Lessons from Grand Challenges

Jayadev Misra

11/25/2002

The grand challenge facing Christiaan Huygens was to calculate the amount of hemp grown in planet Jupiter. Huygens was one of the most eminent scientists of his day, a contemporary of Newton and a major figure in the study of astronomy, conic sections and the properties of light. What caused this peculiar grand challenge is hard to know, but the logic of it is immaculate. I quote from Carl Sagan:

Consider the curious argument by which he deduced the existence on Jupiter of hemp. Galileo had observed four moons traveling around Jupiter. Huygens asked a question of a kind few astronomers would ask today: Why is it that Jupiter has four moons? Well, why does the earth have one moon? Our moon's function, Huygens reasoned, apart from providing a little light at night and raising the tides, is to aid mariners in navigation. If Jupiter has four moons, there must be as many mariners on that planet. Mariners imply boats; boats imply sails; sails imply ropes. And ropes imply hemp. I sometimes wonder how many of our own prized scientific arguments will appear equally foolish from the vantage of three centuries.

I am honored to have been asked to give the banquet speech to this distinguished collection of scientists. There is not much I can tell you in formulating grand challenges, nor meeting them. The ones I have heard about today, are all truly grand, inspiring and of immense promise of benefit to science, engineering and the society. But a piece of advice I will give you —the only serious advice— is not to undersell your work. How many of you can put your work in these terms, which I saw at a web site?

How are we going to solve the problems and make serious improvements in industrial manufacturing, disease control, environmental pollution control, global climate change, food production, transportation, communications, and —-just to be sure— *others? Nanotechnology promises to make revolutionary contributions.*

This gem comes from the National Science and Technology Council on Nanotechnology. We are seriously underselling ourselves.

I looked at the grand challenges of the ancient past and recent past in a variety of disciplines. Allow me to share my observations and the lessons I learnt from them.

There are grand challenges that arise out of real needs. The real need in the navy in the late 17th century England was to eliminate mathematical training for the sailors. Here is how it arose. The accepted way to find longitude at sea was by precise observations of the moon, which required refined instruments and subtle calculations. A small error could wreck a ship. So, the important nations organized mathematics courses for the sailors. When Charles II set up such courses the teachers found it difficult to satisfy the stated needs. They noted that Drake, Hawkins and other sailors have done splendidly without any mathematical training at all; where is the need? On the other side was Newton: this is an exact quote (translated to modern English):

The mathematical children , ..., are capable of much better learning, and when well instructed and bound out to skillful masters may in time furnish the nation with a more skillful sort of sailors, builders of ships, architects, engineers, and mathematical artists of all sorts, both by sea and land, than France can at present boast of.

So, schoolmasters were actually put on board to instruct the crew in mathematics. It did not quite work out. The rest is history. The parliament promised a reward of 20,000 pounds to one who invents an instrument for telling the longitude. John Harrison claimed the prize in 1761.

Now, don't underestimate the role of luck; in fact most grand challenge proposals factor in lucky breaks as a major component of research. Here is a story about the invention of the telescope.

Galileo was not the inventor of this device, as is commonly believed. He refined an older design and made it immensely powerful. Here is what he wrote in 1623:

We are certain that the first inventor of telescope was a simple spectacle-maker who, handling by chance different forms of glasses, looked, also by chance through two of them, one convex and the other concave, held at different distances from the eye; saw and noted the unexpected results and thus found the instrument.

Well, luck probably played an even more important role than Galileo had realized. According to Daniel Boorstin, an historian:

The most likely story puts the crucial episode in the shop of an obscure Dutch *spectacle-maker named Hans Lippersey, in Middleburg about 1600. Two children, who happened into Lippersey's shop, we are told, were playing with his lenses. They put two lenses together and when they looked through both at the same time toward a distant weather vane on the town church, it was wonderfully magnified. Lippersey looked and began making telescopes.*

He was an illiterate mechanic, but not so illiterate that he did not know how to profit from his good luck. He petitioned the government to grant him a lifetime pension. Something very similar to what we are all attempting here.

The telescope story continues. Galileo had heard about the design and built his own, a refined piece. Boorstin says:

Prudent people were reluctant to allow the first hand evidence of their sight to be overruled by some dubious novel device. To persuade "natural philosophers" to look through Galileo's instrument was not easy. .. Father Clavius, professor of Mathematics at the Collegio Romano, laughing at Galileo's pretended four satellites of Jupiter, said he, too, could show them if he were only given time "first to build them into some glasses" .

So, rejoice if you are ridiculed. It means you have not been ignored!

Galileo did not sell his device, but made a gift of it to the Venetian Senate. The senate responded by giving him tenure, a professorship for life, and more than doubled his salary. The fellow academics strenuously objected; since others had invented the instrument, all that Galileo is entitled to is a good price for the device. Ah, envy! The true measure of scientific success; how it transcends time and space!

In my readings of grand challenges, I have come to believe they belong to a small number of categories. Here are the ones that best describe them.

The Fantastic Type: These are challenges that depend on a series of other grand challenges (some of them equally fantastic) succeeding at exactly the right times. The up side in such a challenge is you might get funded. The down side is that all other challenges might succeed.

The Enthusiastic Type: Here, abundant energy and enthusiasm shines through. We have a group of smart people connected together with high bandwidth lines; they will think of something out of these jumble of ideas that are presented as a challenge. The up side is that a nice infrastructure gets implemented for their use; the down side is that a large number of random papers get published.

The Scientific Type: A small group of scientifically-minded people, who know that their discipline is in imminent danger of collapse, prepare a tedious polemic about the lack of scientific rigor in the field. Only if we can avoid the short-term engineering approach, they argue, we can begin to ask penetrating questions, damn the answers. The up side is that it might get funded; the down side is that it might get funded.

The Academic Type The major characteristic here is that many parallel, often conflicting, pet projects of the participating professors are bundled into a package, using a stapler as the major integration tool. And, there are many many participants; the strategy being to include all potential rivals as collaborators to increase the chances of funding. The structure of the project often resembles an inverted pyramid[1]. The top layers are occupied by the professors, the next layer has the post-docs, and at the very bottom is a single undergraduate who comes in twice a week after classes to do major design, implementation and documentation.

The up side is that no participant has to read the whole proposal, let alone understand it. The down side is that many use-never systems will be built.

The Managerial Type: This is where all the components are available. The challenge is to put them together. At the head is a manager who plans to go top-down and bottom-up simultaneously. She has an elaborate plan for delegation of responsibilities; there are work charts, milestones and evaluation criteria. It is also the kind of project we like in the modern times, emphasizing collaboration, group-think and consensus. The up side is that consequences of failure are far less gruesome in the modern times; no part of the body will be chopped off. Better yet, if this is not a publicly visible project, as in the military, you can sidestep all responsibility. I used to work for a large computer manufacturer whose next operating system was expected to be so large that it would have kept all the men, women and children in the United States working full time on coding. When it was aborted, some key managers got transferred.

The down side is, when we come to that crucial juncture in the project, where we are all counting on the others, it may not be easy to pass off the whole thing as a mere communication problem.

[1]This observation is due to Chandy.

The Visionary Type: Pose a challenge that definitely can not be met in your life time. The down side is, there is none. If your vision was totally ridiculous, no one will remember it unless you are famous or you have made too many enemies. And the up side is if it succeeds, even only partially, and for totally independent reasons —say, because of a breakthrough in quantum computing, or because of the dedicated work by a superb group of engineers— you will be hailed as the inventor. Dijkstra was told that his shortest path algorithm is crucial in networking; he wryly observed, "what vision".

I asked a colleague for papers that proposed grand visions for computing in its early days. One of the papers he suggested is:

> As we may think, Vannevar Bush, The Atlantic Monthly, July 1945

Vannevar Bush has a large number of intriguing ideas. He talks about instant access to libraries, enabling a professional to look at a number of related items on a topic. And his solution for storage was dry photography and microfiche. And, how are all these to be accomplished? I quote:

they (the computers) *will be controlled by a control card or film, they will select their own data and manipulate it in accordance with the instructions thus inserted. Such machines will have enormous appetites. One of them will take instructions and data from a roomful of girls armed with simple keyboard punches, and will deliver sheets of computed results every few minutes.*

I shudder, too, at the mention of a roomful of girls.

Predictors have often been hailed as the inventors, e.g., Jules Verne for submarine, Arthur C. Clarke for communication satellites. Which reminds me of a saying by a senator from Ohio[2] in the early 19th century: "I, with the concurrence of Moses and some extra help, wrote the Ten commandments". The lesson is, be visionary.

Thank you.

Acknowledgment: Many of the quotes in this speech are from,

> The Discoverers, A History of Man's search to know his world and himself, by Daniel Boorstin, Random House, 1983.

[2]Senator Corwin of Ohio commenting on Daniel Webster's role in the "Clay Compromise".

The first quotation about Huygens is from,

The Solar System, by Carl Sagan, Scientific American, January 1997.

The quotation “I, with the concurrence of Moses and some extra help, wrote the Ten commandments” is to be found in,

Profiles in Courage (in the chapter on Daniel Webster), by John F. Kennedy, Harper and Brothers, 1961.