

OPINION

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How the Guinness Brewery Invented the Most Important Statistical Method in Science

The most common test of statistical significance originated from the Guinness brewery. Here's how it works

BY JACK MURTAGH



The gates of the Guinness Saint James Gate Brewery stand in Dublin, Ireland. Hollie Adams/Bloomberg via Getty Images

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“One Guinness, please!” a customer says to a barkeep, who flips a branded pint glass and catches it under the tap. The barkeep begins a multistep pour process lasting precisely 119.5 seconds, which, whether it’s a marketing gimmick or a marvel of alcohol engineering, has become a beloved ritual in pubs worldwide. The result: a rich stout with a perfect layer of froth like an earthy milkshake.

The Guinness brewery has been known for innovative methods ever since its founder, Arthur Guinness, signed a 9,000-year lease in Dublin for £45 a year. For example, after four years of tinkering, Michael Edward Ash, a mathematician turned brewer there, invented a chemical technique that gives the brewery’s namesake stout its velvety head. The method, which involves adding nitrogen gas to kegs and to little balls inside cans of Guinness, led to today’s hugely popular “nitro brew” styles of beer and coffee.

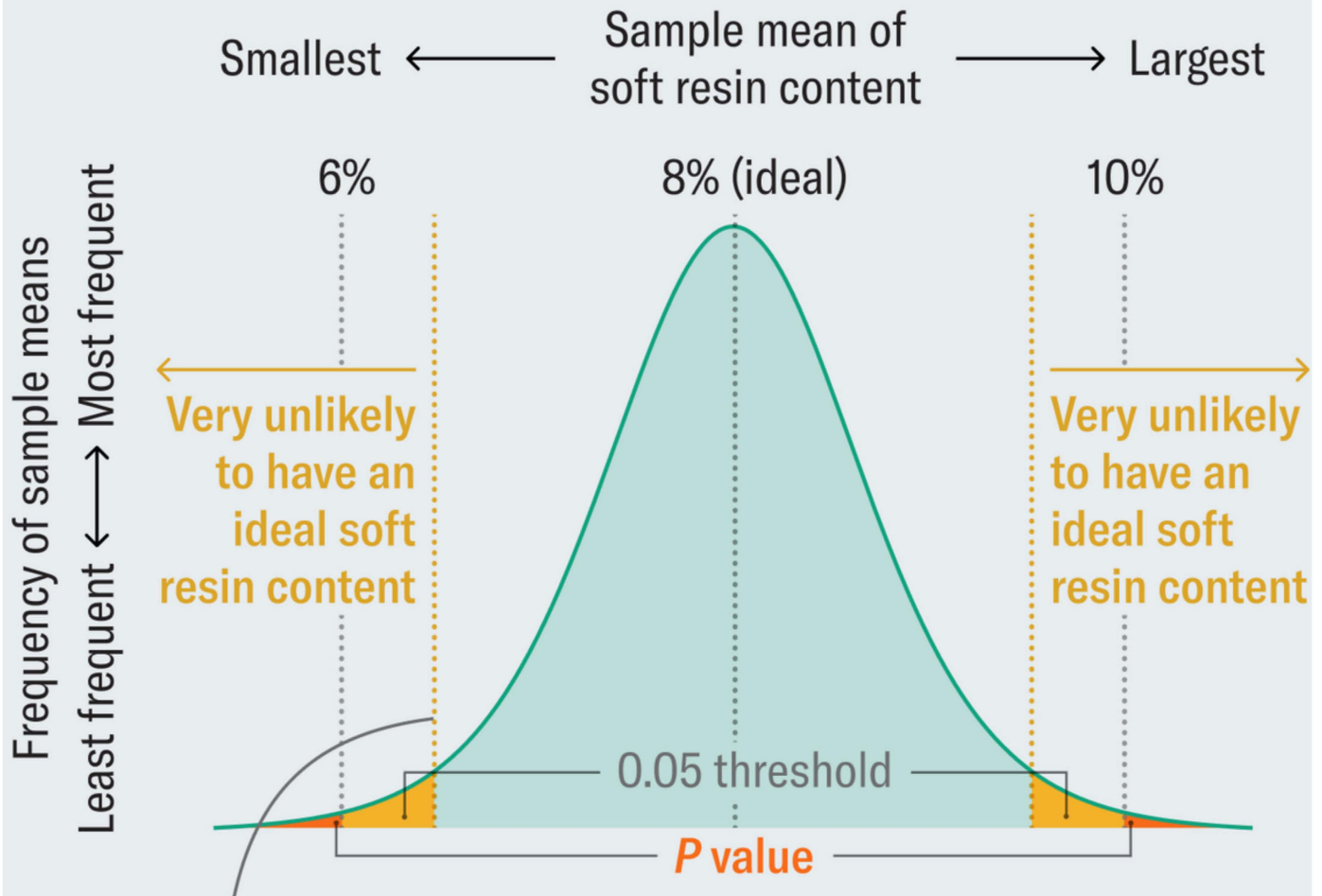
But the most influential innovation by far to come out of the brewery has nothing to do with beer. It was the birthplace of the t-test, one of the most important statistical techniques in all of science. When scientists declare their findings “statistically significant,” a t-test is very often the basis for that determination. How does this work, and why did it originate in beer brewing of all places?

Near the start of the 20th century, Guinness had been in operation for almost 150 years and towered over its competitors as the world’s largest brewery. Until then, quality control on its products had consisted of rough eyeballing and smell tests. But the demands of global expansion motivated Guinness leaders to revamp their approach to target consistency and industrial-grade rigor. The company hired a team of brainiacs and gave them latitude to pursue research questions in service of the perfect brew. The brewery became a hub of experimentation to answer an array of questions: Where do the best barley varieties grow? What is the ideal saccharine level in malt extract? How much did the latest ad campaign increase sales?

T-Test and Hop Flowers

Let’s assume that the average soft resin content in nine samples of hop flowers is 6 percent and that the desired value

is 8 percent. The t -test helps determine whether the sample average of 6 percent is caused by random variation or by genuinely lower than desired resin content in the population.



The **critical value** serves as the threshold ($\alpha = 0.05$) beyond which observations are considered very unlikely.

The **P value**, or probability of collecting a sample with 6 percent average soft resin content if the true average of the full crop were 8 percent, is less than 0.05, indicating that result is unlikely to occur by chance.

Shuyao Xiao

Amid the flurry of scientific energy, the team faced a persistent problem: interpreting its data in the face of small sample sizes. One challenge the brewers confronted involves hop

flowers, essential ingredients in Guinness that impart a bitter flavor and act as a natural preservative. To assess the quality of hops, brewers measured the plants' soft resin content. Let's say they deemed 8 percent a good and typical value. Testing every flower in the crop wasn't economically viable, however. So they did what any good scientist would do and tested random samples of flowers.

Let's inspect a made-up example. Suppose we measure the soft resin content of nine samples and, because samples vary, observe a range of values from 4 to 10 percent with an average of 6 percent—too low. Does that mean we should dump the crop?

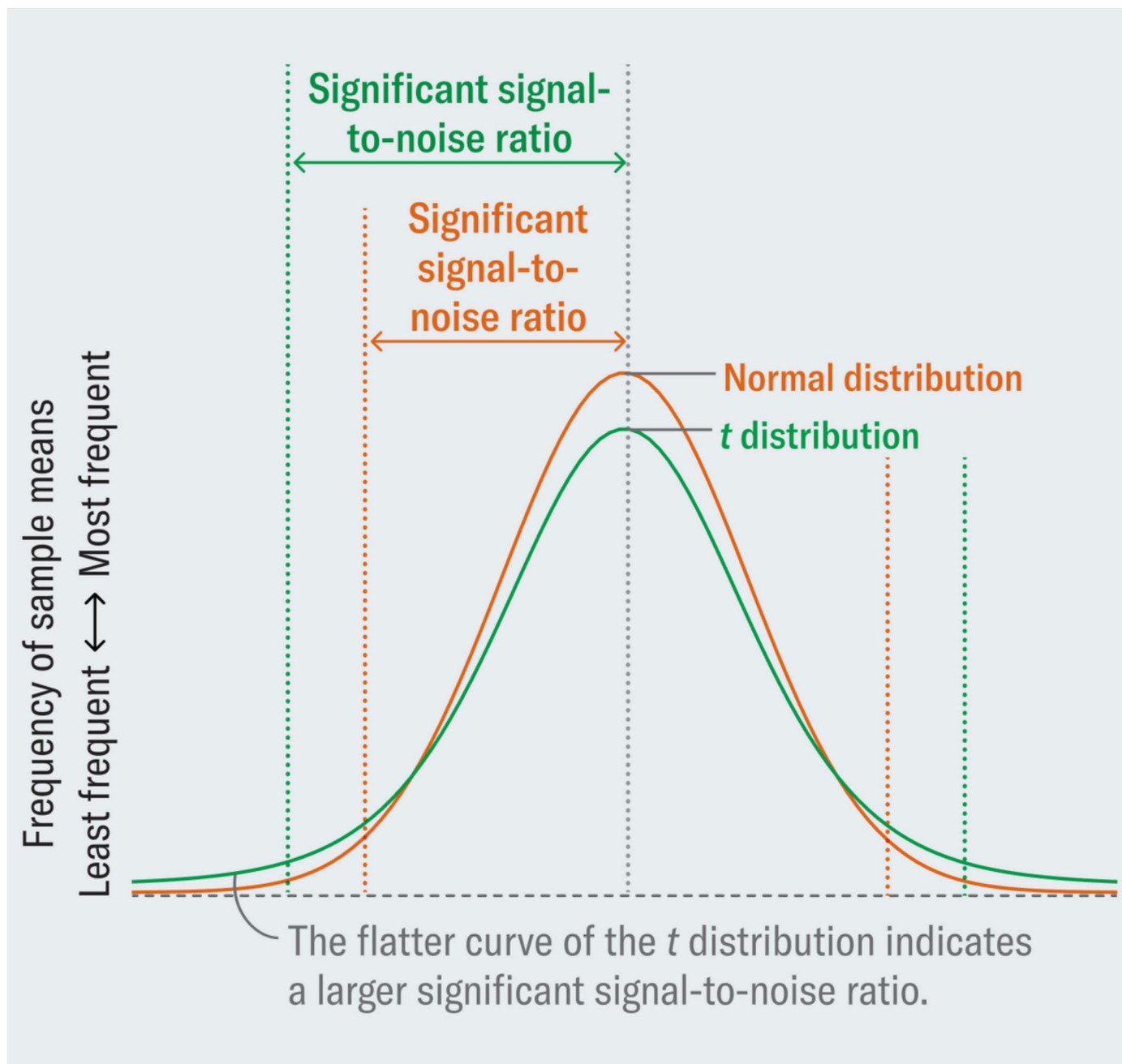
Uncertainty creeps in from two possible explanations for the low values. Either the crop really does have an unusually low soft resin content or, even though the samples contain low amounts, the full crop is actually fine. The whole point of taking random samples is to rely on them as faithful representatives of the full crop, but perhaps we were unlucky in choosing samples with uncharacteristically low levels. (We tested only nine, after all.) In other words, should we consider the low resin in our samples as significantly different from 8 percent or mere natural variation?

This problem is not unique to brewing. Rather it pervades all scientific inquiry. Suppose that in a medical trial both the treatment group and the placebo group improve, but the treatment group fares a little better. Does that provide sufficient grounds to recommend the tested medication? What if I told you that the two groups received two different placebos? Would you be tempted to conclude that the placebo given to the group with better outcomes must have medicinal properties? Or could it be that when you track a group of people, some of them will just naturally improve, sometimes by a little and sometimes by a lot? Again, this boils down to a question of statistical significance.

Small Sample Sizes Need a Larger Signal-to-Noise Ratio to Conclude Significance

..... Statistical significance threshold of normal distribution

..... Statistical significance threshold of t distribution



Shuyao Xiao

The theory underlying these perennial questions in the domain of small sample sizes wasn't developed until Guinness came on the scene—specifically, not until William Sealy Gosset, head experimental brewer at Guinness in the early 20th century, invented the *t*-test. The concept of statistical significance predated Gosset, but prior statisticians worked in the regime of large sample sizes. To appreciate why this distinction matters, we need to understand how one would determine statistical significance.

Remember, the hops samples in our scenario have an average soft resin content of 6

percent, and we want to know whether the average in the full crop in fact differs from the desired 8 percent or we just got unlucky with our sample. So we'll ask a question: What is the probability that we would observe such an extreme value (6 percent) if the full crop were typical (with an average of 8 percent)? Traditionally, if this probability, called a P value, is less than 5 percent, or 0.05, then we deem the deviation statistically significant, although different applications call for different thresholds.

Often two separate factors affect the P value: how far a sample deviates from what is expected in a population and how common big deviations are. Think of it as a tug-of-war between signal and noise. The difference between our observed mean (6 percent) and our desired one (8 percent) provides the signal—the larger this difference, the more likely the crop really does have a low soft resin content. The standard deviation among flowers brings the noise. Standard deviation measures how spread out the data are around the mean; small values indicate that the data hover near the mean, and larger values imply wider variation. If the soft resin content typically fluctuates widely across buds (that is, if it has a high standard deviation), then maybe the 6 percent average in our sample shouldn't concern us. But if flowers tend to exhibit consistency (or a low standard deviation), then 6 percent may indicate a true deviation from the desired 8 percent.

To determine a P value in an ideal world, we'd start by calculating the signal-to-noise ratio. The higher this ratio, the more confidence we have in the significance of our findings because a high ratio indicates that we've found a true deviation. But what counts as high signal to noise? To deem 6 percent significantly different from 8 percent, we specifically want to know when the signal-to-noise ratio is so high that it has only a 5 percent chance of occurring in a world where an 8 percent resin content is the norm. Statisticians in Gosset's time knew that if you ran an experiment many times, calculated the signal-to-noise ratio in each of those experiments and graphed the results, that plot would resemble a "standard normal distribution"—the familiar bell curve. Because the normal distribution is well understood and well documented, you can look up in a table how large the ratio must be to reach the 5 percent threshold (or any other threshold).

Gosset recognized that this approach worked only with large sample sizes; small samples

of hops wouldn't guarantee that normal distribution. So he meticulously tabulated new distributions for smaller sample sizes. Now known as t distributions, these plots resemble the normal distribution in that they're bell-shaped, but the curves of the bell don't drop off as sharply. That translates to needing an even larger signal-to-noise ratio to conclude significance. His t -test allows us to make inferences in settings where people couldn't before.

In 2008 mathematical consultant John D. Cook mused on [his blog](#) that perhaps it should not surprise us that the t -test originated at a brewery as opposed to, say, a winery. Brewers demand consistency in their product, whereas vintners revel in variety. Wines have "good years," and each bottle tells a story, but you want every pour of Guinness to deliver the same trademark taste. In this case, uniformity inspired innovation.

Gosset solved many problems at the brewery with his new technique. The self-taught statistician [published his \$t\$ -test](#) under the pseudonym "Student" because Guinness didn't want to tip off competitors to its research. Although Gosset pioneered industrial quality control and contributed loads of other ideas to quantitative research, most textbooks still call his great achievement "Student's t -test." History might have neglected his name, but he could be proud that the t -test is one of the most widely used statistical tools in science to this day. Perhaps his accomplishment belongs in Guinness World Records (the idea for which was dreamed up by Guinness's managing director in the 1950s). Cheers to that.

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JACK MURTAGH writes about math and puzzles, including a series on [mathematical curiosities](#) at *Scientific American* and a weekly [puzzle column](#) at Gizmodo. He holds a Ph.D. in theoretical computer science from Harvard University. Follow Murtagh on X [@JackPMurtagh](#)

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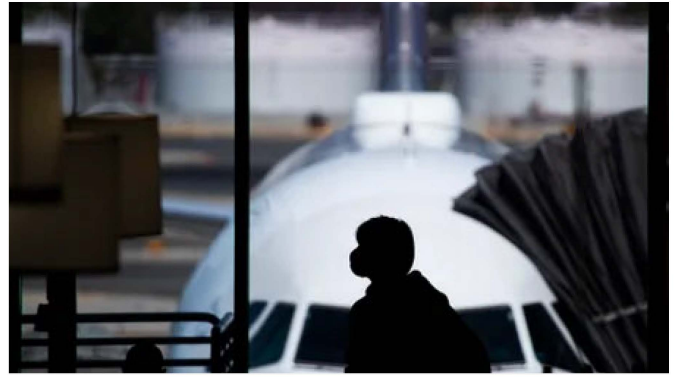


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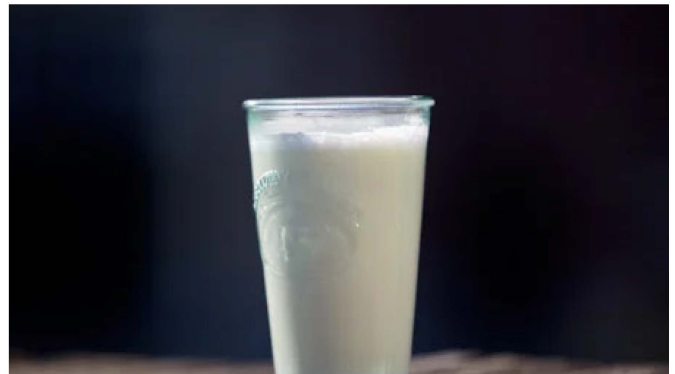


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