frontiers FOR YOUNG MINDS

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Twenty tips for high-school students engaging in research with scientists

Berta Andújar[1], Gerard Campderrós[1], María García[1], Macarena Marino[1], Marta Mas[1], Lara Narbona[1], Laia Pérez[1], Pau Rodrigo[1], Anna Júlia Velásquez[1], Joana Vilà[1], Daniel Laguna[1], Timothée Flutre[2], Mathilde Bonnefond[3], Guillaume Sescousse[3], Livio Riboli-Sasco[4]

1 Institut Lluis de Requesens, Molins de Rei, Catalunya, Spain
2 UMR AGAP, INRA, Montpellier, France
3 Donders Institute for Brain, Cognition and Behavior, Radboud University Nijmegen, Nijmegen, Netherlands
4 Atelier des Jours à Venir, Paris, France

Reviewed by:

Abby
15 years old

Ten high-school students from Catalunya and two neuroscientists from the Netherlands started a research collaboration in 2012 investigating how colors may influence learning abilities. This research question was defined and developed solely by the students, with researchers joining the project later through the guidance of a facilitator and a teacher. This rather radical approach to "citizen-science" involved research collaborations on citizen-generated questions and was extremely rewarding for both parties involved. It provided skills, empowered participants, and enhanced the social relevance of science while allowing interactions that might have never happened otherwise. But the process was also challenging, which motivated the team of 10 students to propose "Twenty Tips" for other students interested in embarking on a similar journey. In the spirit of all research within this project, this article was a collaborative effort between the participants and thus departs structurally from other scientific articles.

THE RESEARCH QUESTION: HOW DO COLORS INFLUENCE LEARNING IN THE BRAIN?

The question itself was the product of brain-storming sessions in 2012 by our group of 10 high-school students, trying to ask how science could improve our close environment. We wondered whether painting our old school building could positively affect our mood and capacity to learn. With the help of our computer science teacher, D. Laguna, this question developed into a 2-min video for the scientific competition "Science of the City"[1]. Our facilitator (Livio Riboli-Sasco, evolutionary biologist) used this question as a starting point to involve two neuroscientists (Mathilde Bonnefond

[1]http://www.scienceofthecity.net/ contest collecting short videos about science made by non scientists. Our video attracted the attention of some members of the jury, a team of young researchers who are also social entrepreneurs in innovative science education, including Livio Riboli-Sasco.

and Guillaume Sescousse from the Donders Institute in the Netherlands)[2].

In early 2013, our scientific research journey to ultimately answer our novel question took off. The scientists served as a resource for existing knowledge, but most importantly engaged with us in building an innovative research project. This included defining a series of sub-questions about the relationship between colors and learning in a variety of contexts (e.g., focusing, reading, memorizing, etc., see e.g., Mehta and Zhu [1] for previous research) and replicating the results of existing research. We have now designed our own experiments based on this understanding and have acquired some data in our school in Molins de Rei, Catalunya (Figure 1). This may lead to further research projects incorporating brain imaging.

Our regular meetings and collaboration with the professional scientists involved in this project provided important insights about the research process. After reading the particularly helpful article *Twenty tips for Interpreting Scientific Claims* [2], we decided to write 20 tips for high-school students interested in taking part in the research process. These tips fall into four main categories: our opinions about the best individual and group attitudes for embarking on such a project, advice about how to deal with such an unusual team of researchers, our thoughts on how to conduct research as young scientists – from designing the protocol to analyzing data and drawing conclusions, and, finally, on how to enjoy yourself in the process.

[2]At the time, the non-profit cooperative company, *Atelier des Jours à Venir*, had just received the support of the *Fondation de France* to facilitate a process where non-professional scientists would be curious enough to ask open questions and co-construct fundamental research projects together with professional scientists. This framework, called *Nouveaux Commanditaires Sciences* is based on 20 years of experience of the *Fondation de France* to engage any group of citizens to be patrons of art pieces. *Atelier des Jours à Venir* is now extending and adapting this framework from art to science see http://www.joursavenir.org/ncs/en

What Approaches and Are the Most Beneficial for Group of Young Investigators?

First, Ask Yourself Why You Want to Engage in Doing Research at All

For our first research experience, we wanted to ask a question that could contribute to the improvement of education for future generations. If school architects understood the current research about the influences of color on the brain and learning, it could benefit their designs. Our question focused on our own environment, in hopes that our work could have an impact. These questions may leave you wondering whether our school looks like a painting by Miro – but while gray on the outside, the interior is actually quite colorful. Our personal interactions with color in our environment inspired us to ask more.

FIGURE 1 - Our school in Molins de Rei, Spain.

Learn About Research Methodology Before Starting Your Experimental Research Project

Look for background information by exploring the field of research you will be working in and by reading available publications. Ask for guidance from scientists, in particular, about accessing the relevant scientific literature. Indeed, our lack of expertise in the field made it easy to get lost digging into issues of little relevance. Consider reading a few research articles to start. Though it may not be easy, the concepts are much more accessible if you read them step by step. These articles will help you decide

if your research is feasible and if your hypothesis is both logical and can be tested.

Remember that You Cannot Answer All Questions at the Same Time

While you may start with a general question, it is important to gradually narrow down toward a clear and very precise question. Once again, reading scientific articles helps this process. This journey toward a narrow fundamental research question takes time. For our group, it took a year to refine from the generic phrasing "What is the effect of color on learning?" to the better-defined question "Does the beneficial effect of red versus blue on attentional focus depend on baseline attention level?"

Do not be Afraid of Asking All Kinds of Questions

All questions, including the ones you are afraid could be seen as "stupid," have the potential to help the whole group. When someone in your group poses an idea or question, make sure that the group is listening. Otherwise, some members of your group could be left behind or good ideas could end up going unexplored. When discussing probabilities, Berta from our group asked the seemingly simple question of whether it was more likely to get a 6 than a 1 when rolling dice. Instead of dismissing the question, Ana-Julia made the plausible suggestion that the six holes on "face 6" could make it lighter than "face 1" and thus bias the dice. Any plausible idea should be listened to, and some of these ideas should be tested.

Do not Limit Yourself to Set Hours

Some of these 20 tips came from the unexpected inspiration of Ana-Julia from our team, who woke up at 2 a.m. shouting "rainbow" (the team name). But when you are motivated to work on something out of your own interest – rather than school obligation – make sure not to let your work on the personal project interfere with your work from school.

Engage in a Project Without Expecting to Directly Improve Your School Grades

Although we learned a lot through this research project, we still needed time to learn the academic content required by our school programs. Unfortunately, few of the exams we currently take will test and value the research skills we are acquiring. For example, the understanding we have gained about *p*-values and statistics are not part of our curriculum, but we know that they are valuable to know.

Know that Sometimes Things will have to be Explained More than Once

On several occasions, there were topics that we were only able to understand after the scientists repeated the explanations. If you have doubts about your understanding, try to make a graphical representation of your ideas. To understand the concepts of *p*-value and statistical significance, which are crucial to doing research, we watched a video while also listening to comments by the scientists. This facilitated communication and mutual understanding, particularly because members of our group spoke different languages. In fact, the desire to do research would be a good motivator for developing your skills in languages commonly used in science, like English.

Build a Strong and Reliable Team of Investigators

Compose Your Group with People of Diverse Talents and Thoughts

Creating this kind of group allows people to better contrast in their opinions and perspectives. While everyone should share a high level of motivation, the perspectives and specifics behind those motivations can, and should be allowed to, vary.

Try to Strike a Good Balance Between Men and Women

There is currently an imbalance between the men and women who conduct scientific research, and achieving a better balance can start as early as groups like ours. Our group actually had a majority of women (8 out of 10), but other groups involved in similar projects should at least be mindful of trying to have at least 50% women.

Listen for the Soundest Arguments

Be aware that when doing science, deciding based on the majority vote or expecting consensus may not

always be the best approach. Sometimes the minority has the soundest arguments, but everyone in the groups has to be willing to listen objectively for what is best for the project. Even if this comes from a small group, be sure to listen!

Nurture a Good Quality of Social Interactions in the Group

Take the time to listen to each other and enjoy relaxing conversations, which do not necessarily have to be about science. This can help everyone to feel more at ease and more able to trust the group. Having someone we trusted to mentor us, our teacher Daniel, was also key to our success.

Create a Group that Shares Interests Rather than Just School Obligations

Our own group formed progressively, with some members joining the team later than others. By being open to anyone with common interests, we were able to add valuable members to our team.

Keep Communicating with Your Collaborators

Remember that professional scientists are usually logged on to their email and may answer you surprisingly quickly. Even with that availability, it is still important to make decisions about the next steps to take between collaborative meetings. A lack of such clear goals at the start of the project meant that our commitment sometimes dropped between sessions. It is important to have someone who will be persistent enough to bring you back on track when needed. Our teacher Daniel fulfilled this role.

Designing a Research Protocol and Analyzing the Data Takes Time and Energy, but it is Worth it!

Have a Clear Research Question and Formulate a Clearly Defined Hypothesis that Speaks to this Question

Discuss the various experiments you could do and find the most worthwhile and yet achievable one. Define the variables that you are interested in, simplify the way you will be conducting measurements, and keep as many things as you can unchanged in between experiments. This will increase the chances that the variations you observe between different conditions are indeed specific to the parameters you are playing with and interested in. If you work with humans, try to imagine all their possible behaviors. For example, when we ran our first experiment to get some training, we did not expect the participants to look at each others' computer screens while they engaged in a task on their own computer.

Decide How You will Record and Organize the Data Before Performing Experiments

Failing to do this may have dramatic consequences, even to the extent of being unable to analyze your data. Our group was almost unable to analyze the data for one of our experiments because we had forgotten how they were encoded (list of words encoded with numbers). Whenever possible, especially when doing experiments on human behavior, try to use a computer program to collect data. For our project, this was more reliable than doing it by hand, and was a good way to get started with programing! We were also surprised by the high quantity of data required to reach a scientific conclusion.

Record as Much Information as Possible During the Experiment Even Things You Think it may not be Useful to You

You never know which piece of information you might want to come back to. We eventually used many of these related observations to further refine our interpretations and frame further research questions. Without properly tracking this information, this refinement would not have been possible.

Be Willing to Critically Assess Your Results

Be aware of possible misleading interpretations and try to differentiate what you would like to obtain from what you actually obtained. Also, ask yourself whether your results are realistic. If we were to find that the color red increased the capacity of students to memorize fivefold, we would know this is likely excessive.

Try to Replicate the Results of Previously Published Experiments to Confirm Your Methods are Sound and Your Technique is of High Quality

In our case, we read a publication by Doerksen and Shimamura [3], and replicated their research showing that people better remember words associated with emotions. The first experiment you conduct will certainly be chaotic. We were surprised by how much we eventually had to improvise on the spot. Rather than being surprised, accept that unexpected failures in early trials provide opportunities to learn and reduce improvisation for the next experiments. If you have initially chosen to repeat an experiment known to produce robust effects, you may even manage to replicate the results despite the chaos! Before running our main experiment, we tested the experimental setting related to our own questions on a few subjects. This pilot experiment is meant to identify what could go wrong for this particular question, so everything will be ready when we start our actual experiments.

Be Proud of What You Are Doing and Enjoy[3]!

Great Research Ideas can Come from any Student with a Critical Mind; not Just the Top Students in the Top Schools

The students involved in this project were just normal, interested students in an average suburban school in Barcelona. But their engagement made it possible to take part in a meaningful fundamental research project. Curiosity and deep thinking are not a privilege limited to a certain group. We are delighted to hear that students from all backgrounds are getting involved in this kind of research, including schools in Lisbon where there might not be many other opportunities for science.

Lastly, Have Fun!

Our group wanted to write these tips because we found research to be a very fulfilling experience. We have met great people, and even if the project was not to be implemented as intended, the bonds that were created are invaluable and a fulfilling outcome in itself.

Final Thoughts

We hope our experience will inspire many others to get involved with similar research projects, and we would be happy to hear from them if they do. Additional details and updates about our project can be found on our website[4]. Our last piece of advice, which could be considered as a 21st tip, is to use your science to connect with others. Our group has formed great connections and asked questions using our blog. We have shared these tips because this experience has left us feeling highly empowered, and we want others to have that same chance. Science can be a powerful tool to influence and shape the world around you, even if it is on a local scale.

Facilitator (Livio Riboli-Sasco)

I realized that these ideals can become true, if you work hard on very precise and local settings. You also need to involve people who value concrete outcomes at least as much as big ideas. The scientists involved should understand that the pace of real science with high-quality scientific results is surprisingly slow. Slowing down allows such unusual collaboration and ensures we end up producing meaningful knowledge.

Students

We learned what science really is about, how long it takes to produce what can feel like very little knowledge, and how research methodology is useful to have a critical view on the world, especially when reflecting on potentially biased information as reported by the media.

Scientists (Mathilde Bonnefond and Guillaume Sescousse)

We learned to supervise in a different way than we are used to. We wanted to make sure that the students would develop their own ideas while being able to refine them into specific hypotheses well embedded in the scientific literature. While working outside of our usual environment, we felt how important it was to provide an open access to the scientific literature.

[3] Tips by the facilitator, the scientists, and the teacher.

[4] http://icilproject.wordpress.com/

We also wanted the students to remain motivated despite having to go small step by small step (answering one question after the other) and despite the amount of work. Overall, this experience strengthened our belief that there is a scientist in each of us who just needs a bit of guidance, and that the main quality of a scientist is curiosity, which young minds are not lacking! We were astonished by the relevance of the questions of the students and by their quick understanding of how to develop a research question and run an appropriate experiment. In summary, we learned a lot on our side, including additional humility, and we thus strongly encourage other scientists to engage in such projects.

Teacher (D. Laguna)

I have learned the importance of connecting school activities with real world professionals: scientists in our case. These kinds of activities have an important transformative power for both students' and teachers' conceptions of what learning actually should be, something that is too often forgotten in schools. Moreover, it has become clear along the process that situating students in the role of researchers improves motivation. We have been surprised by the amount of extra time invested and the responsibilities taken by the group. I also think that this project shows that any teacher, regardless his or her subject, could be engaged in scientific research with the adequate support, and that science, seen as a one of our most valuable cultural artifacts, should be cross-curricular.

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AUTHOR CONTRIBUTIONS

BA, GC, MG, MM, MM, LN, LP, PR, AV, JV (high-school students) wrote 38 tips in Catalan, which were then condensed into the 17 first tips found in this paper. LR-S (facilitator), DL (school teacher) and TF (geneticist) led the discussion on the *Nature* article, which inspired this paper. LR-S wrote tips 18–20, translated, and edited the manuscript. MB and GS (neuroscientists) edited the manuscript. LR-S, DL, MB, GS, and all the students wrote the introduction and conclusion. All contributed equally to the ongoing research project.

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REVIEWED BY:

Abby, 15 years old

I am a freshman in high school. My favorite classes are physics and history because I love figuring out why things are the way they are. That fascination began when I was little and my mom, who is a neurosurgeon, set up experiments for me to do in her lab. When I'm not busy with school, I spend my free time riding my horse and hanging out with my friends.

Livio Riboli-Sasco

I am a researcher in philosophy of biology, which means that I try to understand what biologists mean when they use concepts in biology, such as "individuals" or "inheritance." Are you what you are because of what you inherited from your parents? Do you inherit habits, ideas, and culture just as you do for genes? Are you bonded to your physical body? Are your gut bacteria part of yourself? Besides my research activity, I am committed to open possibilities for any citizen to ask research questions. With the colleagues of our cooperative company we travel all over Europe and the Middle-East to facilitate activities, which aim to empower youth and adults. We encourage them to revive their curiosity, transform it into precise questions, and further engage in small research projects.

AUTHORS

The Rainbow Investigators

The primary authors of this paper are 10 students in their last year of high school in Molins de Rei, Catalunya, Spain. Senior authors include a teacher from their high school as well as four researchers based in the Netherlands and France. All these people met in 2012 with the desire to conduct an original research project investigating the role of colors in learning. The scientific question was entirely designed by the students, who initiated this research project outside of their school obligations. In turn, the researchers made their question part of their own research agenda. This paper reflects thoughts from the students along the way about the research process.

Guillaume Sescousse

I am interested in how we make risky decisions, especially in the context of gambling. I am fascinated by the diversity of attitudes towards risk: if you put different people in front of a slot machine game, some will not even touch it, whereas others will be unable to stop playing until they have spent all their money. Why does the latter category of people develop an addiction to gambling? To answer this question, I look at whether the brain of these people reacts differently to winning money, to losing money, to the actual probability of winning and losing… The ultimate goal of my research is to help develop new treatments for people suffering from gambling addiction.

Timothée Flutre

One day, I learned that the genome of virtually all living organisms contains so-called "selfish elements." These are small chunks of DNA able to move and multiply, their ecosystem being the genomes themselves! Although they can be involved in intra-genomic conflicts, they also generate heritable diversity, the raw material on which adaptation depends. And I ended up doing a Ph.D. on this topic. After focusing on the genomic aspects of living organisms, I am now working on how genomes interact with the "environment" to build-up organisms. Interested in agriculture and climate change, I currently focus on plants, and grapevine, in particular. As an example, my colleagues and I try to find how genetic variation between grape varieties is associated with variation in berry quality, a key determinant of wine, notably when water is scarce and temperature is increasing.

Mathilde Bonnefond

I am interested in how we deal with the wealth of information we experience in our environment. If we analyzed everything we see, hear or smell, we would be overwhelmed. The brain is thus equipped with mechanisms to select only a small part of what surrounds us and ignore most of it. I try to understand how such an attentional selection works in the brain. Understanding that could help people with attentional disorders.