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How to handle risky experiments producing uncertain phenomenon like cold fusion?

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Abstract

Some experiments are risky in that they cannot repeatedly produce certain phenomenon at will for study because the scientific knowledge of the process generating the uncertain phenomenon is poorly understood or may directly contradict with existing scientific knowledge. These experiments may have a great impact not just to the scientific community but to mankind in general. Banning them from the study may incur societies a great opportunity cost but accepting them runs the risk that scientists are doing junk science. How to make an informed decision to accept/reject such study scientifically for the mainstream scientific community is of great importance to mankind. Here, we propose a statistical methodology to handle the situation. Specifically, we consider the likelihood of not observing the phenomenon after n trails so that it is statistically significant to have nil result. Consequently, we reject the hypothesis that there is some probability that we observe the phenomenon.

Keywords: risky experiments; cold fusion; statistical methodology; random model.[2]

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1 Introduction

From time to time, experiments (e.g., by Meissner and Ochsenfeld [28], Mössbauer [35] and Bednorz and Müller [5]) have produced controversial, important phenomena from unknown processes (e.g., [24]). However, such experiments may not be welcomed by the scientific community. A good example is the cold fusion experiment in which Profs Fleischmann and Pons [13] claimed excess heat release from their experiment, which was thought to be due to some unknown nuclear process. This claim has been thought to be debunked [23] by some scientists as some expressed doubts (e.g., Horanyi [18]; Keddam [20]; Schultze et al., [39]) because many claimed that they were unable to replicate the experiment at least in some way (e.g., by Armstrong et al. [2], Bennington et al. [6] and Astakov et al., [3]). After the Department of Energy (DOE) warmed to cold fusion [10] as well as the American Chemical Society [38], 60 Minutes in 2009 reignited interests of both scientists and the public in cold fusion research (see [42] for a review). Recently, Google scientists [15] have been trying to achieve cold fusion. Despite their failure, they are still hopeful that they can achieve cold fusion in the future. However, some scientists are still skeptical about cold fusion as a legitimate subject of scientific inquiry, and some are concerned that it was publicized in some academic society's press conference. Debates over whether cold fusion should be treated as a scientific inquiry can be observed, for example, from blogs in Physics Buzz [8]. This raises an interesting question as to whether funding agencies and academic societies should accept such research as legitimate scientific inquiry as some regard cold fusion as undead science [41].

An accepted way to deal with such a situation is to wait for the paper on the experiment to be published, and then replicate the experiment. However, some experiments are hard to replicate due to their delicate and unknown nature. If the academic society had banned the research of such experiments, the paper would not be published at all. Publishing a scientific paper takes time, and there are possibilities of (omission) errors. These errors may be omitted unintentionally as the process generating the phenomenon is poorly understood. Even if a paper on a risky experiment (e.g., [19]) is published, there is no guarantee that other scientists can replicate the experiments with high reliability. In this case, the scientific community may fall into yet another debate (e.g., [1]) with the controversial experiment.

One way is to ask a committee of experts to judge whether the concerned phenomenon exists by reviewing a set of papers about the phenomenon and ask them to vote for or against the concerned phenomenon. While experts can comment on the problems with the experiments, the judgments are usually subjective based on just reading the papers (as in the DOE meeting). Experts can voice out their own subjective opinions about the experiment or phenomenon, which can damage/enhance the reputation of the experiment/phenomenon. Instead, what we need is an objective way to decide whether the concerned phenomenon exists. As it is usually hard to gain widespread acceptance/rejection, reviewing papers based on a committee of experts is not very conclusive to decide the acceptance/rejection of experiment/phenomenon. Therefore, this subjective way to make decisions is not preferred. Similarly, we should not rely on the process of reviewing papers by journals as this is also subjective and some journal may have a hidden embargo of papers on certain topics. Therefore, we need to seek a more objective way to make a decision than (pure) subjective judgment.

Another way to deal with such a situation is to send a group of experts (e.g., representatives from funding/government agencies like DOE, representatives of academic society like the American Physics Society and representatives from scientific journals/magazines like Nature) to the laboratory that claims certain phenomenon exists, and let the experts inquire. The laboratory can then demonstrate the phenomenon by carrying out the experiment. If it cannot be done once, the experts can wait for another attempt. However, how many attempts should the experts wait for a successful demonstration? Similarly, as in a reproducibility crisis [4], when replicating other researchers' work, how many times does the experiment need to be repeated before one declares that the experiment results cannot be reproduced?

2 Our Approach

To decide, we need to find a scientifically accepted way to deal with risky situations. The common, accepted method used in science is to use statistical tests as they are commonly used to accept or reject the hypothesis in science. The common idea is to accept the risk that the decision is wrong with a certain amount of percentage. For example, to accept a hypothesis with 95% confidence means that the decision to accept the hypothesis is wrong for less than 5% of the time. In using this statistical method, we accept that we cannot have absolute certainty about accepting or rejecting a hypothesis since there is risk [27]. Therefore, we should use statistical tests to handle how many times we should allow the experiments to be repeated in order to accept the hypothesis that the phenomenon exists or not.

Before we formulate the statistical test, one important observation should be made. According to falsification [36], only one case is needed to refute that a theory is true. To show that a theory is true with absolute certainty, we need to confirm the theory with infinite repetitions of the experiment, which is practically not possible and that is why we need to use statistics to accept or reject the hypothesis (testing the theory with a finite number of times).

For risky experiments with an uncertain phenomenon, the situation is different or the opposite. If an experiment showed that the uncertain phenomenon existed once or it is shown to produce the target result once, then the existence of the phenomenon (like excess heat in cold fusion) should be accepted, because the logical argument is that if the phenomenon once existed, then it implies that the phenomenon exists. Therefore, one only needs to know something existed once to determine its existence. Put this in another way, if we have shown that the phenomenon existed once, then we cannot say that the phenomenon never existed. Now, if we cannot repeat the experiment mechanically, it is due to our ignorance of the process to produce the phenomenon instead of the non-existence of the phenomenon. The demand of requiring mechanical repetition [11] of the phenomenon is over stringent because we do not understand the underlying mechanism that generates the phenomenon, so it is hard to repeat the results at will. If we know the underlying mechanism, then probably we can generate the phenomenon mechanically (although this depends on how controllable the process is). Such over-stringent requirement will prevent the discovery of many phenomena because they are poorly understood at the time of the experiments, so they demand to be studied. However, the over stringent requirement prevents such study by banning them as unscientific. Such over stringent requirement would be doing a disservice to the scientific community or even mankind. Therefore, to show that an uncertain phenomenon exists, only one successful demonstration is needed. Note that to demonstrate a theory or a model works, repeatability in experiments is still needed, so repeatability is not abandoned at all because in this particular case, we have knowledge of the underlying process of how the phenomenon is generated assuming that we can control the process. By comparison, we do not have the knowledge about the risky experiment nor are we capable of controlling it to reproduce at will. However, we need to study it because it is important. That is why we relax the repeatability criterion.

Before any demonstration to the experts, the experimental set up must be checked and validated by the experts and the proponent because there should not be any dispute about the experimental set up after the experiments start. Also, these experts should have the same degree of belief and disbelief that the phenomenon (e.g., excess heat for cold fusion) exist, so we can ascribe a subjective probability of 0.5 as the degree of belief of the experts, which is higher than the proportion of success (i.e., 0.3) in some cold fusion experiments [19]. After n independent trials, if none of the experiments is successful, then the probability that n trials failed in succession is 0.5^n. This probability should be less than the probability, p, that we incorrectly reject the hypothesis that the phenomenon exists (i.e., a Type I error) with probability a half occurring. Typically, p is 0.05, so $n > 4$ in this case for a one-tail test. However, most of the demonstrations of cold fusion are required to be repeated with just one or two trials which are too few to give the cold fusion proponent a "fair" chance to demonstrate. As a result, the proponents may feel that it is unfair to them to reproduce the results mechanically at will as they know their experiments can only be repeated with a certain probability. Therefore, they may be reluctant to demonstrate. By allowing a fair number of trials, they may be enticed to the demonstration as they have a fair chance of success.

In summary, we used a random model to help us to decide how many trials the laboratory has to yield a successful demonstration. The advantage of this is that no prior knowledge can influence this decision as such prior knowledge (or existing theory) may be contradictory to the concerned phenomenon (that is why scientists or theorists want to ban such study). It should be noted that scientific knowledge is provisional (as discussed in Luk [27]) so it can be wrong even if it is accepted. Although theories can be falsified by experiments, experiments may not be falsified by a theory which can be wrong if the experiment after checking for its validity can repeat the (falsifying) results for reliability. Having said that, experiments can be wrong, for example, measurement errors or making wrong wired connections. So, experiments are not immune to errors but they can be checked and double-checked for validity (before the demonstration).

If the experts inquire about the success rate, α, of replicating the experiments, then α can be used to decide how many trials they need to wait for a successful demonstration. In this way, if α is too low, the experts may not need to visit the laboratory because they have to wait for too many trials for a successful demonstration. Acceptable success rate can be worked out by assuming that experts can tolerate at most n trials, so that $\alpha > 1 - p^{1/n}$. The laboratory takes the risk of failure to demonstrate the phenomenon with the probability of $(1-\alpha)^n$. In this way, the laboratory has been given a "fair" chance to demonstrate, and the experts can conclude in a scientifically accepted way, acknowledging there is risk in their decision.

Instead of assuming the trials are independent, we can use the Laplace law of succession [12] to estimate the probability of having n successions of failure, which is $1/(n+1)$. For the probability of incorrectly rejecting the null hypothesis to be less than p, we need $p < 1/(n+1)$. If $p = 0.05$, then $n > 19$. So, the experts have to wait for the laboratory to do at least 20 experiments to decide whether the phenomenon exists. This is a more relaxed requirement as the experiments are not necessarily independent, so they may systematically fail for some reason.

Which number of trials, n, to use would depend on the experts who decide whether they should treat each experiment as independent or not. If the experts ask the laboratory to repeat the experiment differently every time the demonstration of the phenomenon fails, for example, changing the way the alloys are cut or prepared for the experiment in cold fusion (because of fracture in the alloy), then each experiment should be considered independent. On the other hand, if the experts request the laboratory to repeat the experiments intentionally without any change, then the experiments are not independent any more so that the use of Laplace law of succession to determine the maximum number of trials *n* for a successful demonstration is appropriate.

Determining the maximum number of trails to wait for the successful demonstration is obviously one important aspect of the determination to accept or reject the existence of the uncertain phenomenon. However, there are other important aspects too, like the experts checking the experimental set up for fraud and deciding whether the signal of the uncertain phenomenon is sufficiently clear (e.g. the amount of excess heat in cold fusion). Therefore, a checklist of items for checking the experiments should be documented and verified by the experts to ensure the credibility of the demonstration. Such a checklist should be publicized along with the demonstration results in order to provide a "fair" chance for the demonstration and to make as informed as possible about the decision to accept or reject the existence of the uncertain phenomenon in the risky experiments. It should be noted that accepting or rejecting the existence of the phenomenon is not final as scientific knowledge is fallible. However, we have used an accepted procedure to make a temporary risky decision about accepting or rejecting phenomenon so that we can temporarily rest with this decision until another challenge arises as new evidence mounts and as the funding for testing the phenomenon permits.

Some scientists may regard it is a fluke or experimental hiccup that appeared to produce the phenomenon and they may want a more stringent test before accepting the phenomenon is real. Then, this can be considered as the problem of scaling the sample size. If no probability is supplied, then we use the probability of 0.5 as the degree of belief that the phenomenon existed compared with the probability of 0.5 as the degree of belief that the phenomenon does not exist for the null hypothesis. Based on the binomial distribution (or approximated to the normal distribution if the number trials is large), we can work out the 95% confidence level (or other agreed confidence level) of the lowest probability that we would reject the null hypothesis. In turn, this lowest probability can translate into the least number of repetitions that we should observe in at most *n* trials that the scientists are willing to check. For instance, if we are willing to repeat ten trials (instead of at most five), then according to the binomial distribution two or more successful demonstrations out of ten indicate that the null hypothesis that the probability of successful experiment is a half is accepted (based on a one-tail test). However, the number of trials may be too large for people to invest the resources to check the phenomenon. Then, we may need to use a more efficient test like the sequential analysis (e.g., Gottman and Roy, 2004), the details of which I let the reader to explore (since it does not affect my argument as it only improves the efficiency of the test). Yet, another alternative is to restart the demonstration forgetting the successful demonstration and allow *n* (e.g., 5 for the 95% confidence level) trials for yet another successful demonstration. In general, the experts and the proponent can agree with the number of restarts to reach the final decision between them before the demonstration starts instead of limiting the number of restart to just one. In this way, the proponent avoids the situation that the experts keep demanding more repetitions to answer more queries or inspections (similar to moving the goal posts), and the experts can limit the number of trials before declaring their judgment of the demonstration. Introducing the restart allows the experts to look for fraud as the experts have knowledge of the experiment after it is completed. Instead of restart, the proponent can run a mock experiment (with or without successful demonstration of the phenomenon) to let the experts to inquire afterwards. In this way, there is no need to restart for the experts to gain confidence in checking the experiment. Therefore, this can reduce the time needed to demonstrate, and this is a harder test for the proponent than scaling the sample size as every restart requires a successful demonstration after *n* trials. In summary, there is an accepted way to deal with accepting risky phenomena but yet does not require mechanical repetitions (at will).

Apart from speeding up the decision making by statistical tests, experimental set up can also speed up the decision-making process. Instead of waiting for one experiment to complete before starting another experiment, *n* experiments are carried out in parallel. This may become important for cold fusion as it may take over a week to boil the water in order to observe the phenomenon. The advantage of parallel experiments is that the time is shortened. The disadvantage is that more resources are required to perform such experiments. In addition, the demonstrator cannot learn from the experiment as to why the experiment failed before starting another experiment to avoid such pitfall although there is no guarantee what is learnt can make any impact on the success of the demonstration as the risky experiments are due to some unknown process. Instead of setting a confidence level of 95% for parallel experiments, one can increase the confidence level a little so that the number of experiments to try in parallel is larger if resources permit, in order to offset the missing learning effect. Yet another approach is to combine both sequential and parallel experiments to carry out experiments in batches. In this case, we may carry out experiment with say a batch of five in parallel and sequentially we carry out two batches to execute a total of ten runs of experiments. In this way, we can save time and can try to learn why the experiments failed.

3 Is cold fusion science?

Coming back to the cold fusion issue, is cold fusion science? First, cold fusion is an experiment rather than a theory. The theory put forward by Pons and Fleischmann was only tentative, so it should be treated as a hypothesis. The focus of the experiment should be on whether excess heat (i.e., the phenomenon) is produced rather than nuclear products as predicted by the tentative theory are observed because the tentative theory can be wrong but there may still be some kind of nuclear process taking place other than fusion. If cold fusion is just an experiment, then it belongs to the working scientific knowledge according to Luk [26] rather than scientific theory or scientific model because to be called a scientific discipline a scientific theory or a scientific model is required according to Luk [25]. However, cold fusion has a nuclear reaction model [13,14], the by-products of which, helium-4, are found to correlate with the excess heat (e.g. [29,30]). Miles [30] got the odds in favor of the correlation of 750,000 to 1 which is well above the ability of the random model of correlation. However, the nuclear reaction model was not initially completely substantiated as the model predicts gamma ray productions with helium-4 but no gamma ray (e.g., [3]) was detected or as the model predicted neutron emission but only a weak rate was reported (e.g., [40]), even though sometimes tritium is detected (e.g., [7,21,44]). Relatively recently, Chubb [9] explained another nuclear pathway where two deuterons fuse to produce helium-4 without energetic particles or gamma rays based on conventional physics. Therefore, the excess amount of helium-4 produced in the experiment is an indication that some nuclear process is taking place even though some [22] may argue that there are other types of nuclear processes (like electron capture [44]) as these are on-going research (e.g., [17,43]). Relatively recently, more evidence of nuclear reaction was found based on identifying or measuring energetic particle (like neutron or tritium) tracks created on CR-39 material (e.g., by Mosier-Boss et al. [32,33,34]) further supporting the existence of nuclear processes in cold fusion experiments. Therefore, it seems certain some kind of nuclear process is taking place in cold fusion but exactly what this nuclear process involves is on-going research as the nuclear process may involve multiple pathways rather than a single pathway. Coupled with the application of the principle of prudence [37] to cold fusion for climate change, it is perhaps apt now to visit the laboratory that claims cold fusion is possible and to decide whether the cold fusion phenomenon exists using our proposed methodology to warrant inclusion in mainstream science (mainly in physics) as this is a catch-22 situation [31] and as some reactor is demonstrated for commercial interests rather than scientific verification (by-passing the scientific enterprise).

Regarding cold fusion as an example of scientific inquiry, we should caution not to dismiss experiments too early as unscientific because it may be possible that in the future respectable scientific theory or model may be able to explain the experiments, so that the experiments may eventually be classified as a scientific experiment. For an experiment to be called scientific, mechanical repeatability is not a mandatory requirement because otherwise many subjects cannot be called science because the experiments cannot be controlled for repeatability or may not be repeated literally like the big bang theory. Instead of repeatability, we believe an assessment of the reliability (using statistics and probability) is more important because there is no guarantee that future experiments can be repeated even if they were repeated mechanically in the past (as in the problem of induction). Therefore, using statistics to assess the reliability of our experiment is more important than demanding mechanical repeatability (to show the phenomenon exists) because the statistics help us to appreciate the risky decision that we are making (about future events).

4 Conclusion

We have shown that there is a statistical methodology that can help to decide how many times an experiment should be repeated before a replication is judged to fail or before the uncertain phenomenon is judged not to exist. This statistical method tells us the risk of our decision in making the incorrect judgment. If the decision is to reject that the phenomenon exists or to reject the experiment can be replicated, this methodology only makes a provisional rejection decision since there is risk in the decision similar to common (scientific) hypothesis testing. As there is more evidence mounting towards the existence of the uncertain phenomenon or the replication can be done, another round of statistical tests can be carried out if resources permit. Therefore, we have a methodology to handle such a situation in a scientifically accepted way.

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