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The Science In Computer Science

How To Talk About Science: Five Essential Insights

by Shawn Carlson

Editor's Introduction

The goal of the LabRats Science Education Program is to inspire secondary school-age students from all backgrounds to love learning about science and technology. Shawn Carlson, the Executive Director of LabRats, presents five key insights that can be integrated into any science and technology program. The purpose of which is to overhaul students' attitudes and motivation to learn. Carlson also offers detailed suggestions on how educators can use these insights to inspire their students to become lifelong learners of science and technology.

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Editor

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Many educators and business leaders are concerned about an ongoing crisis in the fields of science, technology, engineering, and mathematics, known commonly as STEM. Educators are seeking ways to mitigate the well-documented falloff in student interest that appears around 7th grade and continues throughout secondary education. One of the many issues all STEM educators face is the poor perception that students often have of science itself. Students typically acquire these perceptions outside of school, and for many the classroom is the only place where their wrong ideas can be set right.

STEM educators often present students with dictionary-style descriptions of science—for example, experimental method, falsifiability, systematized bodies of knowledge based on empirical data, and so on. Students find these descriptions to be obtuse and bereft of anything that connects to their lives. As a result, STEM educators are losing a critical opportunity to excite their students' imaginations and ignite their passion to learn. We need a new way of answering the "what is science?" question that engages and inspires students to want to learn more.

The LabRats Science Education Program set out to address this problem when it began its initial pilot programs in 2004. What we eventually developed proved to be effective at improving our students' attitudes about science and inspiring them to become more actively engaged in STEM learning.

Our approach breaks the scientific enterprise down into what we call the "Five Essential Insights" (5EI) Since the "what is science?" question can be addressed in any STEM program; any science educator can incorporate these insights into the classroom. We believe any program that correctly, consistently, and frequently returns to the insights to re-energize its students about STEM will see significant improvements both in student attitudes and achievement.

5EI provides a framework for a first conversation about the nature of science. Our goal is to lay a solid foundation on which the full structure could eventually be built. For pedagogical reasons, we have winnowed each insight to a single narrow point that resonates with students and avoids subtleties. We believe the end result can be useful to anyone trying to explain what science is, for example, a parent talking to a child, or coworkers talking to each other.

Our team was led to this particular deconstruction of science as we tried to answer key questions that some of our most thoughtful students kept asking. We have therefore provided with each insight the question that inspired it, as well as some sample patter that teachers can use. We have tested these scripts extensively and know that they work.

The Five Essential Insights

Question #1: **Why learn science?**

Insight #1: "An education in science and technology is nothing less than the power to transform the entire world with a single idea."

Suggestions for presentation: Challenge your students to identify one physical thing in their daily lives that is untouched by science. Can they think of something that was neither created, transported, nor improved for human use without people who devoted themselves to doing the hard work that it takes to figure out new things about how nature works? Trace the threads of discovery and invention behind whatever suggestions they make. Explain that the modern world was invented piece by piece by hundreds of thousands of people who were no smarter than they are, but who learned the science of their day and then used that knowledge to solve practical problems. Lead them to realize that the scientific enterprise is responsible for virtually every physical thing in their lives.

If someone refers to nature itself, for instance, if a student says something such as "Science didn't make Yosemite!" respond with "How did you learn about Yosemite? Did you see a photograph, read about it online, or did see a documentary on TV? And how would you get there? You surely wouldn't walk there in bare feet without ever stepping on a road while foraging for wild berries all the way, right? And don't forget that the trails and the facilities that make it possible for you to enjoy the park once you are there weren't made with stone knives and bear skins."

You might summarize all this by saying, "Science makes every physical thing that we value possible. Without science we'd all get our daily protein by digging up grubs with a stick. (Pause) Alright, well maybe that's a little bit of an exaggeration, but you get the point, right?"

Press on. Explain that while a few people made profound contributions, most were more modest. Provide examples. Continue with, "You may not know their names, but every one of them lived their lives knowing that they had made a difference, that they had helped to change the world. And those of them who are no longer with us went to their deathbeds knowing that their work would live far beyond them because their contributions were still out there in the bank of human knowledge, and there they will remain for as long as culture endures."

State insight No. 1 again. Then ask dramatically, "Do *you,* and I mean you personally, do *you* want the power to make a contribution that might change the world?" Most students will respond with an enthusiastic "Yes!" Then immediately follow up with, "And are you willing to work your tail off to get it? Because remember, nothing comes easy that's worth having." Make certain that you get that second "yes."

This last question inspires many students to make their first real commitment to a long-term program of STEM learning. Teachers who frequently reinforce that commitment find that many of their students will come to work hard today, and everyday, because they see that each new bit of science knowledge they gain or skill that they master is taking them a step closer to the day when they could change the world themselves. This immediacy is far more effective than asking students to think about a distant destination, such as a future career, because it focuses their minds on the successes they are having today. If your program also gives them the opportunity to use what you teach them in creative ways to address problems that they find deeply interesting themselves, you will be able condition many of your students to gain confidence with each new thing that they learn. That, we believe, is the key to creating life-long learners.

The "hard work" question is also important because managing student expectations is essential for their success. STEM subjects are challenging for anyone to learn and no one masters them without hard work. Educators therefore need to make sure that their students understand and fully accept this fact.

Beware of pedagogies that paper over the need for hard work. For instance, many educators believe the secret to engaging students in STEM is to tell them that "science is fun" and then to make their classroom experiences as fun as possible. We agree students should have fun in their classrooms, and all LabRats lessons are careful designed to keep our students engaged and smiling, however, we find "fun" to be only a short-term motivator. To secure a lasting commitment educators must transfer their students' engagement from short-term to long-term motivators, such as a deeply seated desire to obtain a long-term goal, and what we call "stepper" motivators that encourage learners to take the next step in their education, such as training students to feel a swell of pride and enhanced self-worth with every new concept or skill they master. Moreover, the promise of perpetual fun creates false expectations that are eventually crushed under the weight of lab reports and frequent and prolonged struggles to wrap one's mind around difficult concepts. Students who choose a path that they accept will be difficult and who take pride in their accomplishments along the way are more likely to reach their long-term goals than those who have been coached to expect that all learning should be fun.

We suggest you work insight #1 into every lesson you teach so as to nurture your students' commitment to achieve adaptive knowledge in STEM.

Question #2: What is science?

Insight #2: "Science is everything we know about the physical Universe, and how we know it."

Our aim with this insight is to impress students with the fantastic scope of the scientific enterprise, and then guide them to realize that they can use the process of science right now, *today*, to help solve many of everyday problems. The word "physical" here separates empiricism from religious or spiritual quests. Students need to know that science tells us only what the universe is. It does not address moral choices or "spiritual truth."

However, students do need to know what "scientific" or "empirical truth" is. There is considerable confusion on this point. The current fashion is to divide truth into two types: "absolute truth," or what we know to be true beyond any doubt, and "empirical truth," or what we know from direct observation. Empirical truth, the argument goes, can never be absolute because there is always a chance that a future observation will disprove the claim. Science, therefore, is always uncertain.

The first problem with this argument is that it is wrong. There are many facts that scientists are absolutely certain about. For instance, the general shape of the earth is an oblate spheroid. We know this because we've measured the shape in many different ways to a level of accuracy far greater than what is needed to resolve the issue. Moreover, we know this because our observations exactly match the predictions of Newtonian mechanics, the theory that describes the everyday world perfectly. Anyone who insists that future scientists might prove that the earth is actually flat is simply wrong.

There is a second problem. Teaching that science is a fundamentally uncertain enterprise opens students to becoming prey for quacks and pseudoscientists who seek new converts. When challenged on their dodgy claims, these proselytizers often respond: "So what if our claims contradict what scientists think? Science is uncertain! Science can be wrong! Eventually science will come to realize its error and embrace our higher understanding." Educators can inoculate their students against this nonsense by emphasizing the high certainty of scientific knowledge

A third problem with this argument is that it actually denies the scientific enterprise. We humans developed science specifically so we could move away from error and toward ever-higher levels of certainty. Scientific facts are useful precisely because they are highly certain. Whatever its shortcomings, science is the most certain form of knowledge we have.

Shouldn't that be our take-home message?

Suggestions for presentation: First, explain the notion of scientific truth as outlined above. Then read Insight #2 aloud once and pause a moment. Then read it again, intoning dramatically, "Everything we know." (Pause) "And I do mean absolutely everything that we know about the physical universe, and how we know it." Explain that "everything we know" means the facts of science and that the "and how we know it" part is the process of science. Point out that while there is great power in knowing how things work, the greatest power comes from mastering the process of science; for it is the process that leads us to empirical truth. Ask, "Which do you think is better, to always have to be told the truth or to be able to find the truth for yourself?" (Pause) "Find the truth for yourself, right?" Make sure that your students affirm that this is so. "Well am I right?" Get them to say "yes."

Once you've gotten their buy-in to that idea explain that the scientific process can be used to answer almost any practical question they'd care to ask. "It's not only good for making grand scientific discoveries," you might say, "It's the best way to answer any question. For instance, 'Now where did I leave my keys?'" Explain that whenever you lose your keys you make a mental list of all the places where they are most likely to be. Why? So you can carefully and systematically eliminate those places one by one until you find what you're looking for.

Ask rhetorically "So what's the best way to find your keys? Scientifically. The systematic part means going very carefully, step by step, eliminating each option until you find what you're looking for. When you systematically examine each option, you are doing exactly what scientists do to find whatever they're looking for. When you look for your lost keys this way, you are already doing science. You see, science isn't always about carrying out sophisticated experiments in distant, sterile labs—it is about finding reliable answers to your questions, right here, right now. Whether in life or the lab, it's finding the truth so you can make things better for you and the people you care about."

Inspirational closer: "Do you think that this would be a good skill to have? Come on, let me hear you! *Do*... *you*... *think*... that this would be a good skill to have!? (Wait for response) Good! Trust me. You already have it. But if you're not afraid of a little hard work I promise you I will help make you really, really good at it!"

***Question #3*: What is "doing science" all about?**

Insight #3: "Doing science is all about making sure you're not fooling yourself."

The purpose of insight #3 is to give students a clear, practical, and compelling grasp into the only possible foundation on which the search for empirical truth can be built; that is, *getting it right*. It's not enough to imagine that something works; you have to *demonstrate* that it works. Science is not, as the purveyors of pseudoscience often claim, just one of many valid ways to think about the Universe. It's hard to fool yourself if you can demonstrate something is so. Can they demonstrate their claims, or are they fooling themselves?

Suggestions for presentation: Continue the discussion from insight #2. Ask, "So what is this truth finding process all about? (Do not wait for answers.) It's about getting it right ..., right? Finding the truth is exactly the same as making sure you are getting it right—that you are not fooling yourself. And that is what doing science is all about...making sure that you're not fooling yourself."

To help teach this point, all LabRats instructors learn a few simple magic tricks. Magic is all about fooling people. If you first do an impossible demonstration that astonishes your students and then you reveal the embarrassing simple secret behind the mystery, most of them will be willing to admit that even they can be easily fooled. By demonstrating optical illusions such as the "arch illusion" (see Figure 1) your students will come to realize that they cannot even trust their own eyes. They will begin to realize just how careful they must be if they are going to "get it right."

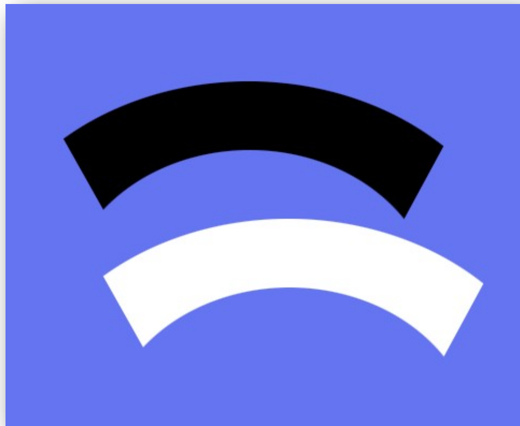

Figure 1. The Arch Illusion. *When arches of identical size and shape are positioned one above the other as shown the lower arch appears to be longer.*

(Educators who don't know any magic can make the point well enough using optical illusions alone. But we strongly suggest that you include magic in this lesson if you can. We find teaching magic significantly enhances students' enjoyment of the lesson as well as their evaluation of the instructor.)

Ask, "So then, what should we have done if we wanted to get this right?" Lead your students to say "make a measurement." Tell them that now they know why scientists make measurements. It's because where our senses often cause us to get something wrong, measurements, when made properly, help us to get things right.

Guide your students through a discussion about specific things that scientists do to make sure they aren't fooling themselves. Lead them to understand that getting it right means taking necessary and specific precautions against making mistakes. How can we be sure we know how fast, how tall, how hot, or how heavy something is? Only by making measurements. How can we be sure that nothing is going on behind the scenes that could affect your conclusions? Only by using control experiments. How can we find out how much confidence we can have in our final answer? Only by statistical analysis. Make sure that each student agrees that taking the "make sure you're not fooling yourself" pledge to problem solving will give them a huge leg-up in all areas of their life.

Scientists have a term for this process: "grounding claims." The claim is what you believe to be true. The grounding is the evidence you gather to convince yourself and others that your claim is true. The key is to make sure that all your claims are grounded by sufficient, relevant, and reliable supporting evidence. Scientists are expert claims-grounders.

Science isn't merely about making discoveries, it's also about communicating those discoveries to others who can put them to use. Unfortunately, for some students the word "communicate" raises images of report writing and public speaking, which can link the idea of doing science to a sense of anxiety. At this first conversation stage we are seeking to inspire interest, not anxiety. That's why we focus exclusively on discovery-making here.

Take a break here and do an activity. Continue with insights No. 4 and No. 5 at your next class meeting.

Question #4: **What makes a scientist a scientist?**

Insight #4: "Always fit theories to facts, never facts to theories."

At first glance it may not be obvious how this insight is related to the question. We developed insight No. 4 to make sure that our students understood that making sure you're not fooling yourself really is about grounding claims; just following accepted procedures isn't enough. The power to follow a correct path to the end of a mystery comes with a price. What if the facts lead somewhere that you do not care to go? Or what if, after exhaustive searching, you can't find sufficient, relevant, and reliable facts that lead to where you do care to go? It takes great strength of character for someone to admit when they are wrong and to embrace a new understanding. Therefore, what makes you a scientist is the willingness to make a deep, personal, and unshakable commitment to follow the facts wherever they lead, whether you like it or not. Insight No. 4 states that commitment precisely and in a way that students can easily grasp.

Suggestions for presentation: Ask your students to acknowledge that all of us have our own cherished opinions and judgments about the world. Give a relevant example from a recent news story that your students are likely to know about. Ask if they agree that when one of those deeply held opinions is challenged, the natural human reaction is to defend it against all comers because people often fear embarrassment at being seen to be "wrong." Point out an historical example of how, when prevailing ideas of the day were challenged by physical evidence, many people choose to reject the evidence outright rather than change their minds. Explain that for someone to become a scientist, he or she needs to become a different sort of person.

Tell your students that neither naked curiosity nor college degrees make someone a scientist. Rather, it is all about how you choose to pursue new knowledge. Tell them that a scientist is someone for whom knowing the truth has become more important than any viewpoint they may currently hold.

What makes a scientist a scientist then is a person's willingness to make a deep and personal commitment to know the world for what it truly is and to always be willing to admit when they were wrong no matter how painful or embarrassing that might be. Tell them anyone can become a scientist at any time simply by looking within themselves and firmly resolving to always hold empirical truth to be more important than anything they currently think is true. A scientist is anyone who remains resolutely skeptical of his or her own ideas and opinions, and who is always willing to change them when presented with sufficient credible evidence that those opinions are wrong.

Encourage your students to think about this carefully and to decide for themselves whether they are willing to always try to be guided by an honest assessment of the facts no matter what. Suggest that those who are willing should make "Always fit theories to facts, not facts to theories" a personal motto. Remind them often to repeat it to themselves until it becomes a habit of mind.

Question #5: **What is the scientist's motto?**

Insight #5: "Investigate!"

LabRats inspires students to learn to love science by doing science themselves. We therefore felt it vital that the last Insight on our list urged each student to integrate inquiry-based habits of mind into their daily lives.

Suggestions for presentation: Tell your students scientists must be actively engaged in the pursuit of new knowledge, whether it's to enhance what they know about an established field or to discover things that no one in human history has ever known before. There is no "authority" in science. Every person—regardless of their birth or background—has an equal right to participate in the great adventure of discovery. Anything scientists think they know can be challenged by anyone. An 8th grader can topple any idea, experimental result, or theory if that 8th grader can marshal sufficient, relevant, and reliable evidence against it. Challenging and testing new ideas, including one's own ideas, is the very engine of discovery. Tell your students that the motto of the scientist is "Investigate!" Research the facts for yourself. Be skeptical. Do your own experiments. Urge your students to adopt the scientist's motto as their own.

If your STEM program involves hands-on, inquiry-based or project-based learning you may tell your students something like this. "You are always free to ask me anything you want. I'll answer your questions if I can. But don't be surprised when you ask me a 'what would happen if' question and I tell you 'I'm not sure. I've never done it before. Why don't you go do the experiment so that you can teach me?'"

A final tip. As your class is breaking up for the day try giving your students a parting inspiration to take home with them. Here's one that resonates well with secondary students. "Always remember. You have the power to discover the truth for yourself. Use it!"

Summary and Conclusion

LabRats inspires its members to love learning about science and technology in part by breaking the scientific enterprise down to what we call the 5EIs. They are:

1. An education in science and technology is nothing less than the power to transform the entire world with a single idea.
2. Science is everything we know about the physical universe and how we know it.
3. Doing science is all about making sure you're not fooling yourself.
4. A scientist always fits theories to facts, never facts to theories.
5. The scientist's motto is, "Investigate!"

These principles are general enough to be incorporated into any STEM program. Further, our experience gives us confidence that any program that frequently repeats and reinforces these insights will energize its students about STEM and see significant improvements both in their students' attitudes and achievements.

We urge educators who wish to put the 5EIs to the test in their classrooms to do so. To assist you and to gain information that can help us do more to advance science literacy, LabRats is working to develop a simple assessment tool to help you gauge the effect that this approach has on your students.

LabRats is also planning a research program to how well our new approach to describing science improves student attitudes and motivation to learn STEM. We are particular interested in the effects this on a students in traditionally under-represented technical careers.

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About the Author

Shawn Carlson is a widely recognized innovator in science education and is known for his creativity, visionary leadership, and passion. He is the founder and executive director of the LabRats Science Education Program. In 1999 he was awarded a MacArthur Fellowship for his contributions to science education.

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