On Being Smart *

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What is the crucial quality important for succeeding in graduate school? I will provide a few examples that suggest that: i) The answer is not intelligence – a minimum of intelligence, such as what everyone reading this article has, is sufficient for succeeding in any graduate school, ii) it is ... hard work. I apologize for the disappointment.

Here is what some of the great mathematicians, *after* having done work considered the very peak of human thought, think about the factors in their success:

Grothendieck, Fields Medalist 1966: *'Since then I've had the chance, in the world of mathematics that bid me welcome, to meet quite a number of people, both among my "elders" and among young people in my general age group, who were much more brilliant, much more "gifted" than I was. I admired the facility with which they picked up, as if at play, new ideas, juggling them as if familiar with them from the cradle – while for myself I felt clumsy, even oafish, wandering painfully up an arduous track, like a dumb ox faced with an amorphous mountain of things that I had to learn (so I was assured), things I felt incapable of understanding the essentials or following through to the end. Indeed, there was little about me that identified the kind of bright student who wins at prestigious competitions or assimilates, almost by sleight of hand, the most forbidding subjects.'*

Gauss: *'If others would but reflect on mathematical truths as deeply and as continuously as I have, they would make my discoveries.'*

The reason why I give credence to these remarks is that i) while both Grothendieck and Gauss were considered amazing geniuses by their contemporaries, ii) both were not exactly known for being modest (Grothendieck said: *'In the history of mathematics, I have produced the greatest number of new ideas'*, and Gauss was famous for putting down other mathematicians). This, together with the fact that even at graduate schools in the US which attract the best and the brightest of students, the drop-out in computer science is over 50%, should suggest that other factors play a larger role in determining success or failure. In my opinion, a rather large reason for failure is the following, rather fragile, learning psychology.

*This article is more a collection of interesting quotations with my commentary. This has the added benefit of providing references for those interested.

In the current environment, everyone wants to be smart, or at any rate, appear smart. This severely interferes with learning, naturally: students who consider being smart important become more conservative in the length and hardness of problems they attempt, which is a reasonable risk-averse way of preserving their image. This approach works for undergraduates, especially under the diseased quarter system since the material covered is relatively shallow and easy. However, once one starts graduate studies and begins to think about problems where its not even clear if a solution is possible, the habit of following the risk-averse strategy just doesn't cut it.

Students not used to prolonged thinking on a single problem start off well. However, soon they find motivation and inspiration leaving them, and they start dreading working on the problem as failure would lead them to question something they (by now) crucially identify with: "smartness". Procrastination kicks in, and soon the student is busy in a diverse set of academic (but non-research!) activities to hide the reality of not working, like writing complicated scripts to automate their soon-to-be-coming publication phase, optimizing their daily vitamin B12 intake, getting heavily involved with political and religious movements and so on. Few students are able to critically introspect, which is reasonable since society has informed them that smartness is what matters, and if they are unable to solve the problem quickly, the logical conclusion is that they are not smart. In this world-view, it is hard to even consider the suggestion that smartness matters fairly little in such matters and most fall prey to heavy depression. Some do manage to climb out: Feynman, physics Nobel Prize 1964, had developed a reputation for being an extremely smart guy at Los Alamos. He paid for this afterwards as an assistant professor at Cornell, where for the first two years he was paralyzed by this fear, and unable to do any worthwhile work. During this time, he received an invitation to join the prestigious Institute for Advanced Studies (where Einstein was one of the members) but refused since he felt useless as a researcher. Fortunately for science, later a positive reaction set in for him and he was able to overcome his fear (and later ended up writing books with titles "What Do You Care What Other People Think").

Instead of intelligence, persistence is the crucial parameter for success in graduate school:
Gowers, Fields Medalist 1998: *'To illustrate with an extreme example, Andrew Wiles, who (at the age of over 40) proved Fermat's Last Theorem ... and thereby solved the worlds most famous unsolved mathematical problem is undoubtedly very clever, but he is not a genius in my sense. How, you might ask, could he possibly have done what he did without some sort of mysterious extra brainpower? The answer is that, remarkable though his achievement was, it is not so remarkable as to defy explanation. I do not know precisely what enabled him to succeed, but he would have needed a great deal of courage, determination, and patience, a wide knowledge of some very difficult work done by others, the good fortune to be in the right mathematical area at the right time, and an exceptional strategic ability.*

This last quality is, ultimately, more important than freakish mental speed: the most profound contributions to mathematics are often made by tortoises rather than hares. As mathemati-

cians develop, they learn various tricks of the trade, partly from the work of other mathematicians and partly as a result of many hours spent thinking about mathematics. What determines whether they can use their expertise to solve notorious problems is, in large measure, a matter of careful planning: attempting problems that are likely to be fruitful, knowing when to give up a line of thought (a difficult judgment to make), being able to sketch broad outlines of arguments before, just occasionally, managing to fill in the details. This demands a level of maturity, which is by no means incompatible with genius, but which does not always accompany it.' [1]

Though not directly related to research, the phenomenon that is Judit Polgar provides another fascinating insight into the reasons behind spectacular success in intellectual activities:

'Forty years ago, Laszlo Polgar, a Hungarian psychologist, conducted an epistolary courtship with a Ukrainian foreign language teacher named Klara. His letters to her weren't filled with reflections on her cherubic beauty or vows of eternal love. Instead, they detailed a pedagogical experiment he was bent on carrying out with his future progeny. After studying the biographies of hundreds of great intellectuals, he had identified a common theme – early and intensive specialization in a particular subject. Laszlo [sic] believed he could turn any healthy child into a prodigy. He had already published a book on the subject, Bring Up Genius!, and he needed a wife willing to jump on board.' [2]
The result were three sisters: Susan, Sofia, and Judit. Judit is *by far* the best female chess player in history, and ranked in the top-10 chess players in the world. Susan is the next(!) best female chess player in history. Sofia has a record-breaking performance in Italy that has become known as the 'Sac of Rome'.

'Anders Ericsson is only vaguely familiar with the Polgars, but he has spent over 20 years building evidence in support of Laszlo's theory of genius. Ericsson, a professor of psychology at Florida State University, argues that "extended deliberate practice" is the true, if banal, key to success. "Nothing shows that innate factors are a necessary prerequisite for expert level mastery in most fields," he says ... His interviews with 78 German pianists and violinists revealed that by age 20, the best had spent an estimated 10,000 hours practicing, on average 5,000 hours more than a less accomplished group. Unless you're dealing with a cosmic anomaly like Mozart, he argues, an enormous amount of hard work is what makes a prodigy's performance look so effortless. **"My father believes that innate talent is nothing, that [success] is 99 percent hard work," Susan says. "I agree with him."**'

The effect of psychology on learning is illustrated nicely in an interesting recent experiment [3]: A group of researchers led by Carol Dweck of Columbia University went to a very competi-

[1] Excerpted from the excellent book 'A Short Introduction to Mathematics'.

[2] `http://psychologytoday.com/articles/index.php?term=pto-3789.html&fromMod=popular_parenting`

[3] See the excellent article: `http://nymag.com/news/features/27840/`

tive school's 5th grade class, and randomly split it into two groups. Both groups were given the same easy puzzles to solve, and the performance of each child noted. Both groups scored well. After the exam, the first group was told *'you must have really worked hard'*, while the second group of children were rewarded by saying *'you must be smart at this'*. For the second round, both groups were given the same choice: either take another easy exam, or a much harder exam. Here's the punchline: over 90% of students in the first group chose the harder exam, while the *majority* of children in the second group chose the easier exam. In the third round, everyone had to do the harder exam:

Dweck: *'When we praise children for their intelligence, we tell them that this is the name of the game: Look smart, don't risk making mistakes ... [In the third round, children in first group] got very involved, willing to try every solution to the puzzles ... Many of them remarked, unprovoked "This is my favorite test" [while for the students in second group] you could see the strain. They were sweating and miserable.'*

The NYMag article ends with the following sage advice, on which I'll also end: 'The brain is ultimately just a muscle. Make it stronger by working it out.'