Problems with Popular Science

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Popular science is often misleading and even false. Here is a list of common problems with popular science.

Introduction

Popular science is often misleading and sometimes even false. Mistaken impressions from popular science lead to many bad decisions and unhappy experiences from bad investments in science or technology related companies to improper or useless medical care.

First, in this article *popular science* refers to almost any presentation of science and scientific issues outside of so-called "professional" scientific venues, mainly research papers and conferences. I include coverage of science in mainstream newspapers such as the *New York Times* and the *Wall Street Journal*. I include "science" magazines such as *Scientific American* or *Discover*. I include special science TV shows such as the *PBS Nova* show. I also include popular science books found in the science sections of bookstores, both books written by science journalists and books ostensibly written by practicing scientists such as Brian Greene's *The Elegant Universe*. I include works from both scientists who are "popularizers" such as the late Carl Sagan and scientists who are not (many Nobel Laureates produce a book after they receive their prize).

I also include a lot of non-technical material, science ideology/pseudo-history/philosophy, found in high school, college, and graduate level science textbooks. I include science articles aimed at the general public in prominent science journals such as *Science* and *Nature*. I also include some science fiction portrayals of science or scientific issues as these form a continuum with factual popular science. I do not include so-called fringe, New Age, non-mainstream science sources covering topics such as UFO's, ESP, and so forth. These have their own problems.

In this article, I use research primarily to refer to activities that precede a working prototype or proof of concept. I use development to refer to activities after a working prototype or proof of concept exists. Research and development refers to both. This is a more precise definition than often used in popular science, especially business coverage of technology-related businesses. So-called high technology companies often use terms like research, research and development, and so forth to refer to what I call development. Most commercial software development is what I call development, even though it is often described as research or research and development. There are significant differences between research and development.

In general, popular science is very positive. It would not be unfair to characterize a great deal of popular science as "science cheerleading" or even "science propaganda". With that general theme in mind, here is a list of common omissions, distortions, and falsehoods in popular science.

The Perpetual Ph.D. Shortage

Since at least Sputnik in 1957, there have been claims that there is a shortage or imminent shortage of Ph.D.'s both in general and in specific fields. It is implied or claimed that because of this shortage or predicted shortage there are excellent long term career opportunities in science in general and in specific fields. Both prominent individual scientists and professional associations frequently promote these claims. These claims are often repeated uncritically in business-oriented newspapers and media such as the *Wall Street Journal*. The *Wall Street Journal* editorial page has a long history of promoting these claims[1,2].

These claims are usually false. Most research fields produce far more Ph.D.'s than long term positions exist or will exist. The projected shortages never materialize. In many fields, about half of new Ph.D.'s end up leaving the field after receiving their degree. In many fields, those who remain become post doctoral research associates or "post-docs", a short term temporary position. Most post-docs leave their field. In many "hard science" fields such as physics, the Ph.D.'s have become programmers or "software engineers" in recent decades.

Graduate students in particular are extremely cheap labor. Graduate student salaries frequently do not rise with experience except for a cost of living increase. Consequently a graduate student becomes increasingly cheaper labor with time. Post-docs and other temporary positions receive higher salaries but they are also cheap compared to industry salaries. This is the reason for the perpetual claims of a Ph.D. shortage or deficit.

The Rosy Schedule

Research and development projects have a long history of large cost and schedule overruns. In many cases, this is an unavoidable consequence of the nature of research and development. The everyday instinct that costs and schedules might run over by a few tens of percent does not apply to research and development. There is a joke "to get the real schedule, multiply the official schedule by PI (3.14) for running around in a circle". Research and development projects often run over by factors of 3 or 4 times. This is often hidden so even reported massive cost and schedule overruns are actually low.

Popular science coverage often repeats official schedules uncritically. Where cost and schedule overruns occur, this is often treated as unusual or an aberration. Popular science coverage rarely discusses the long history of large overruns both in R&D generally and in the specific field, nor the long history of optimistic cost and schedule estimates from senior scientists and researchers. This is part of a general pattern (discussed below) in popular science of presenting research and development as significantly more predictable than it is.

The September 19, 2008 explosion of superconducting magnets at the Large Hadron Collider (LHC) at CERN (the European Organization for Nuclear Research) is an example. This has delayed LHC by at least a year, and comes on top of years of cost and schedule overruns. Particle physics has a long history of large cost and schedule overruns and substantial startup problems in new accelerators and accelerator upgrades[3,4,5,6,7,8,9,10]. This is often omitted from popular coverage of the accelerators and particle physics (see for example the coverage of LHC in *The Elegant Universe* PBS Nova show in 2003).

In his book *Return to the Moon*, former Apollo astronaut and US Senator Harrison Schmitt gives an unusually frank account of the underlying problem:

"Adequate funding and funding reserves" are fundamental to success in large, complex, advanced engineering projects. Such management reserves consist of funds necessary to handle the unknown-unknowns (or unk-unks as they are informally known in engineering jargon) inherent in research, development, and test related to "large, complex, advanced engineering projects." ***Apollo's funding reserve was probably about 100% at the start and every bit of it eventually was needed to meet the Kennedy challenge [emphasis added].*** *Without a sufficient reserve, milestones must slip to free up funds to deal with the "unk-unk" of the month. Repetitive slippage of milestones ultimately creates a "milestone fence" that cannot be breached without new appropriations from Congress. The Space Shuttle reached such a fence in about 1978.*[11]

Schmitt discusses other massive cost and schedule overruns and project cancellations at NASA including the International Space Station, X-33, X-34, and X-48 projects.

*Potentially unethical advocacy of underfunded and poorly managed new initiatives came forth in the guise of the Space Station, the X-33 single-stage-to-orbit reusable booster, the X-34 air-launched reusable booster, and even in the extended life and safety enhancements of the post-*Columbia *Space Shuttle*[12].

Discussions of this long standing problem like Schmitt's are the exception in popular science.

Classified military and intelligence community research and development programs appear to have even worse cost and schedule overruns than ostensibly unclassified fields such as particle physics and space exploration. Several defense and intelligence space programs have run far over budget and schedule in recent years including the Space Based Infrared System (SBIRS) High program (missile detection satellites), the National Polar-orbiting Operational Satellite System (NPOESS) (weather and environmental monitoring satellites), the Advanced Extremely High Frequency (AEHF) satellite program (communication satellites), the Evolved Expendable Launch Vehicle (EELV) (satellite launch systems), the Global Positioning System (GPS) IIF (navigational satellites), and the Wideband Gapfiller Satellites (WGS) (communication satellites)[13]. In a report on these cost and schedule overruns, the US Government Accountability Office (formerly the Government Accounting Office) writes:

Second, as we have previously testified and reported, DOD starts its space programs too early, that is, before it has assurance that the capabilities it is pursuing can be achieved within available resources and time constraints. This tendency is caused largely by the funding process, since acquisitions programs attract more dollars than efforts concentrating on proving technologies. Nevertheless, when DOD chooses to extend technology invention into acquisition, programs experience technical problems that require large amounts of time and money to fix. Moreover, when this approach is followed, cost estimators are not well positioned to develop accurate cost estimates because there are too many unknowns. ***Put more simply, there is no way to estimate how long it would take to design, develop, and build a satellite system when critical technologies planned for that system are still in relatively early stages of discovery and invention [emphasis added]***[14].

The Missing Funding Sources

Popular science frequently omits or glosses over the funding source or sources for a research field. Most research programs such as particle physics are funded by the government, often by a single program office in a single funding agency. Even where there are multiple agencies and programs involved, these agencies and programs are often closely intertwined in the management of the research program.

Popular science often identifies research scientists by their institution, often a university, rather than the funding agency and program office. This creates the illusion of independent researchers with diverse sources of funding without making the demonstrably false claim that this is the case.

Somewhat related to the missing funding sources, popular science often portrays science as pursuing an idealistic, long term, and rather vague goal. Claims that a research program has no immediate practical purpose are often accepted uncritically.

The Scientist as Truth-Seeker

Popular science often portrays scientists as idealistic noble truth-seekers. This is part of a generally idealistic and positive portrayal of science that permeates popular science. Many people go into science because they discover that they are good at it in school, not out of any idealistic desire to find the truth, expand the frontiers of knowledge, and so forth. Careerism, unethical behavior, and even diabolical villainy are sadly as common in science as elsewhere.

Cry Pseudo-Science

The vast bulk of popular science ignores or ridicules any area dismissed by senior mainstream scientists as "pseudo-science". This includes UFOs, ESP, Atlantis, and many other odd areas. The terms "junk science", "pathological science", and "bad science" are sometimes used in place of "pseudo-science". In recent years, it is increasingly common to find critics of the established view assailed as "deniers" or "denialists" in analogy to Holocaust denial – probably no more emotional *ad hominem* argument could be conceived. There are AIDS deniers, evolution deniers, global warming deniers and so forth. The orthodox (often government) line is usually repeated uncritically, even where obvious logical or factual problems with the official view exist.

Now, this doesn't mean one should not be skeptical of fringe ideas. History shows that most fringe scientific ideas fail. History also shows that a few will turn out to be correct, despite severe official ridicule and seemingly compelling counter-arguments or data.

Popular science, however, usually tows the official scientific line even where the official view contains substantial problems. Illogical or questionable official arguments are often repeated uncritically.

The Myth of Falsifiability

Popular science promotes the notion of "falsifiabliity". This is the idea that for something to be scientific it must be possible to prove it is wrong by some experiment. This concept is attributed to philosopher of science Karl Popper[15]. This is usually used to argue that some unorthodox or fringe view is "not science". Falsifiability appears most frequently in debates about the theory of evolution.

In fact, it is usually possible to devise technically sophisticated and plausible explanations for even grossly contradictory evidence or, in some cases, the absence of evidence that one might expect. This occurs frequently in mainstream science. When chimpanzees failed to develop AIDS in the 1980's after being exposed to HIV, researchers discovered that chimpanzees (and other primates) were immune to HIV, ridiculing any suggestion that this was clear evidence that HIV did not cause AIDS[16]. When particle physicists failed to find free quarks in the 1970's and 1980's, they discovered that Quantum Chromodynamics (QCD) predicted that the force between quarks grew with distance thus explaining why quarks were never seen in the lab; a Nobel Prize was recently awarded for this "breakthrough". The neutrino was postulated to explain otherwise grossly contradictory evidence in radioactive decays.

In my opinion, when one encounters a technically sophisticated and plausible explanation for grossly contradictory evidence or the absence of expected evidence, this is a clear warning sign. It is not proof of error nor does it rule out something (e.g. quarks, UFOs) as "not science". By this criterion both mainstream and "fringe" science today contain significant warning signs of problems.

Certainty and Precision

Popular science frequently portrays science as able to provide certain, definite and precise answers. This is most evident in the portrayal of forensic and biometric methods and technologies such as fingerprint identification both in news reporting and popular fiction such as the old *Quincy* TV show, *CSI*, and similar crime shows.

For example, most measurement techniques have false positive and false negative rates. They are not perfect. In the case of fingerprint identification, it is very difficult to pin down the false positive and false negative rates. The FBI, fingerprint examiners, and other sources often claim or imply that fingerprints are perfect in identification. There are many known cases of incorrect fingerprint identification. These are usually blamed on errors by fingerprint examiners rather than fingerprints that cannot in fact be distinguished.

A recent high profile example is the case of Brandon Mayfield. After the Madrid train bombing, Spanish authorities recovered a fingerprint of the apparent bomber. The FBI matched this fingerprint to a Muslim-American attorney Brandon Mayfield who had been involved in the defense of alleged terrorists in Oregon. The FBI conclusively identified Mayfield. Meanwhile, the Spanish police identified an Algerian suspect and also apparently decided that the fingerprint did not match Mayfield's fingerprint as the FBI concluded. Note that the FBI claimed that several different presumably top fingerprint examiners at the FBI lab had identified the print conclusively as Mayfield's fingerprint. After the Spanish police arrested their Algerian suspect and publicly cleared Mayfield, the FBI dropped their case against Mayfield[17].

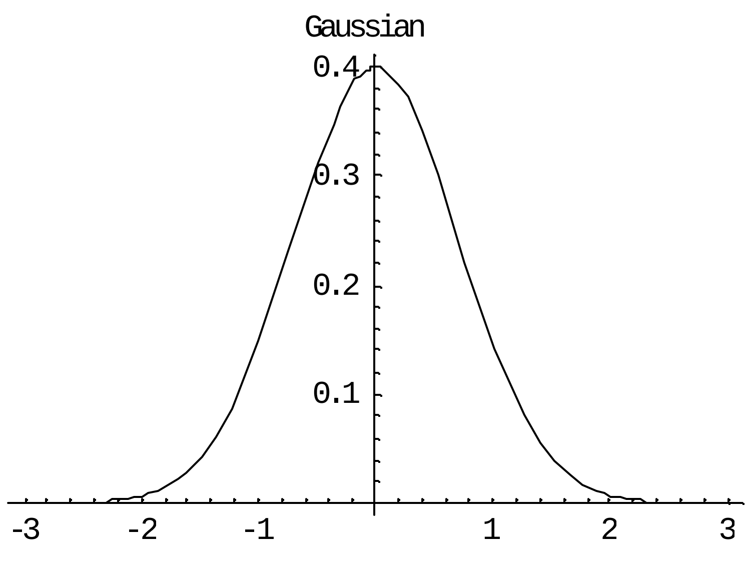
Despite cases like Mayfield, popular science frequently portrays scientific methods and scientists as extremely accurate, precise, and certain. This is not just a problem with forensic and biometric methods and science. Popular science often portrays any science or "scientific" method as certain, precise, and accurate, even where there is strong evidence to the contrary.

It is important to realize that science is human. It is fallible. Even time honored "scientific" methods such as fingerprints have flaws, errors, and failure rates. In the case of fingerprints, the failure rate is very difficult to determine[18].

Gaussian Statistics

[This section is somewhat technical and may be skipped on a first reading.]

Science and scientists frequently use Gaussian (or Normal or Bell Curve) statistics even where it is demonstrably not applicable (for example in so called financial engineering). This is admittedly a rather technical point, and it is not surprising that science journalists with limited technical knowledge have difficulty with this problem. The Gaussian and the assumption of independent identically distributed variables with which it is closely associated is widely overused in science.



The Gaussian falls off exponentially as one moves away from the peak. This means that the probability of an event even five so-called standard deviations (also known as sigma) from the peak is almost zero. In reality, distributions often have long non-Gaussian tails for various reasons, some understood and some not understood.

In both popular science and science it is common to encounter confidence levels and other statistics based on a Gaussian assumption (this is often not stated especially in popular science). Thus, it will be said that something is known with a confidence level of 99.999%. This actually means that the measurement is five (or ten) sigma from the peak based on Gaussian statistics. Often Gaussian statistics does not apply. Particle physics, for example, is littered with breakthrough discoveries at the five or ten sigma level that turned out to be spurious. The improper use of Gaussian statistics and closely related assumptions such as independent identically distributed variables contributes to the illusion of certainty and precision in popular science.

Improper use of Gaussian statistics has apparently played a major role in the current financial crisis (2008) and in previous financial fiascoes such as the Long-Term Capital Markets failure[19].

The Scientific Revolution

Popular science promotes the idea that a scientific revolution took place around 1600 represented by Galileo Galilei and Isaac Newton especially. Prior to the scientific revolution, people lived in superstitious ignorance and fear, misled and oppressed by the Church. This is closely associated with the notion of a dark age between the fall of Rome and the Renaissance, during which civilization fell into decay. Then, scientists and science appeared, discovered the scientific method, and led mankind out of darkness and decay into the modern scientific era.

The mythology of the scientific revolution portrays a sharp break between religion, magic, alchemy, and astrology and the new "science" of the Renaissance. This is strikingly at variance with the historical record. Galileo was an astrologer. Isaac Newton was an alchemist and wrote more Biblical exegesis than works on physics. Tycho Brahe and Johannes Kepler were astrologers and alchemists with deeply mystical and religious views[20].

The basic concept of constructing a theory, in fact a precise mathematical model, and comparing the predictions of the theory with observation is clearly visible in astrology dating back to ancient Sumeria. The astrologers (astrologers and astronomers were the same thing) built complex sophisticated models of the heavens and compared these models with the actual observed locations of the planets and stars. The models were revised, increasing their accuracy, when disagreements with data were observed. Believing the motions of the planets, seen as gods or angels, influenced future events, they wanted to predict the future more accurately by predicting the motions of the planets more accurately. Johannes Kepler's "scientific" discovery of the elliptical orbit of Mars (and other planets) fell entirely within this tradition[21].

Similarly, alchemists conducted extensive experiments very much in the scientific style. It is important to realize that alchemy produced many methods and techniques that worked and some are still used today. The earliest alchemical manuscripts contain valid formulae for creating substances such as brass that resemble natural gold. They also contain methods to apply coatings or colorings to the exterior surface giving the appearance of gold. Over the centuries alchemists discovered and passed on numerous ways to synthesize new substances. Alchemists discovered caustic potash, bicarbonate of potassium, sulphuric ether, hydrochloric acid, zinc, the existence of gas, sodium sulphate, phosphorus, tin oxide, porcelain and benzoic acid[22].

A number of scientific ideas commonly attributed to Galileo and Newton are found in the works of the medieval scholastics[23]. Concepts strikingly similar to the putative "scientific method" are found in the works of Albertus Magnus, Thomas Aquinas, and Roger Bacon amongst others.

Technological progress continued and may even have accelerated after the fall of Rome. Major inventions occurred during the so-called Dark Ages. By the time of Thomas Aquinas and the medieval scholastics, the technological level of Western Europe was far above that of Rome.

The Flat Earth Myth

A common myth is that people before Columbus believed the Earth was flat. The scholars and theologians of the Catholic Church during the Dark Ages and Middle Ages believed the earth was flat in the face of "obvious" evidence. This is not true[24].

The Earth is described as a sphere about 8000 miles in diameter in Aristotle's *On the Heavens (De Caelo)*, in Plato's *Timaeus* (Plato does not give the diameter just the shape), and in Claudius Ptolemy's

Almagest. In fact, most educated people including the leaders of the Catholic Church during the Dark Ages and the Middle Ages believed the Earth to be a sphere about 8000 miles in diameter (the correct size). This knowledge may date back to ancient Sumeria (modern day Iraq).

The ancients did believe that the Earth was the center of the solar system. However, they did understand the size and shape of the Earth correctly. The geocentric models of the solar system predicted the motions of Mars and other planets to within a few percent. The initial heliocentric model proposed by Copernicus was not as accurate as the state of the art geocentric models. Popular science accounts frequently omit that the heliocentric model of Copernicus was not as accurate as the geocentric models and also relied on epicycles just like Ptolemy. The heliocentric model is often portrayed as "obviously" right, rejected due to the superstition and prejudice of the Church. It was not until Johannes Kepler discovered the orbits were elliptical that the accuracy of the predictions was dramatically improved to an accuracy of about 1 part in 100,000 (0.001 %).

Invention and Discovery

Popular science frequently attributes major inventions and discoveries to extreme intelligence, technical proficiency, and hard work, especially to extreme intelligence. Scientific discoverers in particular are usually portrayed as possessing some sort of extreme intelligence, far beyond both the common herd and other scientists. Often the actual process of invention and discovery is omitted from accounts, with the common exception of the "flash of insight" that often occurs.

In reality, almost all major scientific discoveries and technological inventions took many years, typically five to twenty, and involved large amounts of trial and error and lengthy conceptual analysis of the problem. It takes time. Opportunity and the resources to spend years on the problem is essential. Luck almost certainly plays a significant role. While most discoverers and inventors are above average in intelligence, so are many people. Academic prodigies and people with extreme intelligence as conventionally measured usually do not make major scientific discoveries or inventions. Extremely intelligent people as conventionally measured are, of course, more common among scientific discovers and inventors than the general population. Scientific discoveries and inventions involve lengthy conceptual analysis usually expressed in words and pictures which is difficult to measure in ordinary exams, homework, standardized tests, and IQ tests all of which are quite short, usually a few hours.

While basic competence is obviously essential, high levels of technical proficiency are not always necessary to make a major scientific discovery or invention. The famous physicist Albert Einstein was weak in mathematics by the standards of theoretical physics at the time and made numerous mistakes[25]. In striking oil, it is most important to drill where there is oil. One does not have to be the best driller in the world – just competent. Scientific discovery and technological invention are somewhat similar.

Even hard work is not as important as one might think. Einstein for example worked on his theories *part-time* while working as a patent clerk. But, one thing is clear, major inventions and discoveries almost always take *time*.

Invention and discovery is *extremely* unpredictable. Kepler, for example, bet that he could solve the problem of the orbit of Mars in eight days. He was very wrong. It took five years of frustrating trial and error (nothing worked) before he realized that the orbit of Mars was an ellipse. This realization occurred in just a few days, the famous "flash of insight", but this was after a long and frustrating process. Flashes of insight almost always follow years of trial and error and conceptual analysis.

Popular science usually attributes major discoveries or inventions to one or at most two people independent of the actual circumstances. For example, Octave Chanute is often omitted from popular accounts of the invention of the airplane which sometimes focus exclusively on the Wright Brothers. Popular science also frequently avoids mentioning any serious controversies over credit, evidence that the invention or discovery was stolen, or even cases where the common attribution found in textbooks and popular culture is demonstrably false. For example, Robert Fulton is frequently misidentified as the inventor of the steam boat, although steam boats had been in existence for decades prior to his successful steamboat business in New York[26]. Businessmen like Fulton who successfully commercialized an invention are often either claimed or implied to have invented the invention even when they clearly did not.

In addition to attributing inventions to businessmen who commercialized the invention, popular business coverage of inventions frequently omits early companies that commercialized inventions but later failed, focusing on survivors that still exist today. For example, accounts of the computer industry today frequently focus on Apple and

IBM, omitting Radio Shack and Commodore[27] as well as the early kit computer companies MITS and IMSAI. Similarly, Digital Research and the early computer operating system CP/M are frequently omitted from accounts which often emphasize Microsoft and DOS.

These omissions and distortions contribute to the myth of "the first mover advantage". The first mover advantage is the idea that the first company to bring a new invention to market has the advantage and often comes to dominate the market. Thus, Microsoft is often incorrectly seen as the first mover in the personal computer operating system market in the 1970's, leading to its present dominant position. In fact, it is probably more accurate to say "first mover disadvantage". First-movers mostly fail. Often, second movers like Microsoft survive and dominate a market. First-movers bear the brunt of the trial and error process. First-movers make mistakes, both technical and business, which often seem obvious in retrospect. Second-movers often learn from the mistakes of the first-movers, avoiding costly trials and errors.

These business myths about invention and discovery are often promoted by stock promoters, some sincerely and some not so sincerely (see the discussion of free market myths below). These myths have the effect of greatly understating the risks of investing in technology-related businesses, by which is meant businesses based on commercializing a new invention or discovery.

The Breakthrough of the Month

Popular science is full of reports of breakthroughs. Every year brings seeming cures for cancer, diabetes, and so forth. NASA discovers evidence for water on Mars year after year. Genuine breakthroughs are actually quite rare. Remarkably the major advance in video compression technology in 2003 that made possible YouTube and similar fare attracted very little reporting at the time or since. This was actually a major breakthrough that will probably have major effects on our society (by enabling telecommuting and thus reducing the daily commute, gasoline costs, and so forth) in the years to come.

The Accelerating Rate of Progress

It is common to encounter claims that we live in an era of unprecedented change, technological progress, and so forth. The rate of technological progress is said to be both high and increasing. In recent years, this is often supported by reference to computer and electronic technology. Notably, until recently, the clock speed of computers and electronic devices doubled every eighteen months.

At best, this is questionable. I, in fact, believe that we live in a period of slower technological progress compared to the nineteenth century and early twentieth century. This is clearly visible in some important fields such as aviation and rocketry. In 1900, the human race could barely fly with a few balloons, dirigibles, and primitive gliders. By 1970, men had walked on the moon and inexpensive commercial jet travel was common. Supersonic transport was just starting. Since 1970 there has been minimal progress in aviation, rocketry, or other power and propulsion technologies. The lack of substantial advances in power, propulsion, and engines underlies current concerns about energy supplies. This differs from the rapid progress in engines and power systems between the late eighteenth century (practical steam engines) and the mid twentieth century (jets, rockets, nuclear fission reactors, fission and fusion bombs). Many other fields including physics[28] show little progress since around 1970. Even in computers, often seen as fast moving, progress in artificial intelligence technologies has been very limited in almost forty years (this may change).

The Limits of Science Journalism

Science journalists often have limited technical knowledge and skills which makes it difficult to critically evaluate scientific and technological claims. A recent example of this is Sharon Weinberger's entertaining book *Imaginary Weapons* about the so-called hafnium hand grenade[29]. While it is likely the hafnium hand-grenade is nonsense, the author freely admits a lack of technical understanding of the physics issues and relies instead on the physicists from major national laboratories that have an obvious conflict of interest. The hafnium hand-grenade, if successful, threatens the funding of the mainstream nuclear weapons and physics "community".

Many scientific fields involve theories and technologies that take years of study to master. Most science journalists don't have this experience. They are often forced to rely on the experts. Because scientific research is often funded by a single funding agency and program office, or a few closely interconnected agencies and offices (such as the US nuclear weapons R&D program), it is very difficult to get truly independent opinions and advice.

The highly centralized funding and management of many research programs means that a journalist who does raise questions must worry about access to leading scientists and institutions. This does not require a conspiracy by researchers, simply groupthink by researchers who attend the same conferences, science policy panels (like the High Energy Physics Advisory Panel or HEPAP in particle physics that supposedly advises DOE and the government), and groups[30]. A critical journalist may be stigmatized as a nut case or pseudo-science promoter.

Imaginary Weapons and the leading physicists described in the book characterize the hafnium research as pseudo-science, using a range of *ad hominem* techniques often used in attacks on "pseudo-science". For example, the hafnium researchers are consistently described as "hafnium believers" throughout the book, not scientists with a different opinion or theory. A journalist labeled as a "pseudo-science promoter" is likely to find their calls unanswered, interviews difficult to get, and so forth.

Free Market Myths

Conservative, libertarian, and business sources promote a number of ideas about modern science and research, especially in the context of science and technology-related businesses, that are simply incorrect. Conservative supply-side author and high technology stock investment adviser George Gilder is an example of this problem[31]. Many people, including apparently Gilder, lost significant amounts of money relying on Gilder's investment advice with its buoyant inspiring picture of "free market" innovation[32].

The Silicon Valley in particular is a poor example of free market ideals. The conservative, libertarian, and business picture of the Silicon Valley is frequently of private inventors in garages or maybe corporate labs, conducting research and inventing new technologies that they then bring to market. The government funded Internet is actually presented as a private free-market invention. Free-market boosterism in a nutshell: Perceived good news is private, free market. Perceived bad news is government.

The Silicon Valley grew out of secret military programs to develop spy satellites at Moffett Field. In space, size, weight, and power are at a premium. A rocket can send only a small weight into orbit. Consequently transistors and solid-state electronics had a special advantage compared to vacuum tubes in the 1950's and 1960's. Thus, the Air Force, CIA, DARPA, and other closely interrelated government agencies heavily funded secret research into solid-state technology, creating Fairchild, Intel, and many other companies.

Without always realizing it, the Silicon Valley has depended on government, often military programs, for the research and early development of technologies. Venture capitalists and other "sophisticated" technology investors follow a rule to only invest in technically feasible proven technologies, that is a working prototype already exists[33]. Well then, where did the working prototype come from? Someone's garage? Very often not. In case after case, the technology can be traced back to a working prototype (or system as with the Internet) in a government funded research project.

Science and research and development underwent extensive changes around the time of the Second World War. Science became much more "professionalized" with increasing reliance on formal credentials such as the Ph.D.. Universities, especially research universities, reorganized along more corporate lines than in the past. The role of the independent inventor, the semi-mythical "lone" inventors like James Watt or Octave Chanute and the Wright Brothers, went into decline. Research, in particular, shifted to a massive government funded, often bureaucratic, process. Not a good example of free market ideals. Significantly, ostensibly "private" firms came to rely on these government research programs for research, often creating the working prototypes, proofs of concept, or pilot experiments that the firms started with.

Conservative, libertarian, and business sources continue to describe research and development as though the old pre World War II system existed. They often claim or imply that various private businesses or entrepreneurs invented things like the integrated circuit or the Internet without significant government funding or program management. In the case of the Silicon Valley, this is often false.

The heavy reliance on government research means that where the government research program is on the right track, there is progress. Government research programs are often focused on a single "right way", a ruling paradigm, to the exclusion of all other ideas, often stigmatized as fringe or pseudo-science. Where the government research program is on the wrong track or simply stagnant for some other reason (politics, bureaucratic infighting, laziness), ostensibly "private" industry often makes little progress. This is probably the case in many areas such as artificial intelligence, cancer, and fusion power.

Private firms, including so-called high technology Silicon Valley firms, usually lack both specific technical research skills and a general understanding of research. Internet zillionaire and PayPal founder Elon Musk encountered this problem with his rocket startup SpaceX. He did eventually succeed in getting a satellite into orbit (kudos), but by his own admission found it much more difficult than expected. SpaceX has only duplicated the existing state of the art in rocketry, not gone beyond it, not found a revolutionary breakthrough in propulsion.

Silicon Valley type companies specialize in the transformation of working prototypes into commercial products and further incremental improvement of these products, whether they are aware of it or not. From personal experience, I am pretty sure many do not realize (like Elon Musk) this and don't realize the differences between research and commercialization of working prototypes. This is not to say that commercialization is easy, only that it is different and research involves other problems. Research is significantly more unpredictable than commercializing a proven technology; it requires significantly *more* trial and error and conceptual analysis.

Good News Only

Popular science deals mostly with successes or purported successes. The history of science in most textbooks describes a succession of successes, omitting the blind alleys, fiascoes, cost overruns, and other problems. As a result, science appears much more reliable, more accurate, and more predictable than in reality. Indeed, science and scientists often appear magical.

With honorable exceptions, scientists themselves promote these views. This picture of science makes it easier to raise funds, recruit graduate students, and engage in other activities. Popular science writers are usually only repeating what they have been told. This rosy picture also makes it more difficult to engage in genuine breakthrough research with its long time scale and very high failure rates.

Conclusion

Popular science is very positive with noble super-intelligent super-scientists and reliable, accurate, predictable, almost magical science.

Popular science is frequently "science cheerleading" or even worse "science propaganda". This both creates unrealistic expectations and leads to serious mistakes such as failed investments in risky high tech companies. It also makes it difficult to fund and pursue the time consuming, tedious, and highly unpredictable activities that in the past have achieved major technological leaps and genuine breakthroughs. The real activities cannot compete with the magical super-science of popular science. Anyone who is honest about the real difficulties may be dismissed as a poor scientist.

It is extremely unwise (I write from personal experience) to base major business, investment, or life decisions on popular science. It is also extremely unwise to accept the claims of scientists and science uncritically, an uncritical acceptance cultivated by most popular science. Especially with the centralized funding and management of many modern research programs, it can be quite difficult to get independent advice, a good second or third opinion. When an auto mechanic claims that you need to replace your transmission at great cost, you can usually take the car to another independent auto mechanic and get an independent opinion. This is not so easy with science. It is especially difficult to get an independent objective opinion of the established view or paradigm of most scientific fields. Popular science will almost always endorse the established view.

About the Author

John F. McGowan, Ph.D. is a software developer, research scientist, and consultant. He works primarily in the area of complex algorithms that embody advanced mathematical and logical concepts, including speech recognition and video compression technologies. He has many years of experience developing software in Visual Basic, C++, and many other programming languages and environments. He has a Ph.D. in Physics from the University of Illinois at Urbana- Champaign and a B.S. in Physics from the California Institute of Technology (Caltech). He can be reached at jmcgowan11@earthlink.net

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than long term positions. Most Ph.D.'s in particle physics end up in some form of software engineering.

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[16] This is a simplification. One could write a book on chimpanzees and AIDS. According to published accounts one chimpanzee, out of hundreds exposed to putative HIV in the 1980s, died of an illness identified as "AIDS" in 1996. Another chimpanzee reportedly contracted AIDS from blood or fluids from this chimpanzee. Hundreds of chimpanzees are apparently still alive that were exposed to HIV in the 1980s. At times researchers, the NIH, and popular science sources have claimed that chimpanzees and other animals were immune to HIV, that there is no animal model for HIV/AIDS, and more recently that it has been proven that HIV causes AIDS in animals. I have actually read the claim that there is no animal model for HIV/AIDS and the claim that studies of HIV-2 in baboons proved that HIV causes AIDS in the same NIH fact sheet. In fringe fields, this sort of thing would be correctly taken as a strong warning sign of trouble.

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