Introduction: the technological golem

'Science seems to be either all good or all bad. For some, science is a crusading knight beset by simple-minded mystics while more sinister figures wait to found a new fascism on the victory of ignorance. For others it is science which is the enemy; our gentle planet, our slowly and painfully nurtured sense of right and wrong, our feel for the poetic and the beautiful, are assailed by a technological bureaucracy – the antithesis of culture – controlled by capitalists with no concern but profit. For some, science gives us agricultural self-sufficiency, cures for the crippled, a global network of friends and acquaintances; for others it gives us weapons of war, a school teacher's fiery death as the space shuttle falls from grace, and the silent, deceiving, bone-poisoning, Chernobyl.

Both of these ideas of science are wrong and dangerous. The personality of science is neither that of a chivalrous knight nor pitiless juggernaut. What, then, is science? Science is a golem.

A golem is a creature of Jewish mythology. It is a humanoid made by man from clay and water, with incantations and spells. It is powerful. It grows a little more powerful every day. It will follow orders, do your work, and protect you from the ever threatening enemy. But it is clumsy and dangerous. Without control a golem may destroy its masters with its flailing vigour; it is a lumbering fool who knows neither his own strength nor the extent of his clumsiness and ignorance.

A golem, in the way we intend it, is not an evil creature but it is a little daft. Golem Science is not to be blamed for its mistakes; they are our mistakes. A golem cannot be blamed if it is doing its best. But we must not expect too much. A golem, powerful though it is, is the creature of our art and our craft.'

This extract from the first volume of the series, *The Golem: What You Should Know About Science*, explains why we chose a golem as our motif.[1] Now we turn from science to its applications; things are not so different.

Like its predecessor, this book contains seven stories. These are the themes: it is very hard to say whether Patriot missiles succeeded in shooting down Scuds during the Gulf War; the blame for the explosion of the *Challenger* Space Shuttle is much less easy to assign than it is usually taken to be; conclusions about safety drawn from deliberate crash-tests of a train and an airplane were less clear than they appeared; the origins of oil are more controversial than we thought and surprisingly difficult to pin down; economic models built by the British government advisors have such big uncertainties that they are useless for forecasting; the consequences of the radioactive fallout from Chernobyl were misunderstood by the official experts; and research on a cure for AIDS needs the expertise of patients as well as doctors and researchers.

The stories, we hope, are interesting in themselves, but their full significance must be understood in terms of the escapades of golem science. The problems of technology – we use the term loosely to mean 'applied science' – are the problems of science in another form.

As with *The Golem*, *The Golem at Large* has a very simple structure. The substance is in the stories but we also draw out the consequences in a short conclusion. We do not expect the conclusion to carry conviction without the substance. While the basis of the argument is drawn from the history and sociology of scientific knowledge, we have introduced only a few technical principles from that field. As in the first volume, we have made considerable use of the notion of the 'experimenter's regress'. This shows that it is hard for a test to have an unambiguous outcome because one can never be sure whether the test has been properly conducted until one knows what the correct outcome ought to be.

Another idea introduced in this volume is the notion that in science and technology, as in love, 'distance lends enchantment'. That is to say, scientific and technological debates seem to be much more simple and straightforward when viewed from a distance. When we find ourselves separated from our loved-ones we remember only why we love them; the faults are forgotten. In the same way, science and technology, when understood through others' inevitably simplified accounts, look artless. Closer to the centre of a heated debate, the less pre-determined and more artful do science and technology appear. The irony is that, quite contrary to what common-sense might lead one to expect, it is often that the greater one's direct experience of a case, the less sure one is about what is right.

A third idea, made much use of in the chapter on the Patriot missile, is the notion of 'evidential context'. It shows that the meaning of the same experimental finding, or test outcome, can seem positive or negative depending upon the problem that the finding is taken to address.

In each story we have tried to display technical details in as simple a way as possible. Even if the overall conclusion of the book is resisted we hope to explain some technology to those who might not otherwise encounter it. Mostly we tell of technological heroism but we present it as a human endeavour rather than a superhuman feat. Technology should not be terrifying or mysterious, it should be as familiar as the inside of a kitchen or a garden shed; as we will see, the decisions made by those at the frontiers are, in essence, little different from those made by a cook or a gardener.

Technology is demonstrated and used in conditions which are under less control than is found in scientific laboratories. As we will see in this book, those faced with the uncertainties of technology are inclined to look toward the controlled environment of science as a golden solution. But science cannot rescue technology from its doubts. The complexities of technology are the same as those that prevent science itself from delivering absolutes; an experimental apparatus is a piece of technology and, looked at closely, the conditions seem as wild inside the lab as outside. Both science and technology are creatures of our art and our craft, and both are as perfectible or imperfectible as our skill allows them to be. As we showed in *The Golem*, science at the research frontier is a matter of skill, with all the uncertainty that that implies; technology at the frontier is the same.

While technologists dream of the perfection of science, the reliability of everyday technology is often taken to prove the enduring infallibility of science. Rockets go to the moon, airplanes fly at 30,000 feet and the very word-processor on which this book has been typed seems to be a tribute to the irrevocability of the theories used in its design. There is something suspicious about this argument too. Why do scientists who, as they see it, work in maximally controlled conditions, turn away from the laboratory to verify their position in the world and the truth-like character of their enterprise? And, if technology is the staff of science, why is it that when technology fails – as in the Chernobyl melt-down and the Space Shuttle explosion – science does not fail? Furthermore, how is it that superb technologies like the barrel and the waggon wheel seemed to lead a life independent of science? The argument from the reliability of technology has a 'no-lose' clause: Chernobyl and the Space Shuttle can verify science if they work but cannot damage it if they do not. The clause is enforceable because failures of technology are presented as failures of human organization, not science.

When science seems less than sure, technology is cited in its defence, and when technology seems less than sure, science is summoned to the rescue; the responsibility is passed backward and forward like the proverbial hot potato. And if the potato is dropped it is always people who are said to drop it. Our picture of the relationship is far more straightforward. Both science and technology are skilful activities and it cannot be guaranteed that a skill will always be executed with precision. Technology is not the guarantor of science any more than science is the guarantor of technology.

This is not to say that we advise the readers of this book to worry more when they board an airplane. Just as science may enter a realm where no one questions or disputes its findings, so technology becomes more reliable as our experience grows and our abilities develop. The workings of gravitational wave detectors and solar neutrino counters are still matters of dispute; the workings of voltmeters and small, earth-bound telescopes are not. The workings of Space Shuttles and AIDS cures are still matters of dispute; the working of barrels, waggon wheels, personal computers, and motor cars are not.

It would, of course, be foolish to suggest that technology and science are identical. Typically, technologies are more directly linked to the worlds of political and military power and business influence than are sciences. Thus, as we show, the outcome of the argument over the success of the Patriot anti-missile missile links directly to the economic fortunes of the firms that make it and to the military postures of governments. Relationships of a similar kind can be seen in respect of every case discussed in this book, whereas in the first volume of the series the distance between the science and the national and business environments was far greater. But these are difference of degree; the influences of military, political, economic, and other social forces may give obvious vigour and longevity only to certain technological debates, but the potential of these forces is found in the structure of scientific and technological knowledge. Since all human activity takes place within society, all science and technology has society at its centre.

The book can be read in any sequence but the end of the volume stresses the contributions of 'lay experts' more heavily. The idea of golem science and golem technology does not imply that one person's view is as good as another's when it comes to scientific and technical matters; on the contrary, the Golem series turns on the idea of expertise. But where is the border of expertise? What is clear from the latter cases is that the territory of expertise does not always coincide with territory of formal scientific education and certification.

The examples of Cumbrian sheepfarmers and AIDS patients presented in this book are cases where people normally referred to as laypersons made a vital contribution to technical decisions, but these are only laypersons in the sense of their not possessing certificates. In fact the farmers were already experts in the habits of sheep and the flow of water on the Cumbrian fells, and the AIDS patients already knew most of what could be known about the habits of AIDS sufferers, their needs and their rights. Furthermore, as time went on, many of the AIDS patients trained themselves to become fluent in the language and concepts of medical research. Bringing such persons into the technological decision-making process should not be seen simply as a democratic necessity; rather it is good sense in terms of using available expertise even when it is found in unexpected places.

In our cases, undemocratic reflexes may have delayed the recognition of this 'lay-expertise', but the solution was not just more democracy. After all, what expertise does a member of the public, as a member of the public, bring to technological decision making? Expertise is too precious for the problem of its recognition to be passed wholly into the sphere of politics. Lay political activism may sometimes be necessary to jerk people out of their comfortable assumptions about the location of expertise, but success in this sphere makes it all too easy to jump to the conclusion that expertise can be replaced with heartfelt concern; this is wrong.

Authoritarian reflexes come with the tendency to see science and technology as mysterious – the preserve of a priest-like caste with special access to knowledge well beyond the grasp of ordinary reasoning. It is only through understanding science and technology as golem-like – as failure-prone reachings out of expertise into new areas of application – that we will come to understand how to handle science and technology in a democratic society and resist the temptation to lurch from technocracy to populism.

Finally, let us be clear that we look only at cases where conclusions are the subject of dispute. Such events are a statistically unrepresentative sample of science and technology because most science and technology is undisputed. But disputes are representative and illustrative of the roots of knowledge; they show us knowledge in the making. As we journey forward into the technological future we see the technological past as through mirrors barring our route. These backward-looking mirrors provide a distorted perspective in which everything is seen as settled almost before it was thought about; *The Golem at Large* is meant to lead us from the hall of mirrors.

NOTE

[1] In fact the first volume was called *The Golem: What Everyone Should Know About Science*. The title has been slightly changed for the new edition which also includes a substantial 'Afterword' discussing scientists' reactions to the book.

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A clean kill?: the role of Patriot in the Gulf War

THE GULF WAR

In August 1990 Iraqi forces invaded Kuwait. The United States presented Iraq with an ultimatum – 'withdraw or face a military confrontation'. The Iraqi president, Saddam Hussein, responded by threatening to stage 'The Mother of All Battles'. Over the next four months the United States set about building up military strength in neighbouring Saudi Arabia with the intention of driving Saddam's army from Kuwait. Given Iraq's confrontational stance, this meant building a force capable of destroying all of Iraq's military resources.

Considering the scale of the imminent confrontation, and its distance from the American continent, the United States needed the backing of the United Nations and the military and political cooperation of many nations, notably Iraq's neighbours. A critical feature of this alliance was that a set of Arab states would side with the Western powers' attack on a fellow Arab state. As the old saying goes, 'my enemy's enemy is my friend', and at that time all the Arab states except Egypt had an enemy in common – Israel. On the other hand, America was Israel's staunchest ally, while Iraq was viewed as an important player in the confrontation with Israel. Thus the political alignment that the US needed to hold in place was continually in danger of collapse. It was crucial for American policy in respect of the forthcoming Gulf War that Israel did not take part in the conflict. Should Israel attack Iraq, creating circumstances in which the Arab states would be directly supporting Israel in its attack on an Arab ally in the Middle East conflict, it might become impossible for the other Arab states to continue to support America. Iraq's strategy was clear: they would try to bring Israel into the confrontation that had started with their invasion of Kuwait.

On 17 January 1991 the allies launched a massive air attack on Iraq that would last for five weeks. The war was over before the end of February following a devastating ground attack lasting four days. This is the setting for the argument that has raged about the effectiveness of the Patriot anti-missile missile.

On the first night of the air attack, Iraq fired six Scud missiles at Israel. The Scud was a Soviet-built missile extended in length and range by the Iraqis and known locally as the Al-Husayn. Thereafter Iraq launched many more Scuds at Israel, and at Saudi Arabia, especially at the American bases. On 25 February, a Scud hit an American barracks, killing twenty-eight and wounding ninety-eight military personnel. Otherwise, in spite of the fact that at least some Scuds landed and exploded, it was a failure in terms of its ability to damage men or materiel. As a propaganda and political weapon, however, it was, from the beginning of the war, potentially a potent force.

The Patriot was used in the Gulf War to combat the Scud. It was used first in Saudi Arabia and then it was rapidly deployed in Israel after the initial Scud landings. It may be that the military ineffectiveness of the Scud was due to the success of Patriot. It may be that irrespective of its military effectiveness, Patriot played an important role in keeping Israel out of the war; the fact is that Israel did not attack Iraq and the alliance held. During the course of the war the best information is that more than forty Scuds were directed at the allied forces and around forty at Israel. A total of forty-seven Scuds were challenged by 159 Patriots. The question is, how many Scuds did Patriot actually destroy?

WAR, SCIENCE, AND TECHNOLOGY

War is a confused and confusing business. Martin Van Creveld, the respected writer on military command, says on page 187 of his book *Command in War*, that war is 'the most confused and confusing of all human activities'. In the case of Patriot, technological fog and 'the fog of war' are found in the same place with quite extraordinary results. What we want to do is explain how it can be that it remains unclear whether the Patriot actually shot down any Scuds. Though there are firm opinions on both sides, we still do not know whether the anti-missile missiles stopped Scuds from hitting Israel, stopped them from hitting Saudi Arabia, or failed to stop them at all.

The art of experimentation is to separate 'signal' from 'noise'. One would have imagined that one of the clearest 'signals' there could be would be the explosion of a ballistic missile warhead; one would think that this would be well out of the 'noise'. Either the Scuds were getting through and causing huge explosions, or the Patriots were destroying them and preventing the explosions – what could be a less ambiguous test of a technological system? It turns out that it was an extraordinarily poor test. The estimated efficacy of the Patriot missile in shooting down Scuds varies from around 100 per cent to around 0 per cent; some said every Scud warhead engaged was destroyed, some said not a single one was hit.

The story of estimates of Patriot's success starts at the beginning of 1991, during the war. Initially 100 per cent success was reported. The score steadily comes down to near zero by the time of a Congressional hearing in April 1992. The confidently stated figure initially moves to forty-two out of forty-five; to 90 per cent in Saudi Arabia and 50 per cent in Israel; to 80 per cent in Saudi Arabia and 50 per cent in Israel; to 60 per cent overall; to 25 per cent with confidence; to 9 per cent with complete confidence; to one missile destroyed in Saudi Arabia and maybe one in Israel. This is what happened as a result of ever more careful enquiries by US government agencies.

It is important not to misunderstand the figures at the lower end of the scale: they do not tell us how many Scuds were destroyed by Patriots; they are estimates of how many Scuds we can be confident were destroyed by Patriots. It may be that more Scuds were destroyed. But, if we are looking for a high degree of certainty, then our estimate has to remain low.

There are groups taking part in this debate with quite clear goals. In 1992, representatives of Raytheon, the manufacturer of the Patriot system, continued to claim that it had shot down most of the Scuds. On the other hand, Theodore Postol, the MIT academic who first drew public attention to doubts about optimistic claims for Patriot's success, continues to believe that he can prove that Patriot was an almost complete failure, and continues to press the case forward. Our interest and curiosity is sparked not by the actual success or otherwise of Patriot, but by the difficulty of settling the argument. We are not going to dwell on the interests, nor are we going to offer any conclusions as to whose evidence is biassed and why; we want to show only that the problem of measurement is hard to solve; we do not have, and cannot have, a clean scientific kill.

Was Patriot a success?

To say that the first casualty of war is truth is to miss the rather more important point that a principal weapon of war is lies. Disinformation confuses the enemy, while favourably biassed reports of success stiffen the resolve of one's own side and demoralise the opposition. It is, then, hardly surprising that, during the course of the war, Patriot was said to be a huge success. Not only was this important for the balance of morale, but it was vital that it was widely believed among Israel's populace that Saddam Hussein's forces were not being allowed to inflict damage on the Jewish State without opposition. It is fair to say that whether or not the politicians believed what they were saying, it would have been naive and unpatriotic of them to say anything other than that Patriot was a flamboyant success. It would be wrong to draw any conclusions for science and technology in general from wartime statements; wartime claims about the success of the missile reflect the demands of war rather than the demands of truth. Two weeks into the war, on 31 January, General Norman Schwarzkopf said, 'It's one hundred per cent so far. Of thirty-three engaged, there have been thirty-three destroyed.' A month into the war, on 15 February, President Bush said that forty-one out of forty-two of the missiles had been 'intercepted'.

After wars are over, the role of patriotic propaganda becomes less clear. Two weeks after the end of the war, on 13 March 1991, US Army officials told Congress that forty-five out of forty-seven Scuds had been intercepted by Patriots. Two months after the war's end, on 25 April 1991, the Vice-President of Raytheon, suppliers of the missile, said that Patriot had destroyed 90 per cent of the Scud missiles that were engaged over Saudi Arabia and 50 per cent of those engaged over Israel.

Any spokesperson for Raytheon has, of course, a clear interest in stressing the effectiveness of his corporation's product. Not only will