Chapter 11
Improving Science for a Better Future

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Abstract Science is the reason humanity reached this stage of progress, and science is humanity's guide to the future. However, to enable science to guide us to a better future, we need to improve the way we do science to accelerate the rate of scientific discovery and its applications. This is important to find urgent solutions to humanity's problems, improve humanity's conditions, and enhance our understanding of nature. In this essay, we seek to identify those aspects of science that need improvement, and discuss how to improve them.

11.1 Introduction

During the first half of the twentieth century, two scientific revolutions took place: *relativity* and *quantum mechanics*. They had a huge impact on our understanding of the universe, and led to many technological advances.

Relativity revolutionized our understanding of space, time, mass, and gravity. This understanding made many technological applications possible, such as particle accelerators, nuclear power plants, and the GPS.

Quantum mechanics revolutionized our understanding of particles and waves. It tells us we can only know the probability of finding a particle in a certain state, thus destroying the notion of a deterministic universe. Applications of quantum mechanics are numerous, such as the transistor, the laser, and the Scanning Tunneling Microscope (STM).

The advances in physics and technology changed our views about the universe. What was thought to be nebulae in our galaxy turned out to be other galaxies with billions of stars. The notion of a static universe became an expanding one that began with a big bang 13.8 billion years ago. Everything we observe in the universe turned out to constitute only 4.9 % of its contents; the rest is dark matter and dark energy.

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Similar revolutions appeared in chemistry and biology: polymers changed our everyday products, medicine eradicated many diseases, the green revolution in agriculture saved us from starvation, and the discovery of the DNA revolutionized our understanding of life.

Science created wonders that would have been unimaginable a hundred years ago; still, wouldn't it be interesting to speculate on the wonders science will create in the future?

11.2 Can We Predict the Future?

> The human race has always wanted to control the future, or at least to predict what will happen. That is why astrology is so popular.
>
> Stephen Hawking [1, p. 103]

Many books were written about the future, and many people have speculated about the future, some of their predictions came true, but many did not.

One of the famous predictions that came true is Richard Feynman's 1959 lecture entitled: "There's plenty of room at the bottom", in which he considered the possibility of manipulating individual atoms [2]. Feynman's prediction came true with the invention of the STM in 1981, and his lecture marked the beginning of nanotechnology.

By contrast, a prediction that failed to come true is that of John von Neumann in 1948 about computers [3, p. 116]: "It is possible that in later years the machine sizes will increase again, but it is not likely that 10,000 (or perhaps a few times 10,000) switching organs will be exceeded..." The *transistor* made it possible to put more "switching organs" in less space; now, one can buy a computer with a billion transistor.

Science fiction novels, especially those of Jules Verne and H.G. Wells, also contain many technological inventions that came true in the future. In fact, almost all future predictions are about technology. However, considering the huge impact of science on our lives, we cannot successfully predict the future without taking into consideration the impact of science. Is predicting science possible?

To understand this question, let us ask another one: did anyone predict relativity, quantum mechanics, or the DNA? No, scientists can predict the *consequences* of science, but not the *scientific knowledge* itself. Physicists predicted the LHC would discover the Higgs boson, but they did not predict its theoretical "discovery" in 1964.

> Predicting the content of new scientific knowledge is logically impossible because it makes no sense to claim to *know* already the facts you will *learn* in the future. Predicting the details of future technology, on the other hand, is merely difficult.
>
> Eric K. Drexler [4, p. 39]

11.3 Choosing the Path to the Future

Science is the reason humanity reached this stage of progress; hence, we can expect that science will shape our future as well. However, the impossibility of predicting science renders any attempt to imagine the future incomplete at best. Thus, we cannot steer the future towards a certain vision. Instead, we can choose the *path* that leads to the brightest future. I believe *science* can lead us there, but we should make the conditions ideal for science to do so.

We should improve the way we do science to accelerate the rate of scientific discovery and its applications. Humanity is faced with many problems that need urgent innovative solutions; science is our guide to find those solutions, and improve humanity's conditions.

In the following subsections, I will try to identify those aspects of science and technology that need improvement, and discuss how to improve them to ensure accelerated scientific and technological breakthroughs.

11.3.1 Transcending Traditional Disciplines

During the renaissance age, science was not divided into disciplines. Disciplines emerged gradually when knowledge increased to enable researchers to study one subject in greater depth, and reach new findings more quickly.

However, nature is a whole that recognizes no disciplinary boundaries; so when knowledge increased, the need arose to combine knowledge from two or more academic disciplines to explain certain phenomena. This is known as *interdisciplinary* studies [3, p. 123], and it is getting increasingly important. This is evident from the number of interdisciplines that appeared recently, such as biophysics, astroparticle physics, nanoscience, and systems science. There are also *transdisciplinary* fields of study that use many disciplines in a holistic approach, such as environmental science.

It is hard for one person to know enough about two disciplines to do research in both, so inter- and transdisciplinary studies usually take the form of *collaborations* between scientists from various disciplines. Collaborations, however, face some challenges: scientists use different methods in each discipline, which can delay the progress of their project. Also, insufficient knowledge of each other's discipline can lead to misunderstanding between them. Further, scientists are usually unaware of problems faced by other disciplines, which can hinder starting collaborations in the first place.

The increasing importance of collaborations between scientists and engineers requires that undergraduate and graduate students be taught how to communicate and collaborate with researchers from other disciplines. Also, before starting new collaborations, researchers should acquire general knowledge about the other disciplines. In addition, university departments should give periodic talks on the problems they are working on to stimulate discussions with researchers from other disciplines, thus opening the possibility of interdisciplinary collaborations.

A great example about the importance of disregarding disciplinary borders is the *MIT media lab*. The lab is based on the idea of creating an environment for researchers from various disciplines to work together to change the world. The lab contains 25 research groups that disregard traditional disciplines. For example, the consortium Things That Think includes computer scientists, product designers, biomedical engineers, and architects working on digitally augmented objects and environments. The lab gave rise to more than 80 companies, and to many commercial products ranging from electronic ink to CityCar [5].

11.3.2 Creating New Specializations

Most engineers who work on renewable energy are mechanical or electrical engineers who decided to apply their knowledge to renewable energy. Wouldn't it be more effective if there were an engineering specialization on renewable energy that starts from undergraduate study?

Most of humanity's problems require knowledge from many disciplines. Collaboration is one way to solve them; another is creating *new specializations* designed specifically towards those problems. There are also emerging fields of study that has the potential of changing our future, such as nanotechnology, biotechnology, photonics, and artificial intelligence. Letting students specialize in those fields early in their study can accelerate the rate of innovation.

An example of this is the undergraduate majors of the recently inaugurated University of Science and Technology in Egypt. These majors include nanoscience, renewable energy engineering, and environmental engineering. In addition, every major has specializations; for instance, environmental engineering includes the specializations: climate change, water recycling, waste recycling, and water desalination [6]. I believe graduates from those, and similar, programs will be more equipped to excel in their field of study.

11.3.3 Big Science Versus Small Science

In the past few decades some *'big'* science projects appeared, such as giant particle accelerators, space exploration programs, gravity waves detectors, and the genome project. Those projects grasped the public attention, and rightly so, since they added a lot to our knowledge. Will the future of science be based on increasingly bigger projects? Or will *'small'* science projects contribute more?

The problem with big science is the cost. This is clear from the cancellation of the Superconducting Super Collider in the US, which would have been the largest particle accelerator on earth. Its cost increased from $4.4 billion in 1987 to $11 billion by 1993, and since foreign sources of funding could not be found, the project was cancelled [7].

> Because the big projects are likely to become fewer and slower while the small projects stay roughly constant, it is reasonable to expect that the relative importance of small projects will increase with time.
>
> Freeman Dyson [3, p. 125]

Does that mean we should do small projects only? No, the problem with big projects can be solved by *international collaborations*. The best evidence is the International Space Station that cost over €100 billion, according to ESA [8], making it arguably the most expensive object ever constructed. This cost was split among the 14 participating countries.

Unfortunately, International projects can be hindered by political conflict between nations. To overcome this difficulty, governments and funding agencies should allocate a certain sum of money to international projects, and form a committee, mostly of scientists, to decide on which projects they should collaborate, disregarding any political conflict.

11.3.4 The Relation Between Science and Technology

Many advances in technology are science applications, which might lead you to think that technology is secondary to science, but actually, there is a *dual* relationship between the two.

Quantum mechanics led to the invention of the *laser*, and the laser affected both science and technology. In science, the laser is an essential tool in many physics experiments; it even led to the emergence of new subfields of physics, such as atomic spectroscopy, and holography. In technology, the laser is used in manufacturing many products, and is part of many appliances, such as laser printers and optical discs.

From this relation between science and technology, we conclude that to accelerate both, we should implement latest technology in scientific experiments and apply latest scientific discoveries to technology. For this to happen there should be better communication between scientists and engineers. This communication should not be through published papers only; scientists and engineers should work together to share and discuss their ideas, and collaborate on projects with mutual interest.

There is also great need for academia-industry collaboration. Universities can provide advanced laboratories and many talented graduate students, while industry can provide funding and market expertise. Why then cannot they collaborate and share the intellectual property?

11.3.5 University Labs Versus Industrial Labs

In 1883, while working on his light bulb, Edison observed the flow of electricity across a gap, in vacuum, from a hot filament to a metal wire. Since he saw no practical application, he did not pursue the subject further. This phenomenon became known as the “Edison effect”, and if he did investigate it, he might have shared the Nobel Prize with Owen Richardson, who analyzed the behavior of electrons when heated in vacuum [9].

This anecdote illustrates a big difference between industrial and university research. In Industry, researchers usually work only on problems that have practical significance, and although this kind of research is important, the downside is that they might overlook something as Edison did, and once they solve a problem they might not have the time or interest to pursue it in a more generalized setting.

In university, by contrast, researchers have the freedom to pursue the research they like, which might not have immediate practical application, but have greater impact in the future. However, they do not have as much resources as in industrial labs, and it might take longer for their research to find applications in industry.

Obviously, both kinds of research is indispensable, but how can we enhance their role? Researchers from university and industry should collaborate on problems of common interest; they will get to work on different kinds of problems than they are used to, and benefit from each other’s point of view.

11.3.6 Improving the Publishing Process

In October 2013, *Science* magazine published the results of a “sting operation” conducted on open access journals. They sent a spoof paper to 304 journals. The paper was too flawed to be publishable; yet, 60 % of the journals accepted it [10].

This shocking result illustrates that some publishers seek only profit from open access journals. “Beall’s list of Predatory Publishers” [11] includes 477 such publishers, from which 137 journals were used in the *Science* study and 82 % accepted the paper. All researchers should report such journals and avoid submitting papers to them.

The *Science* study showed another observation: about 90 % of the journals that accepted the paper used either superficial peer review or no peer review at all. Peer review is very important to help authors improve their papers, and to exclude flawed ones. However, peer review was criticized [12, 13] for causing bias towards the views of referees, and for failing to spot some flawed papers. What can we do to improve the peer review process?

A great idea to improve peer review is to do it after publication. This is the idea behind the *F1000Research* journal; it publishes papers only after a cursory quality check, peer review happens after publishing by referees who post their names, authors then can post comments and revisions when needed [14].

In my opinion, journals should apply this idea, but make any researcher, who published a few papers on the topic, able to review. I also suggest making a site that collects metadata on all published papers and allows researchers to *rate* them based on quality and significance. I think rating papers can be very efficient in identifying good research. In addition, rating can become another measure for significance, besides citations.

11.3.7 Publishing Negative Results

Nowadays many researchers work independently on the same problem; it is normal that many of their approaches fail to produce positive results. It is important that researchers publish those negative (null) results to save their colleagues' time and allow them to pursue other approaches more likely to succeed.

Refraining from publishing negative results leads to *publication bias* [15]. Suppose you are investigating the effectiveness of a new treatment but your results did not exclude the null hypothesis (i.e. the treatment is not effective). Meanwhile, someone else did another study, found the treatment effective, and published the results. If you do not publish your negative result, you cause a biased impression about the effectiveness of the treatment. This does not apply only to medicine, but also to new devices and experimental techniques.

The problem is that most negative results do not get published; why is that? Many researchers are reluctant to publish negative results because they underestimate their importance, or lose interest in the topic. Further, most journals do not publish negative results; they prize original papers.

There are some journals that publish only negative results, such as the All Results Journals (Chemistry, Biology, Physics and Nanotechnology), and the Journal of Negative Results in BioMedicine. However, they get very few submissions.

The entire scientific community should respect and acknowledge negative results; they should cite them, and regard them as valuable pieces of information. Journals must accept negative results, and if they do not, researchers should boycott them. Publishing negative results is not an option, it a *duty*.

11.3.8 Reproducing Research Findings

Scientists at the biotechnology firm Amgen tried to confirm the results of 53 papers that were considered landmarks in cancer studies, but they succeeded in confirming only 6 papers (11 %) [16]. Of those 53 papers, 21 were published in journals with impact factor greater than 20. Furthermore, the mean number of citations of non-reproduced papers was 248. This appalling result is a clear example about the importance of *reproducing* research findings; imagine how many scientists wasted their time and resources pursuing false results.

The reasons for this might, in small part, be outright fraud, but mostly scientists might unconsciously ignore results that contradict their claim; also, in complicated experiments, small errors can make big difference in the final result. A detailed discussion for the reasons of false results is offered in [17].

To solve the problem of reproducibility, the *Reproducibility Initiative* was created in 2008. The idea is that every submitted experiment is sent to an appropriate Science Exchange lab to reproduce it; then, the paper gets a badge for being "Independently Validated", and the validation results get published in the PLOS reproducibility collection [18].

The problem with this idea is that not many researchers would pay, or find a grant, to get their results validated, and even if they did, how sure can we be that the reproduced results are more correct?

In my opinion, reproducibility should be the role of the industrial companies that use the research results, such as pharmaceutical companies. In addition, researchers should not take for granted the validity of research results; if they want to work on a follow-up of a particular result, they should reproduce it and publish the reproducibility result with their original research, and journals must not reject those reproduced results.

11.3.9 Managing Research Literature

In the past, research results took months, even years, to get published. Now, the Internet solved this problem through preprints, and researchers are facing the problem of too many papers. For example, only in March 2014 more than 8,000 papers were submitted to arXiv [19].

To keep up with the huge amount of literature, researchers use reference manager software, they make summaries and notes, and they rely on review papers to provide an overview of a particular topic. However, review papers are usually for topics in which many papers were written already, and they can get outdated quickly.

I suggest making review papers like *wikipedia* articles; once a few papers appear on a new topic, a wiki-review paper is written summarizing their results and suggesting future research. Then, when another paper is written on the subject, its author, or someone else, summarizes it in the wiki-review. This goes on until we have a complete review on the topic.

11.3.10 Encouraging Multiple Research Approaches

In 1916, there was some evidence for the existence of black holes, but many scientists, most prominently Einstein and Eddington, refused to believe in their existence. In the 1930s, Chandrasekhar proved that stars heavier than 1.4 the mass of the sun cannot become white dwarfs, but Eddington and others gave *incorrect* arguments against the idea. Black holes were taken seriously in the 1960s when evidence became hard to ignore; however, much of the research done in the 1960s could have been done *fifty* years earlier [20, p. 138].

A similar situation happened in geology. In 1912, Alfred Wegener proposed the continental drift theory, but it was met by opposition from the majority of scientists, until the idea of plate tectonics was proposed in 1958 [21].

History of science teaches us not to hold to unjustified assumptions, even if they are held by the majority, we should always consider opposing views. Unfortunately, we are making the same mistake again; currently the vast majority of physicists working on approaches to quantum gravity and unification are string theorists. String theory is not the only approach to quantum gravity, but the other approaches receive little attention.

Concentrating on one approach to a given problem is not healthy for the progress of science, and the way out is offered by Lee Smolin in his book "The trouble with physics"; his solution can be summarized in the following points [22, pp. 351–353]:

1. Departments should ensure that rival research programs are represented on their faculties.
2. Scientists should be hired and promoted based only on their ability, disregarding their research approach.
3. All scientists should keep an open attitude towards competing research approaches, and encourage their students to learn about them.
4. Funding agencies and foundations should support scientists with different views from the mainstream.
5. A research program, or a particular view, should not be allowed to dominate any field without convincing scientific proof.

11.3.11 Encouraging Innovation in Global Problems

Currently, environmental and sustainability problems are among the biggest problems faced by humanity. I believe the key to solve those problems is by encouraging scientific and technological innovation.

In the middle of the twentieth century, a series of scientific and technological innovations in agriculture helped increase worldwide food production, which saved over a billion people from starvation; this is known as the "Green Revolution".

A promising innovation in energy is the Traveling Wave Reactor under development by TerraPower. This reactor has high fuel utilization rate, and does not need uranium enrichment or resupply. The reactor can be buried underground and run for 100 years [23].

These examples show that science has the potential of solving our problems, but it needs our support. Research and development does not receive enough funding. For example, in 2013 the US spent only \$2 billion on clean energy R&D, compared with \$72 billion on defense R&D [24]. Governments should create research organizations that join scientists and engineers to work together to find innovative solutions and implement them.

11.3.12 Funding Research and Development

In 2011, The United States spent \$424 billion on research and development (R&D), which represented 30 % of the estimated \$1.435 trillion spent globally on R&D. The EU spent 22 %, China 15 %, and Japan 10 % [25].

In 2001, the number of research papers from China represented 3 % of the world total. In 2011, China's share increased to 11 %, becoming the world's second-largest producer of scientific articles, after the US. This correlated with an increase in funding R&D from 1.0 % of GDP to 1.8 %. This correlation between funding R&D and research output appears in all the Newly Industrialized Countries (NICs).

All countries should understand this relation between funding research and development; money spent on research is an investment that is key for better future.

11.3.13 The Role of Scientists in Global Decisions

Global problems take a long time to be solved, especially environmental ones. They require coordination between nations for decades. Yet, politicians take those global decisions. Politics is local, and politicians usually care only about their election period. Scientists, on the other hand, study these problems for years, and their judgment is only affected by observation and experiment. Why then is the role of scientists limited to advising policy makers?

Scientists should have a more active role in global issues. Parliaments should form committees, mostly of scientists from various disciplines, to prepare the country's policies towards environmental, and other global, issues. These committees' decisions should be considered as a *requirement* for the government to follow, not a suggestion.

Scientists should also exert greater effort in raising the public awareness of environmental, and other global, problems. In 2011, *Eurobarometer* found that for 95 % of Europeans, protecting the environment was personally 'very important' or 'important'. Whereas, in the US a similar survey found only 63 % of Americans share that opinion [26].

The public opinion on environmental issues is reflected on their countries' environmental policy. In the EU, in 2012, 14.4 % of energy was from renewable sources, and the target is 20 % by 2020 [27]. In the US, only 11 % of energy production was from renewable sources [28], and there is no mandatory national target in 2020.

11.3.14 Raising the Public Understanding of Science

"Does the Earth go around the Sun, or does the Sun go around the Earth?" In 2012, a sample of US residents were asked that question, and 26 % answered incorrectly. In the EU a similar question was asked, in 2005, and 34 % answered incorrectly [29].

In 1990, when a sample of US residents were asked about their assessment of astrology, 35 % said it was 'sort of scientific' or 'very scientific'; that number increased to 42 % in 2012 [29].

Why do many people not know such basic scientific facts? Why do they believe in pseudoscience? Because education needs to improve and not enough is being done to raise the public understanding of science.

In democratic political systems, the public decides how much funding goes to science, and how scientific discoveries should be applied. When they understand more about science, they will be able to make better decisions on scientific issues, such as the environment, biotechnology, medical trials, and nutrition. They will also be less prone to be deceived by pseudoscience.

Most of the efforts done to raise the public understanding of science are focused on popular books, magazines, science fairs, and museums; these methods are clearly ineffective. When a sample of US citizens were asked about their primary source of information about science, they answered: the Internet 42 %, the TV 32 %, newspapers and magazines 15 %, books 3 % [30]. Clearly, the Internet and TV have the greatest influence on the public attitude and knowledge about science.

Communicating science to the public should not be the responsibility of individual scientists, but the entire scientific community should participate in an organized effort to do so. Efforts through the Internet should not focus only on scientific news, but also on established scientific facts in short articles containing images and videos. In addition, more TV documentary series should be made to discuss science in an interesting way.

11.3.15 Improving Education

Humanity needs scientists and engineers to accelerate progress. Inspiring a passion for science and technology in students is the first step towards that goal. Education, however, needs urgent improvements, and much has been written about that. That is why I will not discuss pre-university education, but talk about undergraduate education.

Universities are the place where scientists and engineers are trained, but most universities are not giving enough effort to education. Carl Wieman, who is a Nobel winning physicist, says [31] “There is an entire industry devoted to measuring how important my research is... Yet, we don’t even collect data on how I am teaching.”

Wieman developed a new method for teaching undergraduates based on active learning and deliberate practice. To test his method, an introductory physics class at the University of British Columbia (UBC) was split in two groups, one used Wieman’s method and the other used traditional lectures. The first group scored twice as high as the control group on a multiple choice test. Wieman’s method is now widely used at UBC [32].

To improve undergraduate education, Wieman suggests that universities should release data on their teaching methods as a condition for federal funding. Students then can use these data to decide which university to choose, thus forcing universities to improve their teaching methods [31].

11.3.16 Empowering All Humanity to Participate

In 2008, the total number of research papers from all African countries (55 countries) was about 27,000 papers [33]. For comparison, the US produces more than 310,000 papers annually [34]. Africa contains 1.1 billion people, three times those in the US; if that number effectively contributed to building the future, imagine how much difference they would make.

Many problems need remedies in Africa, but in my opinion, *education* is the most important factor in the development of any country. The African Institute for Mathematical Sciences (AIMS) is a fine example for the efforts that need to be done in that direction. AIMS was established in 2003 in South Africa, and 479 students from 34 countries have graduated from it [35]. Organizations working on development in Africa should consider supporting and establishing similar educational institutes.

However, to spread high quality education to many people, use the Internet. In the past few years, Massive Open Online Courses (MOOCs) witnessed a big increase in the number of students and courses. Coursera, the biggest MOOC platform, started in April 2012, and by January 2014, it had over 22 million enrollments from 190 countries across 571 courses [36].

MOOCs only need a computer and an Internet connection, but many African countries have bad Internet connection, and not many computers. However, some measures can easily be done to solve these problems:

- The One Laptop per Child project [37] is a great example on how to provide students with low cost computers.
- Local schools and universities should open their computer facilities to all learners.
- Developing organizations should create computer facilities in major cities for online learning.
- MOOCs should include pre-university courses.
- MOOCs should make verified certificates free, at least for learners from developing countries.

11.4 Conclusions

I believe science will be our guide to the future, but we need to improve the way we do science to accelerate the rate of scientific discovery and its applications. This is crucial to find urgent solutions to humanity's problems and improve humanity's conditions. In this essay, I have tried to identify those aspects of science that need improvement, and discuss how to improve them. Those issues are complex and no one essay can adequately cover them. We need the entire scientific community to pay attention to those issues. I hope this essay will open a window for discussion in that direction.

References

1. Hawking, S.: The Universe in a Nutshell. Transworld Publishers, London (2001)
2. Feynman, R.P.: There's plenty of room at the bottom. Eng. Sci. **23**(5), 22–36 (1960)
3. Ron, J.M.S.: The past is prologue: the future and the history of science. In: González, F. (ed.) There's a Future: Visions for a Better World. T.F. Editores, S.L.C. (2012)
4. Drexler, K.E.: Engines of Creation: Challenges and Choices of the Last Technological Revolution. Anchor Press Garden City, New York (1986)
5. Moss, F.: The power of creative freedom: lessons from the MIT Media Lab. In: González, F. (ed.) Innovation: Perspectives for the 21st Century. T.F. Editores, S.L.C. (2011)
6. The University of Science and Technology: Curriculum structure
7. Appell, D.: The supercollider that never was. Scientific American. http://www.scientificamerican.com/article/the-supercollider-that-never-was/. Accessed 28 Jan 2015
8. International Space Station: How much does it cost? http://www.esa.int/Our_Activities/Human_Spaceflight/International_Space_Station/How_much_does_it_cost. Accessed 28 Jan 2015
9. Rosenberg, N.: Innovation: it is generally agreed that science shapes technology, but is that the whole story? In: González, F. (ed.) Innovation: Perspectives for the 21st Century. T.F. Editores, S.L.C. (2011)
10. Bohannon, J.: Who's afraid of peer review? Science **342**(6154), 60–65 (2013)
11. Beall, J.: List of predatory publishers. http://scholarlyoa.com/2014/01/02/list-of-predatory-publishers-2014/ (2014). Accessed 28 Jan 2015
12. Lee, K., Bero, L.: What authors, editors and reviewers should do to improve peer review. Nature **471**, 91–94 (2006)
13. McCook, A.: Is peer review broken? The Scientist **20**(2), 26 (2006)
14. Rabesandratana, T.: The seer of science publishing. Science **342**(6154), 66–67 (2013)
15. Dirnagl, U., et al.: Fighting publication bias: introducing the negative results section. J. Cereb. Blood Flow Metab. **30**(7), 1263 (2010)
16. Begley, C.G., Ellis, L.M.: Drug development: raise standards for preclinical cancer research. Nature **483**(7391), 531–533 (2012)
17. Ioannidis, J.P.A.: Why most published research findings are false. PLoS Med. **2**(8), e124 (2005)
18. The Reproducibility Initiative. http://validation.scienceexchange.com/#/reproducibility-initiative. Accessed 28 Jan 2015
19. ArXiv monthly submission rates. http://arxiv.org/stats/monthly_submissions. Accessed 28 Jan 2015
20. Thorne, K.S.: Black Holes and Time Warps: Einstein's Outrageous Legacy. W.W. Norton & Company, New York (1994)
21. Oreskes, N.: From continental drift to plate tectonics. Plate Tectonics: An Insider's History of the Modern Theory of the Earth. Westview Press, Boulder (2001)
22. Smolin, L.: The Trouble with Physics. Mariner Books, New York (2007)
23. LLC TerraPower: Traveling-wave reactors: a truly sustainable and full-scale resource for global energy needs. In: Proceeding of ICAPP 2010 (2010)
24. National Science Foundation: Federal R&D funding by budget function: fiscal years. http://www.nsf.gov/statistics/nsf14301/pdf/nsf14301.pdf (2012–14). Accessed 28 Jan 2015
25. National Science Foundation: Research and development: national trends and international comparisons. http://www.nsf.gov/statistics/seind14/index.cfm/chapter-4/c4c.htm. Accessed 28 Jan 2015
26. National Science Board (US): Science and engineering indicators. http://www.nsf.gov/statistics/seind14/index.cfm/chapter-7/c7s4.htm (2014). Accessed 28 Jan 2015
27. EurObserv'ER: Estimates of the renewable energy share in gross final energy consumption for the year. http://www.eurobserv-er.org/pdf/press/year_2013/res/english.pdf (2012). Accessed 28 Jan 2015
28. U.S. Energy Information Administration: Monthly energy review. http://www.eia.gov/totalenergy/data/monthly/. Accessed 28 Jan 2015

29. National Science Board (US): Science and engineering indicators. http://www.nsf.gov/statistics/seind14/index.cfm/chapter-7/c7s2.htm (2014). Accessed 28 Jan 2015
30. National Science Board (US): Science and engineering indicators. http://www.nsf.gov/statistics/seind14/index.cfm/chapter-7/c7s1.htm#s3 (2014). Accessed 28 Jan 2015
31. Mervis, J.: Transformation is possible if a university really cares. Science **340**(6130), 292–296 (2013)
32. Chasteen, S.V., Perkins, K.K., Beale, P.D., Pollock, S.J., Wieman, C.E.: A thoughtful approach to instruction: course transformation for the rest of us. J. Coll. Sci. Teach. **40**(4), 70–76 (2011)
33. Adams, J., King, C., Hook, D.: Global research report Africa. Evidence, a Thomson Reuters business (2010)
34. Adams, J., Pendlebury, D.: Global research report United States. Evidence, a Thomson Reuters business (2010)
35. About AIMS. http://www.aims.ac.za/en/about/about-aims. Accessed 28 Jan 2015
36. Coursera: Our student numbers. https://www.coursera.org/about/community. Accessed 28 Jan 2015
37. OLPC's mission. http://one.laptop.org/about/mission. Accessed 28 Jan 2015