How to Judge Flawed Science

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It is perhaps a common belief that materials science–solid-state physics (MS–SSP) has only recently been affected by a rush of fraudulent claims. This is exemplified by the two recent famous cases: the H. Schön situation[1] and the "discovery" of element 118, the Ninov experiment.[2] Over the years, however, there have been examples of fraud and flawed science in our field. Considering the large amount of scientific output in MS–SSP, the incidents of straight fraud are fewer than many other aspects of human behavior. However, it is possible that, as with all scientific research, the incidence of scientific mistakes ("flawed" science) is more or less the same in all areas.

Here we will deal mostly with MS–SSP cases which, at face value, seem legitimate but are nevertheless flawed. Thus we exclude so-called cases of "junk" science (which pushes a non-scientific agenda) or "pseudo" science (based on irrational or mystical thinking) that clearly violate basic laws of nature.[3] Our inspection of some typical cases in MS–SSP in the last 20 years help us classify flawed science and devise a set of simple rules by which scientific research can be judged (see the figure). There is the case of straight "fraud," as in the Schön case, in which a researcher many times deliberately made up data, mostly on the behavior of a variety of materials when incorporated into field-effect transistor (FET)-type structures.[1,4] The less obvious cases are those of "wishful thinking," such as the claims, principally in newspapers, of superconductivity above room temperature in a variety of ceramic oxides very soon after the discovery of 90 K superconductivity in YBCO.[5] Perhaps somewhat less objectionable are cases in which the observation of a "single event" is claimed as the basis of a major discovery.[6] A more difficult case to judge is that of "major discoveries where many others have failed"; a famous case is that of the discovery of gravitational waves by use of solid-state devices.[7] The reason this last one is the hardest to judge is that, clearly in many cases, scientific advance is not possible without major discoveries where others have failed.[8] A last case of flawed science is a purposefully made hoax, illustrated by the Sokal case,[9] which was revealed by the authors themselves, soon after it is perpetuated.

So what do we learn from these and more extensive studies of similar cases?[10–12] While scientific mistakes are not new, one of the major advantages of the scientific method is that it is self-regulating and allows for similar, quantifiable, reproducible results from many different, unrelated observers. This is independent of geographical, cultural, and temporal differences. An extensive literature study of several selected, important cases of flawed science has uncovered some interesting trends and conclusions: (a) effects have been, in many cases, anticipated; (b) initially theorists "are very happy" to extend existing theories with a rush of new ideas, advanced within 6–12 months of the initial "discovery"; (c) questions are raised within 12–18 months, mostly

13 Ivan–Yvan Rules

Scientific Work that Elicits Additional Scrutiny

1. **"Too good to be true":** producing a major development such as cold fusion
2. **"Extreme accuracy":** always at or beyond the accuracy limits of current equipment
3. **"One data point":** on which the whole claims of fantastic physics rely
4. **"Peculiar experimental conditions":** which can only be reproduced in a particular experimental set-up, in a particular geographical location, by a particular researcher
5. **"Violation of statistics":** for instance, that the noise is identical on seemingly disparate experiments or that a perfect Gaussian distribution (with no noise) is found in a random process
6. **"Excuses, excuses, excuses":** for not doing the obvious checks
7. **"Blah, blah, blah":** big smoke screen for something that violates common sense
8. **"What else could it be":** i.e., wishful thinking assigning results to a major discovery when it can as well be explained as a mistake
9. **"Everybody can be Einstein":** very politically correct claims of extraordinary physics done by researchers with no prior background or history of important work
10. **"Bridges don't fall down":** it doesn't affect anything else
11. **"Obscure or sensationalist publications":** especially in the popular press
12. **"Jumping around":** to solve always a new, very important problem which has been unsolved for many years
13. **"Fashion":** always following the trend *du-jour*

from experimentalists; (d) the time lags are probably related to the speed with which relevant, well-controlled theories or experiments can be performed; and (e) consensus is reached very quickly, perhaps at around three years, both by experimentalists and theorists.[7, 12–16]

Over many years of research, interaction with colleagues, refereeing, and a general critical attitude, we were able to distill a set of simple rules that help us judge and determine when a particular scientific work has to undergo extensive, additional scrutiny. While these are not "airtight" and not all scientific work that satisfies these rules is necessarily flawed, flawed science invariably obeys many of the Ivan–Yvan (I–Y) Rules. They are listed more or less in order of importance in the figure.

As an example, we will illustrate the application of some of these rules to the Schön case. In these experiments, when many materials (e.g., organics and oxides) were incorporated into a FET-type structure, their properties could drastically be modified, exhibiting many interesting properties such as high-temperature superconductivity and the quantum Hall effect. These results are too good to be true (Rule #1)! The critical oxide could only be prepared in one laboratory, by one investigator; these are peculiar experimental conditions (Rule #4). The distribution of breakdown voltages was a perfect Gaussian, with no noise, violating statistics (Rule #5). Many of the results appeared in the public press before being scrutinized and reproduced by the expert scientific community (Rule #11). Many other rules were violated as well, and the scientific community called these experiments into question before fraud was uncovered.[17] Thus, these experiments, while plausible, should have been subject to extra scrutiny after a while. They were, and the fraud was uncovered.

On the other hand, we have applied these rules to a variety of situations which may have, at first sight, been considered flawed. Invariably, however, research that obeyed the I–Y Rules but were correct, was reproduced—under a variety of different experimental conditions, in different laboratories, in many places in the world, by different researchers.

In conclusion, it is important to be vigilant on a continuous basis to assure that the instances of flawed science are reduced to a minimum. Being critical is necessary and good! Judicious application of the I–Y Rules can uncover scientific flaws in many cases, as illustrated for the Schön experiments. Perhaps the most important conclusion is that sensational scientific claims that are flawed are invariably uncovered very quickly by the scientific community because *Nature is self-regulating and it always wins*.

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