a thing as the true average”. In statistics each average ne is used in different contexts for different reasons. For example, if you wish to find the numerical centre of a data set then the mean is the average we need to use. So for *n* pieces of data we would calculate as

$$\frac{1}{n}\sum_{k=1}^{n} x_k = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}.$$

But, in the context of statistics, the mean can have disadvantages, so the other average of the median is used. This latter average allows us to find the most representative middle value of a data set, which is found simply by choosing the middle value when the data is arranged in order.

As an example of finding the mean and the median consider the data 2, 4, 5, 7, 8, 10, 12, 13, 83. The mean of this data set is 16 and the median is 8. These are significantly different results for the average! This is because the number 83 significantly affects the value of the mean during calculation whereas it does not affect the value of the median since 8 will always be in the middle whatever the last value of the data is (the last value could be 200, and the median would still be 8).

But the median has a great disadvantage which the mean suffers less from. One of the most common activities to do in statistics is to collect samples. So we might collect a sample of n=7 data values, or n=12 data values of n=21 data values, etc. The median is much more susceptible (or fragile) to small samples. This means that there is a wide variation in values of the median for small samples. For a data set of 100 values, if we take three samples of size n=7 we might get medians to be $median_1$ = 4, $median_2$ = 13, and $median_3$ = 11, whereas we might get the mean values to be $mean_1$ = 6.3, $mean_2$ = 7.1, $mean_3$ = 6.9. (We won't go into the mode in these notes).

So, if there are three types of averages how can we speak of the true way of calculating the average? All we can do is speak of the most appropriate way of calculating the average based on the kind of data we have and what statistics we want to do on it. So, for skewed data (i.e. data which has strangely large or small values compared to the rest of the data set) it is better to use the median, and for data that is normally distributed (like the bell shaped curve) it is better to use the mean.

Note: In the heading "measure of central tendency", the reason for the word "central" is because these averages are designed to find the middle point of a set of data. The reason for the word "tendency" is because all data tends to focus around a central value (i.e. the average) which is usually not one of the actual data values but is always there as an underlying numerical property of the data. If data value are evenly spread out across the average there are then an equal amount of data values to the left of the average and to the right of the average. The reason for the word "measure" is because these averages measure the tendency for the data to lie in the middle of the data set.

4.2. Example: The bell curve (Normal distribution)

Consider the bell curve shown a few pages back. Let us say that this illustrates the distribution of heights of the adult population. Some people are very short, some people are very tall and most peoples' heights lie within a certain range. It happens to be a Truth that the *distribution* of the heights of adult human beings fits this bell-shaped curve.

Now, given the population of a country we could, in theory, calculate the average height of all adults. But in practice we can't do this. Countries have millions of adults so it is practically impossible to measure the height of every adult. Instead, we take a sample of the population (say 1000 adults), measure their height, find the average height of adults for this sample. Finding the average height of 1000 adults does not necessarily mean that any one adult will be of that height. The more adults in your sample the more likely it is that some adults will be closer and closer to that average height. But an average height (of all adults) is not designed to represent any one height (of a single adults). It is designed to represent the height of *the group as a whole*. Statistical conclusions do not apply to individuals cases/situations, so statistics does not deal with the truth of individual things such as heights.

A real example of the normal distribution can be seen in the photograph below. The smallest height is listed as 4 feet 10 inches (= 1.47m) on the left of the photo, and 6 feet 5 inches (= 1.96m) on the right of the photo.

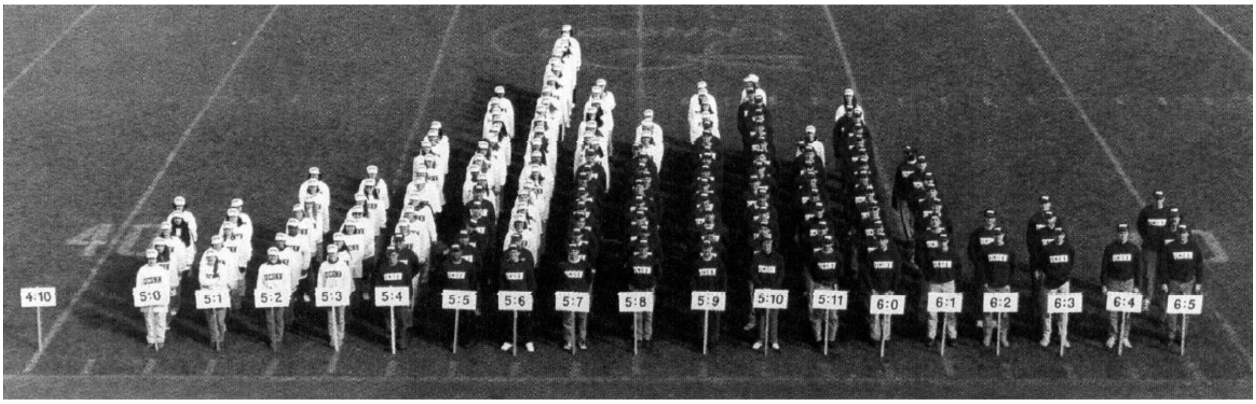


Photo taken from https://evolutionistx.wordpress.com/tag/bell-curve/

So, if we take the example of the heights of the population of adults in the UK, let us suppose that the average height of an adult is 1.77m. Some adults would have heights of say 1.61m or 1.93m, but there would be fewer people at these heights. The number of adults having height of 1.53m and 2.01m would be even fewer.

Notice that in the example of the people in the photo above the shape of the distribution of heights is not a perfect normal curve. This is because the normal curve in the graphs above is a theoretical curve designed to represent the ideal situation of an infinite number of data. As such this theoretical curve is perfectly symmetric, whereas real life is not currently theoretically perfect. So there will always be a difference between the real world distribution of the objects you are studying, and the theoretical distribution which is designed to simulate the real world.

Also, the number of people in the photo is just over 150 people. If you took more people (say 500 or 1000 or 5000 or more) you would get a more symmetric distribution. The more people you take (or the more objects of your study you take) the closer the theoretical bell-shaped curve will represent real world data.

All of this is to show that if we have to predict the average height of an adult population of a country we will (virtually) *never get the exact answer* since our answer will depend on not only the size of the sample but also the sample itself. In other words, choosing 1000 adults from one part of the country will give you the average for that sample, but choosing a sample of 1000 adults from another part of the country will give you a different average because you have chosen a different group of people, and the variation of heights between the two groups will be different.

This is a basic example of why statistics cannot arrive at the Truth on individual cases. The only truths we have are based on large scale data and are that

- the distribution of large scale data is normal (i.e. bell shaped),

and

- there are fewer and fewer data points at the extreme (very low of very high) ends of the distribution compared to the mid range of distribution.

Things become even more complicated when we want to find out if a sample comes from a particular population or not. Suppose we have a sample of adult height and we don't know which country this sample was taken from. We want to know if it is likely that our sample came from a particular population/country. We do this by analysing the average height of our sample. We then perform a statistical test to find out if our sample came from this-or-that population. Since the statistical test is based on probabilities there is no way we will know for certain (i.e. with 100% probability) that our sample will really have come from this-or-that country (for your information the statistical process would be to determine a probability based on a level of significance using a z-score or t-test score, where the level of significance is set against the normal distribution). Our (statistical) conclusion to this scenario would then be something like, "We are 99.5% confident that our sample does/does not come from this-or-that country".

5. Examples of argumentation used to highlight the truth or viability/validity of a claim

The truth or validity/viability of any claim made in a scientific academic paper will usually be found in the analysis/discussion section of the paper.

5.1. Mathematics

There is no such thing as "argumentation" or "discussion" in pure mathematics as there is in the physical sciences. Mathematics does not justify its results using linguistic rationales (as used in the physical sciences). There is no need to "discuss" the validity of the results. The results (for example, theorems) are automatically true/True by dint of the nature of mathematical logic and algebra.

In pure mathematics papers we have only definitions, theorems and proofs. The "argumentation" of pure mathematics, and mathematics more generally, comes from the use of mathematical logic and algebra. There may indeed be some writing, but this writing is very different to that we see in the "discussion" sections of physical science papers. Such writing as used in mathematics papers is actually develops the mathematical logic of the topic. As such this writing requires mathematical vocabulary and phrasing, all of which is very precisely and rigidly defined. In certain cases this writing could be translated into logical symbolic form and process, but one reason why this is not done is that it would make the proof too complicated to read and follow. Some degree of mathematical English is used to make it easier to follow the logical development of the mathematical concepts and processes.

As an example, consider the truth that the number $\sqrt{2}$ is irrational, namely that it cannot be written as a rational fraction p/q where p and q are integers.

Theorem

The number $\sqrt{2}$ is irrational

Proof

We proceed by contradiction. So, assume that $\sqrt{2}$ is rational. Then $\sqrt{2} = p/q$, where p and q are integers and are co-prime. This means that p/q is in its lowest terms. Then

$$\frac{p^2}{q^2} \quad = \quad 2\,.$$

Therefore p^2 is even which implies p is even. But this contradicts our assumption that p/q is in its lowest terms.

Another way of looking at this is that p has to be an odd number for p/q to be in lowest terms. But we have just found that p^2 and p are even, hence a contradiction. Therefore, $\sqrt{2}$ cannot be written as p/q implying that $\sqrt{2}$ is irrational. ■

Here, the "argumentation" used is that of algebra. The truth of the statement that $\sqrt{2}$ is irrational comes from the algebra and the nature of even and odd numbers.

When it comes to applied mathematics, statistics and the physical sciences the aim is to argue in favour of one's thesis. As such, everything you have learnt so far, and will learn, about argumentation applies. Then in order to argue for the truth of one's work we need to

1) have evidence, either
    - Direct evidence from our own experimentation and data collection, analysis and interpretation

or

- Indirect evidence such as via primary sources and secondary sources.

and then

2) Use forms of argumentation as you have learnt in our C1, C2 and/or C3 lessons.

So we will now look at texts taken from professional statistics and physics papers. As I mentioned previously (possibly last week) any academic writing consists of technical vocabulary, terminology, phrasing etc, integrated within normal English phrasing, structure, grammar, etc. Therefore, normal English language acts to wrap around the technical language of a scientific discipline. It is the normal English language which gives us a clue as to the genre of writing (summary, paraphrase, critique, description, argumentation, discussion, etc.) which we are still able to identify even if we know nothing about the technicalities of the discipline.

The aim when reading the texts below is to distinguish the natural English language aspects from the technical, scientific language, and find where in these texts the authors are arguing for the truth/validity/viability, etc. of their approach. For the texts marked as "text 1" this language is highlighted in red. The texts marked as "text 2" will be analysed during the lesson.

5.2. Statistics

Consider the following text taken from "Smoothing Parameter and Model Selection for General Smooth Models", Simon N. Wood, Natalya Pya and Benjamin Säfken (2016), *Journal of the American Statistical Association,* Vol. 111, No. 516 (December 2016), pp. 1548-1563.

> "This article has outlined a practical framework for smooth regression modeling with reduced rank smoothers, for likelihoods beyond the exponential family. The methods build seamlessly on the existing framework for generalized additive modeling, so that practical application of any of the models implemented as part of this work is immediately accessible to anyone familiar with GAMs via penalized regression splines. The key novel components contributed here are (i) general, reliable and efficient smoothing parameter estimation methods based on maximized Laplace approximate marginal likelihood, (ii) a corrected AIC and distributional results incorporating smoothing parameter uncertainty to aid model selection and further inference, and (iii) demonstration of the frameworks practical utility by provision of the details for some practically important models."

5.3. Exercises

A statistics text

Now consider the following text taken from "Inference for Monotone Functions Under Short- and Long-Range Dependence: Confidence Intervals and New Universal Limits", Pramita Bagchi, Moulinath Banerjee and Stilian A. Stoev (2016), *Journal of the American Statistical Association,* Vol. 111, No. 516 (December 2016), pp. 1634-1647

> "We introduce new point-wise confidence interval estimates for monotone functions observed with additive, dependent noise. Our methodology applies to both short- and long-range dependence regimes for the errors. The interval estimates are obtained via the method of inversion of certain discrepancy statistics. This approach avoids the estimation of nuisance parameters such as the derivative of the unknown function, which previous methods are forced to deal with. The resulting estimates are therefore more accurate, stable, and widely applicable in practice under minimal assumptions on the trend and error structure"

A physics text

Consider the text below taken from "Scalable multiphoton quantum metrology with neither pre- nor post-selected measurements", Chenglong You, Mingyuan Hong, Peter Bierhorst, et al. (2021), *Applied. Physics. Review 8.*

> "The quantum statistical fluctuations of electromagnetic fields establish a limit, known as the shot-noise limit, on the sensitivity of optical measurements performed with classical technologies. However, quantum technologies are not constrained by this shot-noise limit. In this regard, the possibility of using every photon produced by quantum sources of light to estimate small physical parameters, beyond the shot-noise limit, constitutes one of the main goals of quantum optics. Here, we experimentally demonstrate a scalable protocol for quantum-enhanced optical phase estimation across a broad range of phases, with neither pre- nor post-selected measurements. This is achieved through the efficient design of a source of spontaneous parametric down conversion in combination with photon-number-resolving detection. The robustness of two-mode squeezed vacuum states against loss allows us to outperform schemes based on N00N states, in which the loss of a single photon is

> enough to remove all phase information from a quantum state. In contrast to other schemes that rely on N00N states or conditional measurements, the sensitivity of our technique could be improved through the generation and detection of high-order photon pairs. This unique feature of our protocol makes it scalable. Our work is important for quantum technologies that rely on multiphoton interference such as quantum imaging, boson sampling, and quantum networks."

Another physics text

Consider the text below taken from "Timestamp boson sampling", Wen-Hao Zhou, Jun Gao, Zhi-Qiang Jiao, et al., (2022), *Applied Physics Review 9.*

> "Quantum advantage, benchmarking the computational power of quantum machines outperforming all classical computers in a specific task, represents a crucial milestone in developing quantum computers and has been driving different physical implementations since the concept was proposed. A boson sampling machine, an analog quantum computer that only requires multiphoton interference and single-photon detection, is considered to be a promising candidate to reach this goal. However, the probabilistic nature of photon sources and the inevitable loss in evolution network make the execution time exponentially increasing with the problem size. Here, we propose and experimentally demonstrate a timestamp boson sampling scheme that can effectively reduce the execution time for any problem size. By developing a time-of-flight storage technique with a precision up to picosecond level, we are able to detect and record the complete time information of 30 individual modes out of a large-scale 3D photonic chip. We perform the three-photon injection and one external trigger experiment to demonstrate that the timestamp protocol works properly and effectively reduce the execution time. We further verify that timestamp boson sampler is distinguished from other samplers in the case of limited datasets through the three heralded single photons injection experiment. The timestamp protocol can speed up the sampling process, which can be widely applied in multiphoton experiments at low-sampling rate. The approach associated with newly exploited resource from time information can boost all the count-rate-limited experiments, suggesting an emerging field of timestamp quantum optics."

6. Exercises

1) Does your discipline deal with truth as you have learnt in your C1 or C2 lessons?
2) Does your discipline deal with Truth as described in these notes? If not, does it deal with the viability or validity of knowledge? Does it deal with restricted truth?
3) Identify the truth/validity claims made for the paper we are currently using as a group, or for a paper of your choice.

For all three questions above what evidence is presented in favour of such truth/validity?