How to Be a Successful Scientist

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Introduction

Studies in the history, philosophy, sociology, and psychology of science and technology have gathered much information about important cases of scientific development. These cases usually concern the most successful scientists and inventors, such as Darwin, Einstein, and Edison. But case studies rarely address the question of what made these investigators more accomplished than the legions of scientific laborers whose names have been forgotten.

This chapter is an attempt to identify many of the psychological and other factors that make some scientists highly successful. I explore two sources of information about routes to scientific achievement. The first derives from a survey that Jeff Shrager conducted at the Workshop on Cognitive Studies of Science and Technology at the University of Virginia in March, 2001. He asked the participants to list "7 habits of highly creative people", and after the workshop he and I compiled a list of habits recommended by the distinguished group of historians, philosophers, and psychologists at the workshop. My second source of information about the factors contributing to scientific success is advice given by three distinguished biologists who each won a Nobel prize: Santiago Ramón y Cajal, Peter Medawar, and James Watson. These biologists provide advice that usefully supplements the suggestions from the workshop participants.

Habits of Highly Creative People

When Jeff Shrager asked the workshop participants to submit suggestions for a list of "7 habits of highly creative people", I was skeptical that they would come up with anything less trite than *work hard* and *be smart*. But the suggestions turned out to be quite interesting, and Jeff and I compiled and organized them into the list shown in table 1. Not surprisingly, we did not end up with 7 habits, but rather with 27 organized into 6 classes.

The first class of habits concerns ways to make new connections, recognizing the fact that creativity in science and technology usually involves putting together ideas in novel combinations (Ward, Smith, and Vaid, 1997). Many successful scientists do not restrict their reading to the particular area of research that they are currently focused on, but instead read widely, including work outside their own field. This enables them to grasp analogies between current problems they face and established ones that may suggest new solutions (Holyoak and Thagard, 1995; Dunbar, 2001). Visual representations may facilitate analogical and other kinds of inference (Giere, 1999; Nersessian, 1992). Working on multiple projects with multiple methods may make possible new approaches to those projects. As Herbert Simon often recommended, researchers should not follow the crowd and work on what everyone else is doing, because it is difficult to do anything novel in such situations. Because scientific explanations and technological breakthroughs often involve the discovery and manipulation of mechanisms, seeking novel mechanisms is often a good strategy (Bechtel and Richardson, 1993; Machamer, Darden, and Craver, 2000).

<<<<< INSERT TABLE 1 ABOUT HERE >>>>>

The second class of habits recognizes the fact that work in science and technology often does not proceed as expected. When anomalous experimental results arise, it is important for investigators to take them seriously and not brush them aside. There is then the possibility of learning from failed expectations, not by giving up, but by recovering from the local failure and moving on to research suggested by the anomalous findings. Much can be learned from both successful and unsuccessful experiments (Gooding, 1990; Gooding, Pinch, and Schaffer, 1989).

Given the frequent difficulties and setbacks in research in science and technology, it is important that investigators have a third class of habits involving persistence. They need to focus on key problems rather than being distracted by peripheral issues, and they need to pursue their research systematically, keeping detailed records about successes and failures. The injunction to "confirm early, disconfirm late" goes against the methodological advice of Karl Popper (1959) that scientists should set out to refute their own ideas. But it allows a research project to develop without being destroyed prematurely by apparent disconfirmations that may arise from difficulties in getting good experimental research underway.

The first three classes all involve cognitive habits, that is ones tied to basic thinking processes of problem solving and learning. The fourth class suggests that successful scientists are ones who also possess a set of emotional habits that get them intensely involved with their research projects (Feist and Gorman, 1998). It is rarely possible for scientists to do a cost-benefit analysis of what projects to pursue, but following their noses to work on projects that are fun and exciting can keep them motivated and focused. Scientific research is not just a matter of doing experiments and forming hypotheses, but in its early stages requires formulating a project that will answer a question that is interesting for theoretical or practical reasons. Interest, excitement, and the avoidance of boredom provide motivation to work hard and do work that is creative rather than routine. Playing with ideas and instruments can be inherently enjoyable. Taking risks to do non-standard research can provoke fear of failure, but this emotion must be managed if a scientist is to move in highly novel directions. For further discussion of the role of emotion in scientific thinking, see Thagard (2002a, 2002b) and Wolpert (1997).

Cognitive and emotional habits both concern individual psychology, but no scientist is an island. The fifth class of habits is social, concerning ways in which working with others can foster a scientific career. Most scientific research today is collaborative, so that having smart collaborators organized into effective teams is crucial (Galison, 1997; Thagard, 1999). Teams should not be homogeneous, but should have members who combine a variety of areas of knowledge and methodologies (Dunbar, 1995). Scientists can also benefit from observing how other researchers have managed to be successful and by listening to the advice of mentors about how to conduct their research. Finally, there is little point to doing research if you do not devote time to communicating it effectively to others by well-written articles and interesting presentations.

The sixth and final class of habits acknowledges that science is not just a psychological and sociological process, but also involves interactions with the world (Thagard, 1999). Scientists can benefit from finding rich environments to study and building instruments to detect features of those environments. Testing ideas is not just a logical matter of working out the consequences of hypotheses, but involves interacting with the world to determine whether it has the properties that the hypotheses ascribe to it (Hacking, 1983).

It would take an enormous amount of empirical research to establish that the above habits really are ones that lead to scientific success (see the discussion below of Feist and Gorman, 1998). One would have to produce a substantial data base of scientists, ordinary as well as illustrious, with records of the extent to which they exemplify the different habits and degrees of professional success. Here I can attempt only a much more modest kind of validation of the list of habits of successful scientists, by comparing it with the advice given by three distinguished biologists.

Ramón y Cajal

Santiago Ramón y Cajal was a Spanish biologist who won a Nobel prize in medicine and physiology in 1906 for important discoveries about nerve cells. While still an active scientist, he wrote in 1897 *Reglas y Consejos sobre Investigacion Cientifica,* which was translated into English with the title: *Advice for a Young Investigator* (Ramón y Cajal, 1999). The book is rich with many kinds of recommendations for pursuing a career in biology.

Ramón y Cajal's book begins by rejecting advice from philosophers such as Descartes and Bacon, insisting that "the most brilliant discoveries have not relied on a formal knowledge of logic" (Ramón y Cajal, 1999, p. 5). Rather, they arose from an "acute inner logic that generates ideas". In chapter 2, he warns beginning scientists against traps that impede science, including excessive admiration for the work of great minds and a conviction that the most important problems are already solved. He also recommends cultivating science for its own sake, without considering its application (p. 9). Ramón y Cajal doubts that superior talent is required for good scientific work. Even those with mediocre talent can produce notable work if they concentrate on information pertinent to an important question.

Concentration is one of the intellectual qualities that Ramón y Cajal describes in chaper 3 as being indispensable for the researcher worker: "all great work is the fruit of patience and perseverance, combined with tenacious concentration on a subject over a period of months or even years" (p. 38). Other intellectual qualities include independent judgment, taste for scientific originality, passion for reputation, and patriotism. Concentration and taste for originality are partly cognitive qualities, but they are also emotional, since they involve desire and motivations. Ramón y Cajal strongly emphasizes the emotional side of scientific thought: "two emotions must be unusually strong in the great scientific scholar: a devotion to truth and a passion for reputation" (p. 40). The passion for reputation is important because eagerness for approval and applause provides a strong motivational force; science requires people who can flatter themselves that they have trodden on completely virgin territory. Similarly, Ramón y Cajal sees patriotism as a useful motivating force, as researchers strive to make discoveries in part for the glory of their countries. Most motivating qualities, however, are more local: "Our novice runs the risk of failure without additional traits: a strong inclination toward originality, a taste for research, and a desire to experience the incomparable gratification associated with the act of discovery itself" (p. 48). Discovery is an "indescribable pleasure – which pales the rest of life's joys" (p. 50).

Chapter 4 is of less general interest, as it is directed primarily at newcomers to research in biology. Ramón y Cajal points to the value of having a general education, with philosophy particularly useful because it "offers good preparation and excellent mental gymnastics for the laboratory worker" (p. 54). But specialization is also necessary if a researcher is to master a particular scientific area. Ramón y Cajal also provides advice about the importance of learning foreign languages, reading monographs with special attention to research methods and unsolved problems, and mastering experimental techniques. Ramón y Cajal stresses the "absolute necessity of seeking inspiration in nature" (p. 62). and urges patient observations designed to produce original data. Researcher should choose problems whose methodology they understand and like.

Chapter 5 provides negative advice – qualities to avoid because they militate against success. Evocatively, the chapter is entitled "Diseases of the Will", and it divides unsuccessful scientists into a number of types: contemplators, bibliophiles and polyglots, megalomaniacs, instrument addicts, misfits, and theorists. For example, theorists are wonderfully cultivated minds who have an aversion to the laboratory, so that they can never contribute original data. According to Ramón y Cajal, "enthusiasm and perseverance work miracles" (p. 94).

Chapter 6 describes social factors beneficial to scientific work, including material support such as good laboratory facilities. Ramón y Cajal also makes recommendations about marriage that presuppose that researchers are male: "We advise the man inclined toward science to seek in the one whom his heart has chosen a compatible psychological profile rather than beauty and wealth" (p. 103).

Chapter 7 returns to more cognitive advice, concerning the operations in all scientific research: observation and experimentation, working hypotheses, and proof. Observation is not to be done casually. "It is not sufficient to examine; it is also necessary to observe and reflect: we should infuse the things we observe with the intensity of our emotions and with a deep sense of affinity" (p. 112). Experiments should be carried out repeatedly using the best instruments. Once data have been gathered, it is natural to formulate hypotheses that try to explain them. While hypotheses are indispensable, Ramón y Cajal warns against "excessive attachment to our own ideas" (p. 122). Hypotheses must be tested by seeking data contrary to them as well as data that support them. Researchers must be willing to give up their own ideas, as excessive self-esteem and pride can prevent improvements.

Chapters 8 and 9 return to more practical advice concerning how to write scientific papers and how to combine research with teaching.

Peter Medawar

To my knowledge, the only other book-length advice for scientists written by a distinguished scientist is Peter Medawar's (1979) *Advice to a Young Scientist*. The title is similar to the English translation of Ramón y Cajal's much earlier book, but the translators must have been mimicking Medawar rather than Medawar mimicking Ramón y Cajal, whose original title lacked the word "young". Medawar was a British biologist who shared the Nobel prize in 1960 for work conducted in 1949, when he was still in his thirties. There is no indication in Medawar's book that he had read the much earlier book by Ramón y Cajal.

Medawar begins by asking the question: How can I tell if I am cut out to be a scientific research worker? He says that most able scientists have a trait he calls "exploratory impulsion" (p. 7), which is a strong desire to comprehend. They also need intellectual skills, including general intelligence and particular abilities required for specific sciences, such as manipulative skills necessary for many experimental sciences.

Medawar's next chapter provides advice concerning: What shall I do research on? His main recommendation is to study important problems, ones whose answers really matter to science generally or to humankind. Young scientists must beware of following fashion, for example by picking up some popular gimmick rather than pursuing important ideas.

Medawar's chapter 4 concerns how scientists can equip themselves to be better scientists. He recognizes that the beginner must read the literature, but urges reading "intently and choosily and not too much" (p. 17). The danger is that novices will spend so much time mastering the literature that they never get any research done. Experimental researchers need to get results, even if they are not original at first. The art of research is the "art of the soluble", in that a researcher must find a way of getting at a problem, such as a new measuring technique, that provides a new way of solving the problem.

Whereas Ramón y Cajal assumed that scientists were male, Medawar includes a chapter on sexism and racism in science. Medawar sees no difference in intelligence, skill, or thinking style between men and women, and has little specific advice for women scientists. Similarly, he sees no inborn constitutional differences in scientific prowess or capability between different races or nationalities.

Medawar states that nearly all his scientific work was done in collaboration, and emphasizes the importance of *synergism,* when a research team comes up with a joint effort that is greater than the sum of the several contributions to it. Young scientists who have the generosity of spirit to collaborate can have much more enjoyable and successful careers than loners. Scientists should be willing to recognize and admit their mistakes: "I cannot give any scientist of any age better advice than this: the intensity of the conviction that a hypothesis is true has no bearing on whether it is true or not" (p. 39). Medawar suggests that creativity is helped by a quiet and untroubled life. Scientists concerned with priority may be inclined toward secretiveness, but Medawar advises telling close colleagues everything you know. Ambition in young scientists is useful as a motive force, but excess of ambition can be a disfigurement.

Like Ramón y Cajal, Medawar encourages scientists to make their results known through publications and presentations. He recommends a policy generally followed in the sciences (but not, unfortunately, in the humanities) that presentations should be spoken from notes rather than read from a script. Papers should be written concisely and appropriately for the intended audience.

Medawar also provides advice about the conducting and interpretation of experiments. He advocates "Galilean" experiments, ones that do not simply make observations but rather discriminate between possibilities in a way that tests hypotheses. He warns against falling in love with a pet hypothesis. Young scientists should aim to make use of experiments and theories to make the world more understandable, not just to compile information. A scientist is a "seeker after truth" (p. 87), devising hypotheses that can be tested by practicable experiments. Before scientists set out to convince others of their observations or opinions, they must first convince themselves, which should not be too easily achieved. Medawar prefers a Popperian philosophy of science based on critical evaluation to a Kuhnian philosophy based on paradigms.

James Watson

My third eminent biologist is James Watson, who shared a Nobel prize in 1962 for his role in the discovery of the structure of DNA. In 1993 gave an after-dinner talk at a meeting to celebrate the 40^{th} anniversary of the double helix, and later published the talk in a collection of occasional pieces (Watson, 2000). The published version, titled "Succeeding in Science: Some Rules of Thumb", is only 4 pages long, much more concise than the books by Ramón y Cajal and Medawar. Watson says that to succeed in science you need a lot more than luck and intelligence, and he offers four rules for success.

The first rule is to learn from the winners, avoiding dumb people. To win at something really difficult, you should always turn to people who are brighter than you are. The second rule is to take risks, being prepared to get into deep trouble. Big success requires taking on a very big goal that you are not prepared to pursue and ignoring people, including your mentors, who tell you that you are not ready for it. Watson's third rule, however, is to have someone as a fallback when you get into trouble. He describes how important it was to his career to have John Kendrew and Salvador Luria behind him at critical moments.

Watson's final rule is: "Never do anything that bores you" (Watson 2000, p. 125). It is much easier to do well things that you like. Watson also remarks on the importance of having people around you that care about you and that you can go to for intellectual help. It is also valuable to have people with whom you can expose your ideas to informed criticism; Watson suggests that his main competitors in the search for the structure of DNA, Rosalind Franklin and Linus Pauling, both suffered from a lack of people who could usefully disagree with them. People should not go into science as a way of avoiding dealing with other people, because success in science requires spending time with other scientists, both colleagues and competitors. Watson's success was partly the result of knowing everyone he needed to know.

Discussion

To what extent does the advice offered by the three distinguished biologists coincide with the habits of creative scientists summarized in Table 1? There is clearly some overlap, for example with Watson's suggestion to take risks and Medawar's suggestion to have good collaborators. But the three biologists also made many recommendations that were not reported by the participants in the 2001 Workshop on Cognitive Studies of Science and Technology. I have listed the additional recommendations in Table 2, which should be read as a supplement rather than as a replacement for Table 1.

<<<<<< Insert Table 2 about here. >>>>>

The three biologists do not add a lot to the cognitive advice in Table 1, although there are valuable nuggets such as Medawar's advice about new techniques making problems soluble, Ramón y Cajal 's and Medawar's concerns about giving up one's own ideas when necessary, and Ramón y Cajal 's recommendation to concentrate tenaciously. The emotional additions are more interesting, particularly Ramón y Cajal 's and Medawar's discussion of the kinds of passion that foster scientific success, such as strong desires for truth, reputation, discovery, and comprehension. The correlate Table 1's advice to have fun is Watson's advice to avoid boredom, which was a major impetus behind his own work on the double helix (Watson, 1969, Thagard, 2002b).

The three biologists also have a wealth of social and environmental advice that goes well beyond that found in Table 1. Ramón y Cajal , Medawar, and Watson all have useful social recommendations summarized in Table 2, ranging from marrying appropriately to communicating well with colleagues and the general scientific community. Ramón y Cajal and Medawar were more emphatic than philosophers, psychologists, and historians of science usually are about the importance of using experiments and instruments to interact effectively with the world. Whereas the workshop participants did an excellent job of identifying cognitive factors in scientific success, the three biologists who have provided advice seem stronger on the relevant emotional, social, and environmental factors.

Table 2 also lists a set of other factors that do not seem to fit into any of the 6 classes in table 1. Both Ramón y Cajal and Medawar recommend studying science for its own sake without worrying too much about practical applications. Ramón y Cajal 's counsel to avoid being too impressed with great minds fits with Watson's injunction to take risks by deviating from established opinion. Medawar 's suggestion not to read too much seems to contradict the suggestion in Table 1 to read widely. Studying important problems and avoiding life disruptions seem like good general advice.

Another possible source of information about what makes scientists successful comes from psychological studies of personality. Feist and Gorman (1998) review a large literature on that compares personality characteristics of scientists to nonscientists. Their major conclusions are:

- Scientists are more conscientious.
- Scientists are more dominant, achievement oriented, and driven.
- Scientists are independent, introverted, and less sociable.
- Scientists are emotionally stable and impulse controlled.

They also reviewed literature that compares eminent and creative scientists with less eminent and creative ones, concluding:

- Creative scientists are more dominant, arrogant, self-confident or hostile.
- Creative scientists are more autonomous, independent, or introverted.
- Creative scientists are more driven, ambitious, or achievement oriented.
- Creative scientists are more open and flexible in thought and character.

From this literature, we could conclude that to become a successful scientist it helps to be dominant, independent, driven, and flexible.

Even without the personality findings, between Tables 1 and 2 we now have assembled close to 50 pieces of advice for scientific success. Surely some of these recommendations are much more important than others for fostering the creative breakthroughs that contribute most to scientific success, but we have no way of knowing which ones are most influential. Perhaps a large-scale psychological and/or historical survey might be able to provide some ideas about which factors are most important (cf. Feist, 1993).

There is also the possibility of providing practical advice about how to conduct a scientific career at a much more low level, for example how to deal with career choices, work-family conflicts, and becoming an aging scientist (see e.g. Zanna and Darley, 1987; Sindermann, 1985). This chapter has not attempted to provide a definitive list of what traits and activities it takes to become a creatively successful scientist, but I hope it has provided both a framework and set of factors for understanding scientific success.

The broad range of the factors for scientific success discussed in this chapter demonstrates the great diversity of what needs to be taken into account in explanations of the growth of scientific knowledge. Science studies need to go beyond the traditional concerns of particular discipline, such as philosophical attention to modes of reasoning, psychological attention to cognitive processes, and sociological attention to social interactions. All these concerns are legitimate, but need to be complemented by understanding how emotions, personality, and intelligent interactions with the world also contribute to the development of science.

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Table 1. Habits of Highly Creative People

1. Make new connections.

Broaden yourself to more than one field.

Read widely.

Use analogies to link things together.

Work on different projects at the same time.

Use visual as well as verbal representations.

Don't work on what everyone else is doing.

Use multiple methods.

Seek novel mechanisms.

2. Expect the unexpected.

Take anomalies seriously.

Learn from failures.

Recover from failures.

3. Be persistent.

Focus on key problems.

Be systematic and keep records.

Confirm early, disconfirm late.

4. Get excited.

Pursue projects that are fun.

Play with ideas and things.

Ask interesting questions.

Take risks.

5. Be sociable.

Find smart collaborators.

Organize good teams.

Study how others are successful.

Listen to people with experience.

Foster different cognitive styles.

Communicate your work to others.

6. Use the world.

Find rich environments.

Build instruments.

Test ideas.

Table 2. More Habits of Successful Scientists

1. **Make new connections.**

Find new ways of making problems soluble, e.g. by new techniques (Medawar).

2. Expect the unexpected.

Avoid excessive attachment to your own ideas (Ramón y Cajal).

Be willing to recognize and admit mistakes (Medawar).

3. Be persistent.

Concentrate tenaciously on a subject (Ramón y Cajal).

4. Get excited.

Have a devotion for truth and a passion for reputation (Ramón y Cajal).

Have an inclination toward originality and a taste for research (Ramón y Cajal).

Have a desire for the gratification of discovery (Ramón y Cajal).

Have a strong desire to comprehend (Medawar).

Never do anything that bores you (Watson).

5. Be sociable.

Marry for psychological compatibility (Ramón y Cajal).

Tell close colleagues everything you know (Medawar).

Communicate research results effectively (Ramón y Cajal, Medawar).

Learn from winners. (Watson).

Have people to fall back on when you get into trouble (Watson).

6. Use the world.

Seek inspiration in nature (Ramón y Cajal).

Have good laboratory facilities and use them (Ramón y Cajal).

Observe and reflect intensely (Ramón y Cajal).

Perform experiments that rigorously test hypotheses. (Medawar)

7. Other

Avoid excessive admiration for the work of great minds (Ramón y Cajal).

Cultivate science for its own sake (Ramón y Cajal , Medawar).

Study important problems (Medawar).

Don’t read too much (Medawar).

Have a quiet and untroubled life (Medawar).