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FEATURE

The rise and fall of a physics fraudster

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The rise and fall of a physics fraudster

Seven years after rumours of massive fraud began to surface, the repercussions of Jan Hendrik Schön's lies still reverberate. In her new book *Plastic Fantastic*, abridged and edited here, **Eugenie Samuel Reich** chronicles how his fraud shook the scientific world

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In the spring of 2002, the world's most productive young scientist was a 31-year-old physicist at Bell Labs in New Jersey in the US. With eight papers published in *Nature* and *Science* in 2001 alone, Jan Hendrik Schön was emerging with breathtaking speed as a star researcher in physics, materials science and nanotechnology. His research was based on an unrivalled ability to transform the properties of materials by the application of an electric field. He built high-performance transistors made not from silicon but from carbon-based materials. He coaxed materials into superconductors, which have an almost magical ability to conduct electricity without resistance. He described the world's first organic electrical laser, and the first ever light-emitting transistor. He even claimed to have built the world's smallest transistor by wiring up a single molecule. It was a dazzling nanotechnology triumph.

But in September 2002, managers at Bell Labs released a report that laid out a series of shocking revelations. Written by a panel of outside scientists (chaired by Stanford University physicist Malcolm Beasley), the report made clear that much of Schön's data were fake. His discoveries were lies. Many of his devices had probably never existed. The case of fraud was uniquely large in scale – unprecedented in terms of the number of discoveries Schön had faked, and the number of other scientists he misled or deceived. Scientists in at least a dozen labs wasted time and money chasing rainbows because of him, and millions of dollars worth of US government research was commissioned to follow up on the fraudulent claims.

In interviews at the time, scientists demanded to know how things had been able to get so far. How had one person – the investigators cleared everyone else of misconduct – succeeded in convincing managers at a top US research institution to back and promote such grossly fabricated claims? Why did journals trusted to deliver news of scientific developments publish the fraudulent papers? And why did the much-celebrated self-correcting nature of science not bring the fraud to light sooner? On the day of the report's release, Schön was fired and fled the US to an unknown location. Answers to these questions seemed to vanish with him.

Great expectations

Schön began working as a postdoc at Bell Labs in Murray Hill in 1998 after a short stint as an intern in 1997. His manager and postdoctoral supervisor was Bertram Batlogg, then head of the Materials Physics Research Department. Earlier, as a graduate student at the University of Konstanz in Germany, Schön had already begun to fudge data (see box on page 28), but in the first year of his postdoc, with the ambitious expectations and relative freedom of the Bell Labs environment both playing a role, his fraud began to escalate dramatically. He kept up links with the laboratory in Konstanz where he had done his PhD, and in September 1999 he returned from a trip there claiming to have made a field-effect transistor out of crystals of pentacene – a hydrocarbon compound consisting of five linked benzene rings – grown by chemist Christian Kloc at Bell Labs.

To get these data honestly, Schön had to have made several technical advances. First, he made field-effect transistors, using a machine to sputter, or deposit, a layer of aluminium oxide onto the surface of the pentacene crystals. Second, by applying a voltage to a gate electrode attached to this layer, he had transformed the pentacene between insulating and conducting states. Although pentacene is usually a p-type material, in which electricity consists of the flow of positive charge, Schön said that he had been able to change the material between p-type and n-type (negative-charge flow) by varying the voltage on the gate electrode from negative to positive, influencing the organic material

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through the insulator. This result, called ambipolarity, would have made it easier to wire the transistors into inverters (logical circuits that are able to reverse the direction of an incoming signal). Third, Schön connected the inverters to form a more complex oscillating circuit. He was not only studying the properties of organic materials, but apparently making prototype organic-crystal electronics.

Three years later, in 2002, Schön revealed to his investigators how he had actually done it. He was doing science backwards. He started from the conclusion he wanted and then assembled data to show it. Although Schön did have several wired-up pentacene crystals in the lab in Murray Hill and in Konstanz, his own writing suggests that he was taking his inspiration rather more from his understanding of other scientists' expectations.

Having created a field-effect transistor set-up that was understood by colleagues to work well, Schön began to claim further advances, always following predictions and expectations. When one colleague suggested that he might be able to tune the crystals into a superconducting state, Schön agreed, and produced the data.

His resistance curves did not look at all like the kind of data that might have arisen from a sloppy experiment. They had a larger-than-life, doubt-dispelling, quality. Schön knew this, because he later told investigators that he had used an equation to calculate a very smooth sweep of data, in order to avoid doubt. When scientists doubt others' claims, they tend to ask detailed questions about the method that has produced them – questions that Schön must have known he would have struggled to answer. The smooth data helped to stall inquiries.

But not everything went smoothly. On one occasion, Schön misunderstood a series of theoretical expectations. He had fitted some of his data using a theory on the transport of charge through organic materials that was conceived by physicist Theodore Holstein in the middle of the last century, and which happened to be described in a textbook Schön had. But in other cases, Schön fitted his data more closely to expectations arising from discoveries made in conventional materials such as silicon. In following two theories – one novel, one more conventional – Schön began to produce contradictions in the heart of his data, and it was not long before theoretical physicists began to notice.

That left Schön in a bind. Either he stood by and allowed the theorists to unravel the story, or he pushed on, hoping that by generating enough data he could throw the theorists off the trail. Schön chose the second option. Pushed to describe his devices, he began to rely increasingly on data that had worked well on

Shadow data
Schön's computer skills enabled him to fabricate compelling data that dispelled colleagues' doubts about his experiments.


Bell Labs

Plausible and friendly
Although quiet, Schön was far from a social outcast. His amiable, eager-to-please nature kept him from making enemies.

previous occasions, littering many of his breakthrough papers with graphs that described a wide range of materials and experiments, but that were duplications of each other.

Scientists astray

As word of Bell Labs' spectacular field-effect transistor set-up spread during the early part of 2000, other researchers began to try to replicate the work. They included research groups led by chemical engineer Dan Frisbie and physicist Allen Goldman at the University of Minnesota.

Frisbie decided to put a graduate student, Reid Chesterfield, onto the task of replicating some of Schön's work. Chesterfield did not have to work alone. Goldman was one of the world's leading experts in superconductivity, and his postdoc Anand Bhattacharya was keen to use the field-effect set-up to try to induce superconductivity on the surface of organic crystals. Towards the middle or end of 2000, Frisbie and Goldman's labs geared up for what Bhattacharya called "a double-barrelled effort" to be the first to replicate, and even to surpass, Bell Labs' promising lead.

The first step was to build a field-effect transistor (FET) set-up. Following Kloc's publications, Chesterfield put together a crystal-growth apparatus in Frisbie's lab and taught himself to grow organic crystals. He also learned to attach metal contacts to the crystals, and made some basic measurements of the mobility of charge through them. He found his measurements varied from one crystal to another, and that the mobilities of charge moving across the crystals were never more than about a tenth of those Schön reported, but in occasional samples of tetracene – a hydrocarbon containing four benzene rings linked together – he sometimes felt he saw a leap in current, evidence for trap-free charge transport, which Schön had reported in late 1998. Still, this was only a precursor to the finding they wanted.

"The killer result was the FET," Chesterfield said.

The labs developed a routine. Chesterfield grew the crystals and put metallic contacts on them, then he gave the samples to Bhattacharya to sputter them with aluminium oxide. If all went well, Chesterfield could then add the gate electrode and the researchers could start making field-effect measurements. But they often never got that far. Frisbie remembered Chesterfield showing him devices in which the aluminium-oxide layer buckled, ripped or failed to stick in the first place. Once, when Chesterfield opened up the sputtering machine, he found it empty, the fragile crystal having disintegrated away into nothing, apparently after being peppered at too high a power with particles of aluminium oxide.

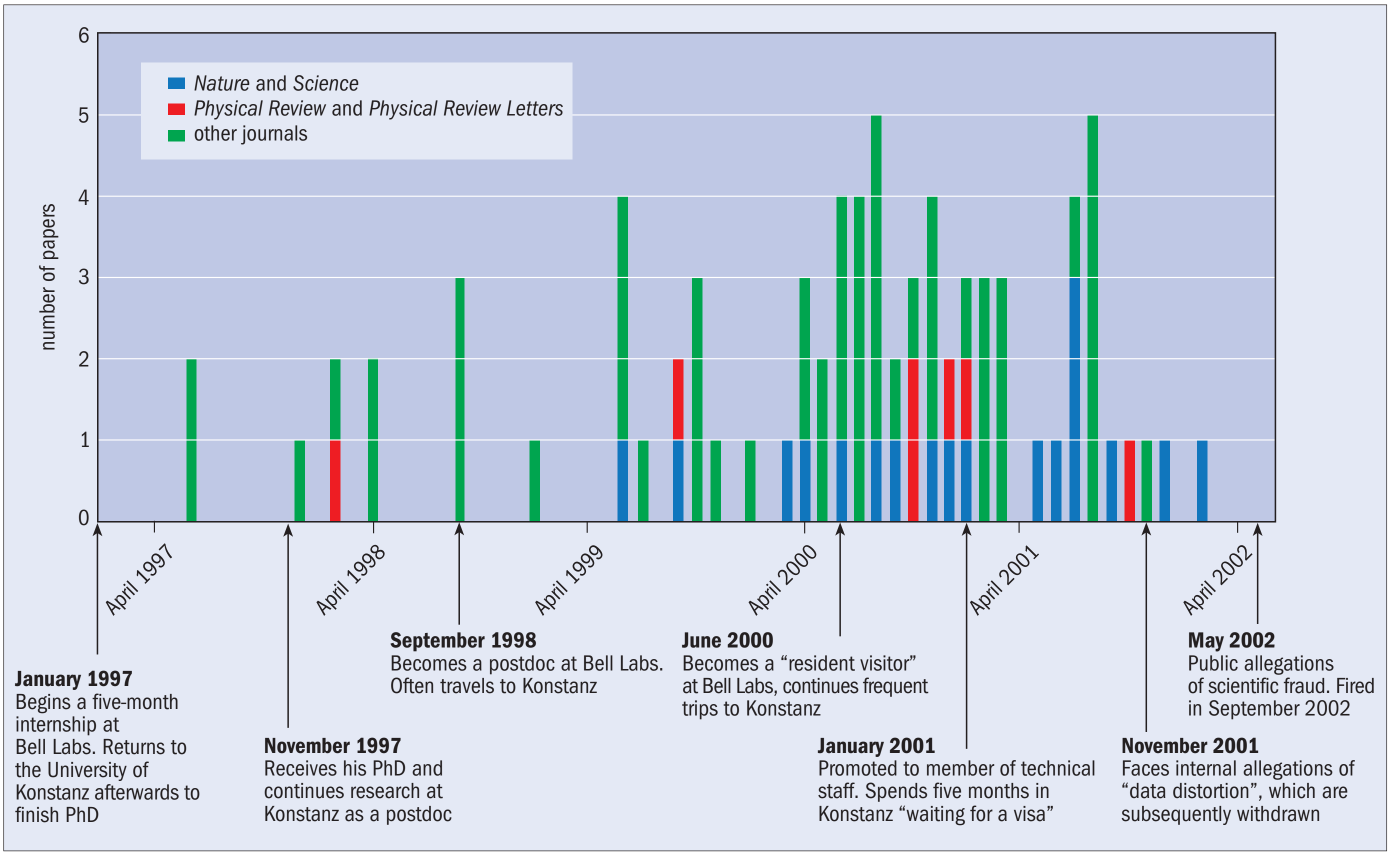
After about six months to a year of failure, Bhattacharya decided to write to Schön directly. Schön was receptive, friendly and encouraging. He urged the Minnesota researchers not to give up. He promised them that if only they were persistent, they would succeed in replicating his work. He offered to answer any questions they had.

They had many. Chesterfield said they asked how far Schön had placed his sputtering target from his sample. He said 15 cm. They placed their target 15 cm from their sample too. They asked for the wattage he was using to fire the gun inside the sputtering machine, and made sure theirs matched. When Schön said that he sometimes repaired damage caused by sputtering the crystals by placing them in hydrogen, Chesterfield plumbed in a hydrogen supply so that they could do the same in Minnesota. Chesterfield let out a heavy sigh as he recounted all the different things Schön suggested and that they tried. "None of it worked."

Eventually, Frisbie and Chesterfield decided to cut their losses and started a new project working with a thin organic film that had nothing to do with Schön's technique. They began to get some results straight away. By the time news came out that Schön's work was fraudulent, Chesterfield said he hardly read it. The information filtered through to him only gradually. After talking to another researcher at a conference in 2003, Chesterfield went home, took one of his old crystals out, and made some final measurements. "Then I concluded Schön was lying," he said.

Meanwhile, Bhattacharya surfaced from his research to notice that his contemporaries were getting papers published and offers of jobs as junior professors at good universities, and that he was not. His postdoc, which he expected to be a short career-stage lasting two or three years, went on to last five. He said that he learned a lot about how to do science, how to follow his nose, and how not go after things in a "holy grail kind of way". But he also had a good introduction to the hitches and surprises that can ruin a field-effect experiment, as they nearly all happened. Eventually, working with three other researchers in Goldman's group, Bhattacharya produced a field-effect transistor set-up using an insulator they had developed trying to pursue Schön's work, and measured field-effect-induced superconductivity in bismuth, rather than in organic crystals. "I will never experience so much satisfaction again in my whole life," said Bhattacharya.

But the fact that the researchers eventually made



The paper trail This timeline of Schön's most active years shows the major events in his research career and a plot of when he submitted papers for publication. Submission dates include 66 provided by journals and 11 estimates. Shortly before his fraud was revealed, Schön submitted several papers that were never published; neither these nor his numerous conference abstracts are shown. Source: ISI Web of Science.

good did not make up for their wasted time. When I visited Goldman's lab in 2006, we passed a small cabinet, which he thumped. The cabinet rattled like it was full of skeletons, or old samples. "Organics graveyard," said Goldman.

Frisbie also sounded disappointed. Despite the major attention given to Schön's exciting claims at meetings and in journals, it had taken a long time to realize that the data were invalid. Although other scientists were having difficulty replicating the work, they did not report their failures publicly. No-one claimed success, but it had seemed possible to Frisbie that people were keeping the details of their progress close to their chests, at least until they were ready to publish. "Can I ask you something?" said Chesterfield when I interviewed him. "Did anyone try as hard as we did, and still not get it?"

They did. Even at Bell Labs, researchers lost time following up on Schön's work. They included Jochen Ulrich, a graduate student recruited by Horst Störmer of Columbia University, who had been the director of the Physical Research Lab at Murray Hill. Störmer had shared the 1998 Nobel Prize for Physics for discovering the fractional quantum Hall effect in gallium arsenide, so the chance to work with him sounded like a wonderful opportunity. But to Ulrich's disappointment, he never got to explore quantum effects in organic crystals, and instead had to spend months on the mundane task of trying to remake Schön's field-effect transistors. Sick of the materials, he switched to a new topic, but still left science at the end of his postdoc. "It was frustrating," he said. "I wouldn't go as far as to say that I left science because of this, but it changed the way I thought about science. I used to have a glorified view. Scientists search for the truth. That's not always the case."

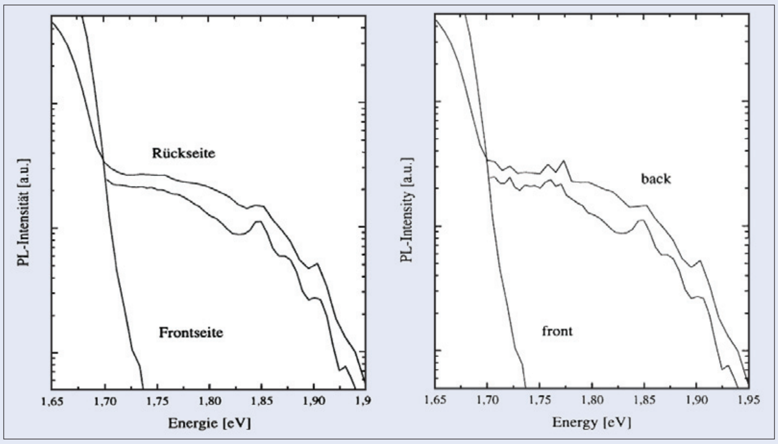
Those who made progress investigating Schön's claims did so by being flexible. They rejected the authority of a famous institution and paid attention to their own experiences in the lab. The self-correcting process happened, but it was haphazard and disorganized, with a lot of self-doubt along the way. In comparison with the archetypal picture of scientists as an army of self-correctors marching in an organized way towards the truth, this was more of a guerrilla war.

First inklings of trouble

Schön's collaborators and managers tried to get him to clarify how his devices had been made. But in 2001, with the dot-com collapse in full swing, Bell Labs' researchers were also under pressure to produce world-class results. Obliging as ever, Schön branched out from organic crystals into nanotechnology. He claimed to be able to control organic matter on the molecular scale and to have built a transistor out of a layer of molecules, and eventually even from a single molecule. Many staff and some managers began to ask serious questions about the devices' theoretical underpinnings.

The circulation of the first nanotechnology data took place against a background of deterioration both in management–staff relations and in the quality of scientific discussion. As the share price and revenues of

Ausreißer: how Schön's fraud began



Left, adapted from figure 3.30 in J H Schön 1997 *PhD Thesis* University of Konstanz. Right, adapted from figure 2 in J H Schön *et al.* 1998 *Solar Energy Materials and Solar Cells* **51** 371.

Jan Hendrik Schön was a year younger than his fellow students when he entered graduate-level research in 1993 at the University of Konstanz in Germany. Given the extensive scale of his later fraud, a natural question to ask is when he first began cheating. Schön's first data from his PhD included many fuzzy, scattered points. When I showed his former PhD supervisor, physicist Ernst Bucher, results that Schön had shown him a decade earlier, the professor read through the text, nodding, then looked at a figure, jabbed his finger at a data point that lay off the main trend, and commented, "*Ausreißer*". The word means "outlier", a measurement that lies some way off the main trend of the data. In German, *Ausreißer* also means "wayward child" or "maverick". Both the presence of outliers, and the scattered, noisy data, suggest that Schön was initially comfortable with representing the flaws and idiosyncrasies in his measurement process honestly to his professor.

After obtaining the data, however, Schön had to analyse them, putting the stream of numbers that came out of his lab instruments into equations to calculate physically meaningful quantities. As commonly happens in experimental research, Schön had problems getting the results of his calculations to match results reported by other scientists. He began to introduce occasional values that were discrepant, fine-tuning his results to match those that others had achieved. Relieved, he would then write that his result "fits quite well" with the scientific literature.

Over time, Schön began to include fewer *Ausreißer*, the outliers that did not conform to the main trend of the data. By the third year of his PhD, he was beginning to cover for his conceptual limitations with irregular data. In photoluminescence, his first area of expertise, scientists measure the light given out when electrons move between different energy levels in atoms or ions. Peaks in the spectrum of light coming off a sample can be interpreted to reveal the positions of those energy levels in the material. But Schön sometimes struggled to make out any peaks, and he admitted in his thesis that he saw nothing but a large, fuzzy background (left). Even when one group of samples did produce some "relatively sharp" peaks, Schön was not able to make them out clearly enough to tell which of two possible configurations of energy levels could explain them, he wrote. Frustrated by the limitation, he submitted a paper to *Physica Status Solidi A* in which he suggested the opposite. Within a month, writing in *Solar Energy Materials and Solar Cells*, he went further. He added a couple of clear peaks to two of his spectra (right), and wrote that the results he derived from his undeclared manipulation were "in good agreement with data reported in the literature".

Schön was therefore sober enough to describe an ambiguous lab experience correctly, but he later revised his account, in stages, to reach a simpler story that fitted better with other scientific literature. As a PhD student, he also cultivated an aversion to disagreements that became so extreme that his early work included almost no discussion of conflicting observations. Instead, he forged agreements, one number or result at a time, as if trying to stay in compliance with science. This helps to explain why Schön did not realize, at least not in the beginning, that he might one day get into serious trouble by faking data. If he stayed in good agreement with other scientists, how far wrong could he go?

Lucent Technologies, Bell Labs' parent company, fell during 2001, the conditions for research worsened. To save money, building managers unscrewed many of the light bulbs in the research buildings, so that places where researchers might bump into each other and talk things through were considerably less well lit than they had been.

Interviewed by reporters at the time, managers tried to sound upbeat, but around them, staff scientists were losing their jobs. The number of members of technical staff in the Physical Research Lab fell from 114 in 1997 to 56 in 2001. Today, under Alcatel-Lucent, the lab no longer exists in anything like its old form, but even eight years ago people were anxious about whether science could continue. So were managers, according to Steve Simon, director of theoretical physics. "People were getting fired, there was downsizing. We wanted to maintain some semblance of activity. It wasn't like anyone put the screws on and said 'publish more', but technical problems with one person's data were not a big enough issue to get on the radar screen."

In November 2001, six months before Schön was publicly accused of fraud, allegations of intentional data distortion were brought to the attention of the vice-president of the Physical Research Lab, Federico Capasso, and the director of Nanotechnology Research, John Rogers. Schön was challenged, but instead of being thoroughly investigated, he was given time to respond. He used this time to generate data that appeared to answer the concerns. The allegations were withdrawn, but scientific controversy continued to rage over the results, and in April 2002 evidence emerged that spelled the beginning of the end for Schön.

Julia Hsu and Lynn Loo were both affiliated with Rogers' department. Neither was trying to blow the whistle on Schön. Instead, consistent with the need to save Lucent money, the two women had shared a hotel room at the American Physical Society meeting in March 2002 in Indianapolis, and started talking about Loo and Rogers' work with soft lithography, a way of patterning and printing circuits onto plastic and other organic materials. Hsu wondered whether soft lithography could be used to make softer and gentler contacts with organic molecules, such as the ones Schön was working with. After returning to Bell Labs, Loo and Hsu ran a series of experiments, and by 19 April were ready to apply for a patent on the idea.

In order to write the patent application, they needed to define how novel their work was relative to what was already known, so Hsu printed out a sheaf of relevant papers and grabbed them off the printer on the way to the Bell Labs patent office. The sheaf included Schön's *Nature* and *Science* papers on molecular transistors. Hsu and Loo had just sat down with the patent attorney when he took a phone call, and the pair started leafing through the papers. Loo declined to comment on what happened next, but a story that was relayed to me second-hand is that she was sleepy, nodding off, things going in and out of focus, when she noticed the duplicated data.

The duplications Loo noticed were the output of the inverters, the logical circuits that Schön had claimed to construct from his molecular devices. The outputs were identical, even down to the noise – the tiny wiggles caused by imperfections in the measuring process. Loo showed the duplication to Hsu, who agreed that the curves looked very similar.

Game over

The graphs were passed to two other researchers who confronted Schön and informed Rogers. Schön admitted that one of his graphs was printed incorrectly, and promised to send an erratum to the journal concerned. In the meantime, Lydia Sohn, a Princeton University physicist who had been following Schön's work, was told to look out for a forthcoming erratum relating to the work on molecular transistors. Working on that information, Sohn independently noticed the same duplications and shared them with a colleague, Paul McEuen at Cornell University, who found further examples. Sohn and McEuen informed the journals in which Schön had published, and McEuen complained to Bell Labs managers, who called in the external panel in May to investigate the mounting concerns.

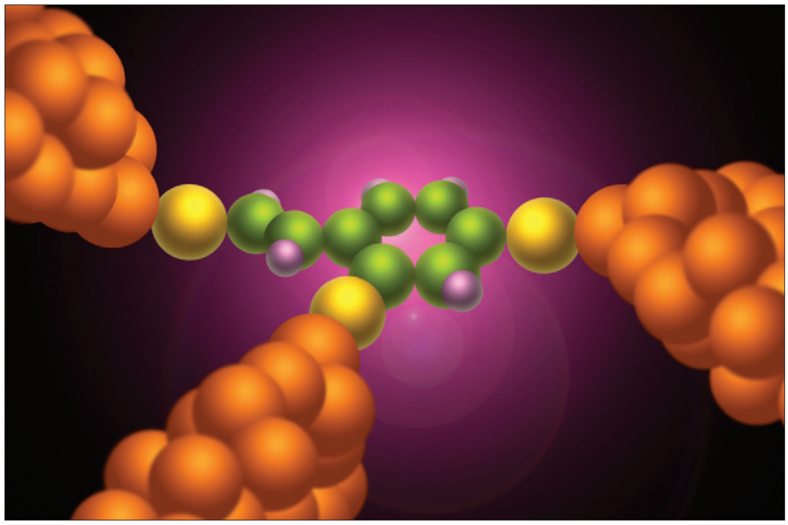
Once the investigation report was ready, Schön and others had some days to read it before managers released it publicly on 25 September 2002. Schön wrote a reply admitting to making "mistakes" and saying that he hoped that he might be able to keep working on his results, if possible. Then Rogers and Cherry Murray, Bell Labs' vice-president of physical-sciences research, fired him. Schön told them, according to what different people later said, that he had had a good time, or that it had been an honour working at Bell Labs, or that it had been "a blast", and left the building calmly and without a fuss, accompanied by two security guards, as if, one external colleague later commented, one security guard would not have been enough.

Back in Germany, Schön told friends and colleagues that he intended to keep working in science. Eventually, he listened to a former member of the lab where he did his PhD, who explained that he could not go back to work in science and suggested a job at an engineering firm in Germany. Schön agreed. One year later, the University of Konstanz concluded that Schön did not commit misconduct in his PhD work, but still took away his PhD. The German Research Foundation reached a finding of misconduct and introduced an eight-year ban on Schön receiving research funding.

"I guess in several cases it was obvious," Schön wrote to his colleague after his disgrace, explaining that some results had been smoothed out – as if it being obvious made it somehow better. He added that although he had misrepresented data, he did not want to go into further details – that he should not have done it, but could not make it undone. The problem, as he kept telling collaborators near the end, was that he did not have enough time. There were too many mistakes, and the work could not be replicated. It was only bad luck, and no-one could be sure that things would not turn out differently; if he had better luck, and a little more time…

Could it happen again?

This dramatic end to Schön's case brings us back to the question of whether science is, or is not, self-correcting. Science was corrected in the Schön case, but not by itself – only because individual scientists made corrections. From would-be replicators in dozens of labs to many sceptics, only a couple of researchers were transformed into whistle-blowers by the unlikely pattern of evidence. The correcting process turned out to be as human and haphazard as the fraud – and certainly less systematic than Schön's single-minded commitment to keep trying to publish fabrications.



University of Arizona

Real science
Many areas affected by the Schön scandal have subsequently yielded genuine experimental fruit. This artist's impression of a single-molecule transistor echoes one of Schön's final "breakthroughs".

The problem is that when data are fraudulent, they are designed to elude all the self-correcting processes of science. Keen to oblige, Schön tuned his data to pass quality-control checks and fulfil expectations for his research programme. Fraud was able to stifle questions about Schön's lab technique that would otherwise have been asked, and to turn review processes at journals into opportunities for additional fabrication. Other scientists' support of the fraud was unwitting, but the decision to place so much trust in a colleague was a conscious rationalization that continues to be defended in science to this day.

That is where the danger lies. Even now, Schön would be happy to work in science again. Somewhere in science, there must be a place for a logical, intelligent, literal and meticulous person who is not brilliant, who does not quite "get it". Schön's gift for agreeing with whatever others want to hear, his uncanny ability to pick up on any demand in any environment and duplicate answers that seem to work well, and to be plausible and friendly as he goes; these qualities will not go away. A couple of years after this article is printed, his ban by the German Research Foundation will expire. Then maybe he will find an opening. If not him, maybe others, and would science fraudsters less extreme, less literal, less once-in-a-generation than Schön be any less dangerous than he was; or more?

In order to know where Schön, or someone like him, might next show up, it helps to keep something in mind: what do scientists most want? What result will help to protect a great lab from an unjustified cut in funding? What will change the reviewer's mind? What will take them, and us, far beyond the frustratingly primitive and slow methods and tools of our time, to new horizons? Hold that thing in mind, think maybe also about the thing you most want for your work to succeed, and there he is. Curly brown hair, half a smile and half a shrug, he is holding out the answer on a printout from nowhere, and asking whether there is any follow-up work that would also be useful.