The scientist studying how scientific discovery comes about: "The number of women winning prizes is 30%, around the same as the percentage of women scientists"

Why did Darwin dedicate only the last pages of "The Origin Of Species" to the idea of natural selection, and what is the ideal composition of a group of scientists? Prof. Brian Uzzi is using big data to study how a revolutionary scientific idea is born

The big scientific discoveries are surrounded by legends. Who does not know of Archimedes' cry of "Eureka" when he resolved the question of how to measure volume, or the story of the apple falling on Newton's head, helping him understand the meaning of gravitational force? Our culture tends to idolize the individual scientific genius; Nobel prizes are awarded personally, and scientific phenomena are named after one or two scientists. Is that really what scientific discoveries look like? The sociologist Prof. Brian Uzzi thinks that, at least nowadays, this description is far from reality.

Uzzi, who comes to Israel every year to teach in the Kellogg Recanati International Executive MBA Program, a joint program between the Northwestern University and the Tel Aviv University, has spent many years studying the work of creative people, and in recent years has been focusing in particular on the sociology of scientists.

"Before becoming involved in the scientific field, I was a New Wave musician. I had a band called "The Foggiest Notion", and we even played in a club that also hosted Talking Heads and Blondie. It was wonderful, but we didn't get the recording contract that we wanted. I decided to take a break, and then I realized that in fact, I wanted to continue on the other path that had always intrigued me – higher education. This is what I did, but I wasn't able to break away from the world of art, and I focused my research on questions about creativity."

Uzzi, who also has a Ph.D. in engineering, studies sociology by means of computerized algorithms, and his research into networks of people is inspired by the study of computer networks. “The training of scientists does not relate at all to the invention of new ideas”, he says. “They receive training in statistics, building a research study, and if they are lucky, also in clarity of writing, but where do they get creativity from? This is the question that I started out with. Albert Einstein, who was very interested in the idea, said that it is more important to train a scientist in how to think than to give him knowledge. But exactly what type of training does this require?”

Darwin’s Origin of Species and Goldilocks’ porridge

One of Uzzi’s groundbreaking articles was the one that refuted the “Goldilocks effect” (Goldilocks and the Three Bears), which claimed that in order to introduce a new idea into the world of science it had to be not too hot (new), not too cold (old), but just hot enough, like the porridge that Goldilocks eventually ate. Uzzi’s research discovered that this principle is in fact a recipe for ideas that are… lukewarm.

“The alternative hypothesis to the Goldilocks effect came to me when I read Darwin’s Origin of Species”, he says. “We are all familiar with the wonderful idea it presents, that environmental pressures and pressure of competition affect survival, but this appears only towards the end of the book, in the last few dozen pages. The majority of the book, maybe 500 or 600 pages, has nothing new. It deals with a subject that was very well known at the time – deliberate reproduction of animals by humans. It is only at the end of the book that we come to the selection that takes place spontaneously in nature.”

Following this insight, Uzzi proposed the hypothesis that the new ideas that create revolutions in their field are those that are presented to the world in combination with a great deal of information that is very familiar. In other words, not just another idea served up like lukewarm porridge, but a dish that combines very hot ingredients and very cold ingredients. Ice cream with flaming brandy, or a hot pancake with frozen fruit.

"With the help of the computer, we examined millions of articles at the same time in order to check whether leading articles are 'Goldilocks' or 'hot and cold'. We asked the computer to look at every two items in all the bibliographies, to see whether they had appeared in the same article in the past, or whether their appearance together was new. When they appeared together frequently, the article connecting them received a 'mainstream' point. Each new juxtaposition gave the article an 'innovation' point. This study validated the hot and cold hypothesis. The articles that had the greatest impact in their field were those that received both the highest mainstream score and the highest innovation score, but not those that showed many juxtapositions of moderate frequency. In cases where around 10% of the juxtapositions in the bibliography were of articles that had never been put together before, while the others were relatively common essays, the article had more chance than others of being influential.

Uzzi also went back to classic articles and books to find evidence of this phenomenon. "When Newton first presented the principles of differential and integral calculus, he did so only after a lengthy introduction in which he showed how we used to try and solve these issues by means of the mathematics that was familiar at that time. Only after this did he get to his innovative method", says Uzzi.

"In this case, we have evidence that Newton wanted to focus the book on the new subject, without the introduction, and his editor understood that in order for the new theory to be accepted it had to be packaged in a 'hot and cold' form, easier to digest by the masses. And this is how the world got differential and integral calculus. So three cheers for the editors."

Today, companies like Google and Microsoft use Uzzi's model when developing new products, in order to make sure that familiar characteristics are retained in the product in addition to one or two radical innovations in each version.

"We use this method today to examine whether there is enough innovation in our articles", says Uzzi. "If we have not attached enough bibliographic sources that have not been put together in the past, it is a good warning sign that the article is not sufficiently interesting, and we need to introduce a radical new idea."

The recipe for an ideal group of scientists

According to Uzzi, the act of searching for a bibliography that is new to the subject, while at the same time is sufficiently relevant to be included in the article, sometimes in itself sparks new ideas. At the same time, he argues that the best way to spark new ideas is to bring people together.

In 2005 Uzzi carried out his first big data study in the sociology of science. He examined no less than 27 million articles, that is, almost all the scientific articles published in professional journals, and he did indeed find that a group of scientists working together had an enormous advantage over an individual scientist. Today this is already an open secret, and scientists are expected to work in a group, but Uzzi was the first to prove this empirically. “And it is not necessary to ask whether this research can be included, because it runs on all the articles ever written”, he smiles.

In what circumstances is it particularly important to work in groups?

“We saw that after the Second World War the advantage of working in groups increased. The reason for this appears to be that science gradually became more diverse and complex, and scientists began developing narrower areas of expertise. This happened in all fields. And so, in order to connect ideas that have not previously been connected, and achieve innovation, it is necessary to present the contribution of a number of people from different sub-fields. Over the years, the gap between the creativity of individuals and the creativity of groups is increasing, and the groups are becoming larger, while specializations are becoming narrower.

“Science recognizes this today. In the past, in order to receive a position or a promotion you had to show at least a few articles in which your contribution was 100%. Today this is no longer customary. Many scientists will not write a single article on their own in the course of their entire career.”

In addition to sharing knowledge, large teams enable the transfer of tacit knowledge, as Uzzi calls it, or knowledge that is unspoken. For example, each of the members of the team is likely to have a different skill, such as building an argument, better emotional coping with rejection, response to critics, and so on. “Someone in the group has knowledge that he doesn't even know he possesses, and when he does things the others learn from him by imitation. They may even ask for an explanation, and this will cause the possessor of the knowledge to sharpen his skill and make it more professional."

As an example, Uzzi talks about his daughter who wanted to learn to drive a stick shift car. "I tried to explain it to her, and of course, it is something that is hard to explain. When she saw what I was doing, she was able to learn from it on a completely different level. The same thing happens with unofficial knowledge in the world of science. Learning it through imitation is the best way of growing as scientists."

A follow-on study carried out by a different group of researchers showed that not only do groups produce more articles, their articles are also more innovative. "This happens in groups of 3 – 5 scientists, but not in groups of 10 scientists", says Uzzi. "This is apparently because big groups are assembled in order to solve 'big problems', so each one comes into the room having already made up his mind, and the scientists are engaged in convincing each other and not in brainstorming.

"On the other hand, small groups also assemble to solve problems at the extremity of the discipline, problems that are not well defined, and sometimes the very fact of jointly defining the problem leads to groundbreaking thinking. When approaching problems that are not completely defined, with solutions that have not been completely established, group thinking can really occur."

Uzzi feels that he has discovered the precise composition of a winning team for creative work. He found it among the writers of Broadway shows, and then examined it with regard to scientists. What does the ideal group look like? "It always includes two people who have worked together in the past, alongside three others who have not previously worked with either of the two, nor with each other", says Uzzi, and explains: "The fact that there are two people in the group who have worked together and who enlist the others means that there is someone who sets the tone for the atmosphere in the group, there are no struggles in this context, and there is trust and a willingness to take a risk in following the ideas of the others. The additional people are needed in order to bring 'new blood' into the group."

How does this interaction develop in the room?

"This recipe needs a chef, who is one of the two or three people who have already worked together in the past, and he has to ensure that the core group is open to hearing the ideas of the new people in the room, and does not relate to them as 'hired hands', because then it is better to leave the cohesive group to work on its own."

You recommend refreshing the group, and working with a slightly different team on each research. Is this different, for example, from a musical band that works for years with the same group?

"The Beatles were together for 10 years, but they brought in different producers for the different albums. Some of the main musicians changed. It is necessary to bring in a new person to produce conflict, but not too much conflict."

What are the incentives for working in groups?

"The confidence regarding the right allocation of credit. In rational terms, it is obvious to people why they should work in a group: the burden of work is shared among them, members of the team bring different abilities to the game, there is personal growth through reciprocal learning, and the work is more enjoyable and less isolated. There are also fields in which the research simply cannot be carried out by one person. But the issue of the struggle for credit is a real one, and the question of how to ensure fair credit is a developing question. For example, the 'Matthew effect' has been documented in science, where the most well-known person in the team gets most of the credit for the work. This effect is named after a line in the New Testament, in the Gospel of Matthew: 'Whoever has will be given more, and they will have an abundance. Whoever does not have, even what they have will be taken from them.'"

In a world where all research is by groups, what will those geniuses who suffer from poor interpersonal relations do?

"They need guidance. When you build an interdisciplinary team, sometimes there are team members who think that their discipline is better. This approach harms the team. The mentor needs to make sure that everyone in the group has a chance to have his say. It's a question of culture and leadership."

Matilda and the prizes

Against the Matthew effect is the Matilda effect, whereby readers of articles – men and women – have a tendency to feel that women contribute less to research. The Matilda effect is named after the activist Matilda Joslyn Gage, who already noticed this phenomenon back in the 19th century.

Uzzi has examined how this effect is reflected in the allocation of prizes to scientists. "Prizes are a very strong incentive in science", he says. "Sometimes two scientists have the same number of articles and citations, but the prize is evidence of which one is considered by the public to be more influential. In addition, the mass media is only interested in prizes and does not care about citations; some prizes are worth a great deal of money; and they also make it easier in the future for the scientist to obtain additional research grants, enlist successful students to work with him, and get tenure."

Although the number of prizes has grown in recent years, the number of prize recipients has not grown to the same degree. Scientists who have already been awarded a prize will often receive additional prizes. "We have succeeded in mapping the connections between the prizes, and predicting the winners of prestigious awards based on them having been awarded less well-known prizes", says Uzzi, and confirms that Israel's Wolf prize is one of the two awards most successfully predicting Nobel prizewinners.

"We asked ourselves whether it is possible to learn about the recognition that women in science receive from the way in which the prices are distributed. We saw that women are underrepresented in prizes, and also with regard to their achievements in citations in practice. In recent years they are beginning to be awarded more prizes and it can be said that the rate at which they win, 30%, is approximately the same as the rate of women scientists. However, a more in-depth analysis shows that women win less prestigious prizes, team rather than personal prizes, prizes for promoting students and contributing to the community, or prizes around science, more than prizes for the scientific achievement in itself. Women win twice as many prizes of this kind as men, but these are prizes that have less impact on promotion and on obtaining funding. So 30% is an impressive number, but not completely representative."

Are the prizes awarded in a way that does not properly reflect women's achievements, or do they really tend to be more involved in the fields of 'service to science'?

"We think that the prize committees are biased by the Matthew and Matilda effect. In addition, many men have a longer history in their field of involvement. 30% of women in in senior positions in science is a relatively new figure. Also, women really do undertake more positions in the department, mainly positions that are related to support for other women students, as part of their commitment to the community of women in general. Women students themselves prefer women as mentors, and so they take on a greater burden."

<u>Brian Uzzi's research</u>

What the mentors of beginning scientists do

"The most important relationship of a scientist is with his mentor, usually the doctorate or post-doctorate adviser, but we do not know exactly what it is that mentors do", says Uzzi. In order to try and understand this, he and his team members examined the fate of students of mentors who, a decade later, won a significant prize, by comparison with researchers who were in a similar place at the same age (the same number of publications, position, and so on), but did not win a prize later. "Our assumption was that if researchers do indeed succeed in nurturing students who are later more successful, this is due to the tacit knowledge that they pass on to them with regard to academic behavior, and not the overt knowledge that they pass on to the student with regard to the field of research itself", says Uzzi, and his study does in fact show this. Students studying with a lecturer who later wins a prize were twice as successful as students studying with a researcher who appears on paper to have the same skills and achievements, but has not won a prize.

The Dropbox research that caused a storm

One of Uzzi's newest studies of scientists gathered information from files in the document-sharing program Dropbox. The company shared information with the researchers in a way that did not allow them to see the content of the research or the names of the researchers, but they could see the number of participants in each study, and the revision dynamics.

The research discovered that small groups (2 – 3 people) are more successful at cooperating in writing a particular document than larger groups. In addition, groups that devote more time to research (a little over six months) achieved better results. A more balanced division of work was a predictor of more successful research than cases where one person did most of the work. The final conclusion was that experience has a substantial effect: the most successful research studies were those in which the senior researcher contributed a greater share.

Despite the anonymity, the Dropbox research created a storm in the scientific community because Dropbox did not inform the researchers that it was going to reveal information about them, and did not obtain their consent.

Business should really be done with friends

One of Uzzi's best-known studies show that it is desirable and worthwhile to do business with friends. When there is a good interpersonal connection, a relationship of trust is formed that makes it possible to take risks together, and saves on emotional resources such as excessive caution. In Uzzi's study, friends tended to help each other even without being asked, and without making an accounting, and in this way the result for everyone was better.

Investors, don’t get too enthusiastic

With the help of an algorithm that analyzed text messages sent to each other by hedge fund investors, information was produced on the investors’ feelings, and it turned out that investors who get moderately excited take better decisions than investors who are cold and unfeeling in general, and also better than investors who get carried away with enthusiasm.