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My First Science Fair

Daniel J. Levitin
Department of Psychology, McGill University, Montreal, Quebec, Canada

> "Why don't those professors get back to doing what they're supposed to do—teaching students—and stop messing around with their laboratories."
>
> —Caller to a CBC Radio call-in show

> "When you encounter an anomalous finding—and you replicate it—that's when you have a real scientific revolution."
>
> —Endel Tulving, interview on the CBC

Whenever I find myself down in the dumps, I turn on public radio and I'm instantly cheered, comforted, or outraged, any one of which can restore me to my normally jovial and gregarious self. But it was the juxtaposition of these first two odd snippets that flummoxed me into wondering if the average person really knows very much about what scientists do or how they do it. Here, on the one hand, is a Canadian taxpayer, so utterly confused about *what universities are for*—the role they play in innovation, and in training the next generation of scientists. And here, on the other hand (my 8th-grade science teacher used to say this is why Darwin gave us two hands), is Tulving, eloquently expressing the pure joy the scientist finds in discovering something he or she doesn't understand.

Often at cocktail parties (as Colin Cherry used to say, a good place to collect data), when people discover I'm a psychology professor, they take a step backward, laugh nervously, and fiddle with their collar, their hair, or wedding ring, as though I'm some sort of Sherlock Holmes, able to see right into their psyches and spot even the slightest neurosis. Explaining that I run a research laboratory and that I study basic processes in auditory perception gets me nowhere—they're too busy guarding their childhood secrets and that time their mother caught them staring at pictures of naked Kenyans in *National Geographic*. Just last week, I ran into a reporter from the local paper who was surprised to know that in June—when school isn't in session—I still showed up to work. "I thought professors only worked 5 or 6 hours a week, and at that, only during the school year." Driving to work the next day, I tuned in to CBC Radio for some friendly intellectual warmth and cheer and heard the radio interviews quoted above.

So it was, feeling flummoxed and not yet cheered, I dropped into my department chair's office. He always looks flummoxed, and so I figured that we could find comfort in each other's company.

"As you know," I began, "I'm going to be teaching Intro Psych next semester, and I don't know what to expect—what kind of preparation our incoming undergraduates have. I thought you might give me some adv. . . . "

"Don't you have things to do?" he bellowed. My chair is a sort of military man in the style of General George Patton—a no-nonsense kind of guy. "What about your committee—you're head of one of the department's committees, aren't you?" It's true, I was head of the Web Services Committee.

"We met last week."

"What are you *feeling* right now?" he asked. Although a military man, he was also the chairman of a *Psychology* department. And he had learned a thing or two about Adlerian interactions on the job.

"Um, I'm not sure. I think I'm feeling a little down in the dumps."

"Life is not a piece of cake," he said. "Straighten up and fly right. Quit your whining." (His internal Patton had very little patience for his internal Adler.)

"Obviously," he said, "you need something to do." He typed a few keystrokes on his computer, and this is how it was that I became a judge in our city's annual science fair.

I did not need this. I had plenty to do. Piles of unopened mail on my desk. Unpacked boxes from when I moved into my house 9 years ago. But much of my work as a scientist lately had involved faraway ideas and places, and I wondered if perhaps I was losing touch with what kids are up to. "Don't forget," I told myself, "children are our future." (In point of fact, old people are our future. Lots and lots of them. But at that point, I was not thinking clearly.)

The regional science fair in my city used the honor system: There were five categories, and I could put a check mark next to the ones I felt competent to judge. No one asked my qualifications; apparently having a PhD in "science" was enough. As

Corresponding Author:
Daniel J. Levitin, Department of Psychology, Stewart Biology Building, 1205 Dr. Penfield Avenue, Montreal, Quebec, H3A 1B1 Canada
E-mail: dlevitin@psych.mcgill.ca

an experimental psychologist, I felt confident checking off "Human Sciences," but not "Life Sciences," fearing that the latter might overtax my memory for the Krebs cycle and protein synthesis. I also volunteered for "Physical Sciences & Mathematics" and avoided "Engineering." I signed up for "Environmental Science" judging, too, because I've recently begun to recycle my take-out food containers.

Lying in bed on the eve of the big day, I reread the judges' instructions. We would be given the students' written report of their project and a scoring form. Students could earn from 0 to 3 points for how innovative the project was, 0 to 6 points for how clearly they stated their hypotheses, 0 to 4 points for whether or not their oral presentation made good use of visual aids. In the morning, we'd be given our assignments, then we'd have to find our students somewhere among the 150 booths in the hall and evaluate the research in person. That night, I had trouble sleeping, wondering what the young geniuses would have waiting for me.

The science fair was held in the city's convention center. Before meeting with the contestants that I had been assigned to judge, I wandered the floor, taking in presentations. There were demonstrations of various principles of magnetism and optics, of electricity, and a diorama of my nemesis, the Krebs cycle. Two girls with wire-rimmed glasses had apparently identified, for the first time, some new types of cancer cells in an experiment that was too complicated for me to follow. Journalists from the local paper were taking pictures.

Another team, a pair of 15-year-old boys, explained to me that listening to classical music, but not other kinds of music, improved performance on extrasensory perception (ESP) tasks. Although their ESP participants never exceeded chance performance, they came much closer to chance when listening to classical music than when listening to rap or rock. (For a moment I shuddered, thinking of the millions of young people walking around with substandard ESP powers. But I got over it.)

I moved on to an exhibit all about perfect pitch, something I've been studying for 20 years. I was not the judge for this project either. The project had been submitted by two high school girls wearing green Catholic school uniforms. One of their judges, a man with short-cropped red hair in his late twenties, was listening intently as they gave their presentation. The two girls were standing about two feet apart, and they alternated telling the story back and forth. Girl #1 was explaining that absolute pitch is quite rare, but she and her friend considered that maybe a lot more people have it than we think. "We had the idea to ask people to sing their favorite songs, and we would compare the notes they sang to the ones on the CD."

Her partner added, "If they sing the right note, this is very close to having absolute pitch."

I'd be disingenuous if I didn't tell you that I felt a balloon of pride swelling in my chest. I had been the author of that experiment 20 years earlier.

"Where did you get the idea for that?" I asked.

"We read about somebody who had done this. . . . " The corners of my mouth started to turn up in a cascade of unfamiliar muscle activity—I was smiling. I had done *something* that had stimulated neuronal activity in these beautiful young minds. In the mysterious way that scientific curiosity can inspire others across the mists of time, I had become one of their intellectual heroes.

Girl #2 explained, "Professor Diana Deutsch did that experiment. She wrote about this experiment in one of the papers we read by her. Have you ever heard of her? She's been giving us a lot of support."

"She used college students," added Girl #1. "We wanted to use people our age and see if it was any different."

The balloon of pride in my chest quickly deflated to its normal level. Maybe slightly lower. Still, this was very good. I gave them my card and told them that I was writing an article on absolute pitch, and that if they sent me their data, I'd include it. (Just between you and me, Professor Deutsch had not done the experiment, but rather had written about *my* experiment in a recent literature review—but why burden their minds with unnecessary details.)

Next to them was a 12-year-old studying sexually transmitted diseases. In Quebec, where the age of consent is 11 (you can look it up), this seemed like a prudent thing to study. She had brought in a microscope and had obtained slides from a local hospital showing what different bacteria look like. She offered to let me look at some gonorrhea that she had growing in a Petri dish. She picked it up and offered to let me hold it. I asked how she was going to prevent the gonorrhea from getting *out* of the dish. She acknowledged that this was a serious concern because it is very, very contagious and even a small amount of this concentrated form on the skin could cause infection. She then explained that the way she prevents it from getting out is that she had scotch taped *almost* all the way around the sides of the dish until she ran out of tape. Carefully, I handed the dish back to her, trying my best to keep it steady.

Finally it was time to visit my five young scientists to give official judgment on the projects to which I'd been assigned. My first team of two high school boys had built an electric generator out of Legos and plastic spoons. Water fell on the spoons from an inverted 7-Up bottle with a valve, which turned a rotor that moved a magnet inside a coil of wire, and the output was connected to a voltmeter. The apparatus itself was quite ingenious.

Their experiment was to see how different amounts of salinity in the water would affect the electricity generated. Their hypothesis was that saltier water, which is more dense than fresh water, would turn the rotor faster when it fell (due to increased momentum). In their experiment, they started out with 400 mL of water, added one salt pack that they had gotten from McDonald's, stirred the water, and then let the water out of the inverted bottle to activate the rotor. They noted the amount of electricity on the voltmeter and repeated the procedure again after collecting the used water, adding another packet of salt to it each time.

It wasn't clear to me how they took the reading from the meter as it fluctuated wildly and there was neither a "max" nor an "average" function on the meter. As they had predicted, there was a more or less monotonic relationship between the amount of salt in the water and the amount of current generated with one exception: the two packets of salt condition actually produced *less* current than the one- or three-packet conditions. I asked them if they knew of any reason that might account for this, and they suggested that they might not have kept the temperature exactly the same throughout the experiment.

This was *science*. Call the Nobel committee! Call the National Academy! We were on to something. With Tulving's voice echoing in my head, I tried to show them that their odd data point was the most interesting scientific question of the experiment. An anomalous reading like theirs is begging to be explained: Was it measurement error, procedural error, or is there something unique about that amount of salt that causes a discontinuity in the curve? Does temperature affect water density, and if so, how? I asked if they had thought of pursuing this line of questioning, and they said they had, but that they had run out of salt packs, and so that was the end of it for them. "Deeper scientific inquiry," I told them, "almost always requires support from outside sources." I gave them "above average."

My next contestant built a bazooka out of a piece of plastic ABS pipe and, using aluminum chlorohydrate as a propellant, shot a potato up in the air as high as he could. He then attempted to determine the muzzle velocity of the potato using Newton's equations for gravity and high school trigonometry. He had a friend stand 30 m from the firing point and, using a sextant they made out of a protractor attached to a toilet paper tube, estimate the maximum height of the potato as a function of the tangent of the angle it made to the friend 30 m away. As he showed in a series of equations in his report, by knowing the height and angle, he could do some algebraic substitutions and solve for initial velocity. He shot the potato in the air five times and recorded the velocity estimates.

The results differed by a factor of 4, which is a lot! I asked what he thought might have contributed to the difference, and he explained that there was no way to accurately measure the amount of propellant in his design; the method was to press on the nozzle of a can of aerosol deodorant for 3 s or so, while counting "one-Mississippi, two-Mississippi...," but this could have produced highly variable amounts of propellant. I asked him to walk me through the equations in the report, but he could not explain how he got from one to another. Had he just copied them from a book?

More important, why did he enter this gun in a *science* fair? He didn't compare the firing of the potato with different propellants, with different muzzle diameters, or even with different vegetables or sizes of potatoes. No variables manipulated. No hypothesis. Notwithstanding Paul Rozin's and Ed Diener's calls to observational and descriptive science—something I fully support—the potato bazooka did not seem to be science to me as much as recreational engineering.

My third contestants tested the ability of different forms of chemical salts to grow crystals in a test tube after the salts were heated. They heated potassium nitrate, sodium nitrate, and potassium chloride up to 40°C in test tubes, which was hot enough for most of the salts to dissolve. They then they cooled the tubes and timed how long it took crystals to form. The interesting result was that increasing the heating temperature decreased the amount of time for crystals to form for two of the chemical compounds, but they obtained the opposite pattern of results for one of the compounds. Like the junior scientists with the electric generator running on salt water, they hadn't tried to redo or replicate the anomaly and weren't at all curious about how it came to be. They seemed annoyed with me when I tried to talk about the discontinuity in their graph.

My fourth entrant had learned that lichen only grew where the air is very pure. Armed with a hypothesis that he would find more lichen on trees that were far from highways than on trees that were closer, he identified 12 checkpoints in the region—4 in parks and 8 along busy roads—and then counted the number of trees in a 30-m^2 section that had more than 50% of their trunks covered in lichen. He had kept wonderfully detailed notes about every aspect of the experiment: the time of day he made his observation, the temperature, weather conditions, how much lichen he found, and what direction the wind was blowing; he even took photographs of each survey spot and close-ups of a representative tree from each of the 12 checkpoints. His hypothesis was borne out, and he noted that it rested on the assumption that pollution was greater near roadways, something that he had only assumed but had not actually tested himself. He understood that the ideal experiment would involve some sort of meter that would measure pollution at each site, and he could then correlate the results with pollution levels, or at least he would have empirical support for his auxiliary hypothesis.

Hold that call to the National Academy. He didn't know the experiment had been done before and didn't cite any other research. That's okay. Many of us work in a bubble. I gave him my highest mark: 85/100. I wanted to shake his hand, but in my role as judge that would have been inappropriate. And it may have had gonorrhea.

My final contestant was Mr. Hydroponics. This student had a missionary's zeal for hydroponic gardening, "solution to the world's hunger problem." He began by describing the three chemicals all plants need to survive ("Carbon dioxide, nitrogen, and carbon!!" he shouted), and he explained hydroponics to me in what I found to be a somewhat condescending tone ("Plants that can grow without soil take up less room and can be grown anywhere!!"). His experiment involved growing plants under a variety of conditions: plain tap water, tap water with fertilizer, hydroponically with no additional agents, hydroponically with fertilizer, hydroponically with a small amount of ionized water added daily, and a few others I don't remember. The astonishing thing (to me) about his experiment is that he used a different plant in each condition.

In his display, he had a potato, some garlic, a bamboo plant, a daffodil, and lettuce. I asked him how he could compare the effectiveness of the different conditions, and his answer was that he simply had to wait different amounts of time for the different plants to grow, as they each had their own intrinsic time to reach a certain level of development. I tried to lead him to the idea of a controlled experiment by asking him if he knew of a way he might be able to improve on the experiment if he had the chance do it over again. He offered that he could have one potato in three of the conditions, and one piece of garlic in the others. I suggested that one potato in all six conditions might be better. He disagreed.

I tried to explain that *interplant* variability might be larger than the conditions he was manipulating, that one potato might naturally grow faster than another even if they were in the *same* condition, and that he might consider having several potatoes in each condition. At this point, he grew noticeably irritated and repeated that the important accomplishment here was that he had demonstrated that hydroponics worked with a *variety* of plants, and that he had proven this because only one of the plants in a hydroponic condition died (a beet, I think). This defense took five mind-numbing minutes.

He was easily the most enthusiastic of the contestants—I gave him the full 10 points for that.

In my written comments, I commended the ingenious engineering of the Lego electricity generator, the sophisticated use of regression equations for the crystal formation girls, and again praised the engineering of the potato gun. I had lots of nice things to say about the lichen observer. I went on and on about Mr. Hydroponics' enthusiasm and engagement with the idea of a better future.

I wandered by a few more exhibits from people I was not judging and had very pleasant interactions with them. The five people I was judging knew that I was their judge, and they seemed preoccupied with trying to show me what they knew. These other students, who knew that I was not their judge, were much more open-minded and relaxed. They were happy to engage in conversation.

The typical high school science assignment in North America, one teacher told me later, asks the student to replicate some well-known experiment, and the student is graded not on the procedures or any discussion of the experiment, but on the final data collected. If the students' data don't match what the textbook says, they lose points. Students are rarely, if ever, taught scientific reasoning, hypothesis formation, or scientific thinking. They are taught that science seeks only to confirm what is already known, and that creativity and discovery have no place in the laboratory. I wonder what China is teaching its high school students?

Experimental psychologists are perhaps unique among scientists in that the questions we are trained to address span the entire range of human activity and behavior, limited only by our own curiosity. Psychology is a natural way with which to engage students with the scientific method. I bet that the students who weren't thinking about inconsistencies in electricity and salt, in crystal formation, or in hydroponic gardening would have reacted very differently if they were testing people rather than abstract principles. To paraphrase Paul Churchland, the sum total of human misery would be vastly reduced if we had a better understanding of the scientific basis for human behavior.

The day after the science fair, I woke up in a sneezing fit, barely able to breathe, and with a swollen, red nose. On standing up, I must have fainted, because the next thing I remember is waking up in a hospital bed with an oxygen mask at a University teaching hospital near my house named the Hôtel Dieu, (French for "The God Hotel"). I had acquired a form of pernicious nasal irritation that had quickly spread to my lungs.

The first word I spoke to the ER physician was "gonorrhea," thinking that I had contracted the disease from the Petri dish. But he had already run a standard blood series and ruled that out—and, in fact, everything else he and his colleagues could think of. My breathing was getting worse. Thank goodness one of the residents had the innate curiosity of a true scientist—he asked me what made me think that I might have gonorrhea, and I told him about the science fair. He asked what I saw at each of the exhibits. A light went off when I told him about the potato gun, and he ran another test that showed that I had contracted *aspergillosis*, a lung disease, from inhaling a toxic mold that had developed on the potato when I brought it near my face to study it more closely. One round of antifungals and I was cured.

I left "God's Hotel" with a new appreciation for innate curiosity. Science isn't just a profession or a subject; it is a personality type, a way of approaching the world and of thinking about things. Many of us—artists, businesspeople, writers, chefs, and engineers—are natural scientists, whether we work in the laboratory or not. Such people find anomalies interesting rather than embarrassing. It's a random mutation—we have a desire to know more, and the effort gives us pleasure.

The kids at the science fair, like my doctor, were acting on their curiosity about the world. Granted, some more than others, but all were engaged with and intrigued by their own version of a burning bush. "Why does it do that?" is the question they asked, not an unholy "who cares?" And if that isn't the quest for God, I don't know what is.

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